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WIND SHEAR: A LITERATURE SEARCH, ANALYSIS, AND ANNOTATED BIBLIOGRAPHY

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FEDERAL AVIATION ADMINISTRATION
ATLANTIC CITY, NEW JERSEY

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February 1977

FINAL REPORT

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16. Abstract

A literature search of recent publications (post 1970) on low-altitude wind shear and its relationship to aircraft operations during approach, landing, and takeoff was made. An analysis of the reviewed literature with respect to (1) wind shear characterization/atmospheric modeling, (2) hazard definition/accident analysis, (3) ground-based equipment, (4) airborne equipment, (5) flight test and simulation, (6) forecasting/meteorology, and (7) flight operations/pilot training was made. The analysis of the 216 documents identified by the search are summarized.

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II HAZARD DEFINITION/ACCIDENT ANALYSIS.

The primary hazard to an aircraft by a wind shear encounter is during low-altitude operations at reduced airspeed. These are the normal operational conditions of the approach and landing or takeoff and initial climb phases of flight operations.

In recent years, there have been several air carrier accidents in which such shears were a contributing factor. These are listed in table 1.

TABLE 1. AIRCRAFT ACCIDENT IN WHICH WIND SHEARS WERE A CONTRIBUTING FACTOR

Aircraft Type	Location	Date
DC8	Naha Air Base, Okinawa	July 27, 1970
B727	New Orleans, LA	July 26, 1972
B707	JFK Airport, NY	December 12, 1972
DC3	LaGuardia Airport, NY	January 4, 1974
B707	Pago Pago, American Samoa	January 30, 1974
B727	JFK Airport, NY	June 24, 1975
B727	Denver, CO	August 7, 1975
B727	Raleigh, NC	November 12, 1975

It should be noted that the above list is not necessarily all-inclusive. In fact, the National Aviation Facilities Experimental Center (NAFEC) is currently reexamining all aircraft accidents from 1964 thru 1975 in an attempt to identify other accidents in which low-level wind shears could have been a factor. The purpose of the reexamination is to evaluate various aspect of the wind shear program identified in . FAA program plan of March, 1976, index No. 63.

A review of the World Airline Accident Summaries for both underrun and overrun landing accidents identifies four known wind shear accidents, 16 additional accidents in which wind shear could have been a potential factor, and 16 other accidents which may have had an associated wind shear factor. In addition, there are wind shear related air carrier accidents which have occurred during takeoff, such as the United Airlines B727 accident in Denver, which was noted in table 1.

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INTRODUCTION

BACKGROUND.

The effects of wind shear on an aircraft during approach, landing, and takeoff have been the subject of many studies and experiments. The potential hazard of wind shear to safe flight operations have received special attention by a spectrum of the aviation community due to several recent aircraft accidents which might have been induced by atmospheric disturbances.

The problem of severe wind shear conditions occurring at low altitudes in the terminal area creates a serious hazard to aircraft encountering them during the final approach and takeoff phase of flight. When an aircraft is flying only slightly above the stall speed, a change in the wind velocity or direction can lead to a loss of lift. If the loss is of sufficient magnitude so that the power response is inadequate to immediately correct the energy deficiency condition, it results in an excessive rate of descent. The altitude at which the encounter occurs, the pilot's reaction time, and the aircraft's response capability, determine whether the descent can be arrested in sufficient time to prevent an accident.

Pilots have often encountered orographic and topographic wind shear when landing at single runway airports which are located in mountainous terrain, or lined by trees and buildings. During a crosswind landing, the pilot is usually aware of this condition by observing the difference between the wind sock at the airport and the correction he is making in flight for the wind to maintain runway alignment. The tree-lined, single-runway wind shear problem is the one most frequently encountered by pilots of general aviation-type aircraft. It is a problem, but not the major type of the wind shear problem considered in this report. The orographic and the topographic shears due to mountainous terrain or large structures and construction are more important to commercial aviation, though the encounter is much less frequent. These types of problems are usually on the airport proper, and their major threat is in direction control, hard landings, or delayed touchdown (ballooning).

Another type of wind shear or turbulence is that generated by the wake and vortex systems of other aircraft operating on other runways or on the same runway during crosswind conditions. This particular problem has been the subject of an indepth investigation by several government organizations, including the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA). While this is a very important constraint on terminal area operations, it is also not the object of this report.

Finally, there is the wind shear which is due to meteorological factors. This is the most hazardous to flight operations, since it is the one least anticipated and most difficult to detect until after the fact. It is this type of wind shear, its detection and effect on flight operations, that is the principal subject of this report. It is important to note that much of the material relating to wind shear detection can be related to all types of atmospheric turbulence detection.

OBJECTIVE.

The objectives of this report are:

1. To review current technical publications and other literature relating to wind shear, its detection, and its effect on aircraft takeoff and landing operational performance. The time frame selected for the selected literature compliments and supplements the NASA contractual effort reported in NASA CR-2360, index No. 172.

2. To determine the status of current related experimentation and developments in the area of wind shear modeling, wind shear hazard, and simulation or flight testing relating to the wind shear problem.

3. To indicate those technological areas which may require experimentation and/or evaluation for enhancing flight safety. At the time of this report's preparation, there are current FAA-sponsored efforts in progress, directed toward resolving and reducing the wind shear hazard to flight safety.

DISCUSSION

GENERAL.

A search was made of NASA's Scientific and Technical Information documents, index No. 211, and the National Technical Information Service's records, index No. 207. These computerized searches were supplemented by independent librarian searches of the technical libraries within FAA. As a result of these combined efforts, 216 published documents were identified and reviewed relating to the wind shear project objectives, these are listed alphabetically by title appendix A.

Each of the 216 documents contained in the bibliography are listed in alphabetical order by title and numbered sequentially. The listing includes the author, date of publication, cognizant organization, report number, and, when applicable, a critical abstract or summary.

An overview of the literature indicated that it was amenable to being grouped into general categories which were similar to those identified in the FAA's wind shear program document of March 1976, index No. 63. Accordingly, the literature has been grouped by principal subject category as follows:

1. Wind Shear Characterization/Atmospheric Modeling
2. Hazard Definition/Accident Analysis
3. Ground-Based Equipment
4. Airborne Equipment
5. Flight Test and Simulation
6. Forecasting/Meteorology
7. Flight Operational Procedures/Pilot Training

It is recognized that some publications may relate to more than one of the above groups, or may not be conveniently categorized within any of these groups. Therefore, a document may appear by title in more than one group, or may not be listed in any group. Such duplication or omission of listing should not be construed as a means of identifying the relative value of a given document.

A subjective evaluation of each document has been made. Those publications which are considered to be of significant merit within a given group are noted by an asterisk (*). The listing within is by title and document sequence number (index No.) as it appears in the bibliography. As a further aid to the reader, an author's index is also provided with the index number reference included.

I WIND SHEAR CHARACTERIZATION/ATMOSPHERIC MODELING.

Wind shear is any change in windspeed and/or wind direction through any thin layer of the atmosphere. It may be a vertical shear, or a horizontal shear. During the literature review, one becomes aware that the same type of wind shear was being described in two different mutually exclusive terms. This error was apparently due to the author's view of the wind shear encounter. The mutually orthogonal (perpendicular), right-hand coordinate system used in this report is shown in figure 1.

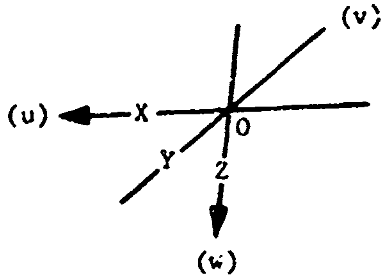

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FIGURE 1. RIGHT-HAND ORTHOGONAL COORDINATE SYSTEM

In this system, X is the longitudinal axis of this inertial (earth) referenced system, with the positive velocity component (u) moving from 0 to X as noted by the arrow. The lateral axis is Y, with the positive velocity component (v) moving from 0 to Y. Finally, the vertical axis is Z, with the positive velocity component (w) moving downward from Z to 0.

A vertical wind shear is one in which the change in a velocity component varies with a change in height (Z). Thus, d_u/d_z and d_v/d_z are vertical wind shears. An example would be where the headwind (u) that the aircraft encounters changes with a decrease in altitude (Z). It is principally this type of vertical shear that the report is concerned with.

A horizontal wind shear is one in which the vertical velocity component (w) varies with a change in the aircraft's track along the ground, either in the longitudinal (X) or lateral (Y) direction. The derivatives, d_w/d_x and d_w/d_y, are horizontal wind shears. An example would be the change from an updraft to a downdraft an aircraft would encounter when in level flight and penetrating a storm cell.

Dr. John C. Houbolt noted in his report of December 1973, index No. 172, that, while much work has been done on the problems of flight in atmospheric turbulence above the planetary boundary layer (1,000-2,000 feet), work relating to operations in the surface boundary layer (100 to 300 feet) was still in the formative stage.

The Federal Aviation Agency's (FAA's) Systems Research and Development Service (SRDS) has been and is currently sponsoring or working with the National Oceanic and Atmospheric Administration (NOAA) and NASA on characterizing the surface boundary layer as it influences terminal aircraft operations. The FAA's current efforts in the total wind shear problem are summarized in L. Langweil's AIAA paper of June 1976, index No. 167.

The Air Registration Board (ARD) model for wind shear in the surface boundary layer is that used by the U.S. Air Force. This model is similar to that defined in the FAA's Advisory Circular 20-57A. The principal difference between the ARB model and the FAA's is that the former uses the wind information measured at 10 meters (approximately 33 feet) and the latter uses information measured at approximately 6 meters (20 feet).

The most comprehensive publication encountered in this literature search of the probable surface boundary layer was the FAA's contracter's report FAA-RD-74-206, index No. 201. This was developed for the certification of approach and landing guidance and flight control simulation. The statistically derived wind shear model was based on low-altitude atmospheric data reported by several independant experimenters and Boeing Airplane Company's own experience. A major difference between the proposed model and the FAA model is that the former includes a term to insure that the shear diminishes to zero with an increase in height above the surface (figure 2). Since both the ARB and FAA models do not include a comparable term, they reflect greater wind shears at the higher altitudes.

NASA has and is sponsoring work in the surface and boundary layer modeling at several universities and research organizations. Some of the more recent published work includes J. K. Luers' July 1973 report, index No. 50, and K. E. Mitchell's December 1975 report, index No. 119. In addition, NASA's G. Fichtl mathematically modeled four categories of surface layer wind shear which were constructed from previous documentation. His memorandum of January 23, 1976, to the Systems Research and Development Service of FAA cited the following models:

1. Logarithmic Profile (similar to that proposed in index No. 100),
2. Nighttime Stable Boundary Lever (similar to that in index No. 135),
3. Frontal Wind Shear (constructed from Logan Iberin accident, index No. 6),
4. Thunderstorm Cold Air Outflow (constructed from JFK Eastern Accident, index No. 42).

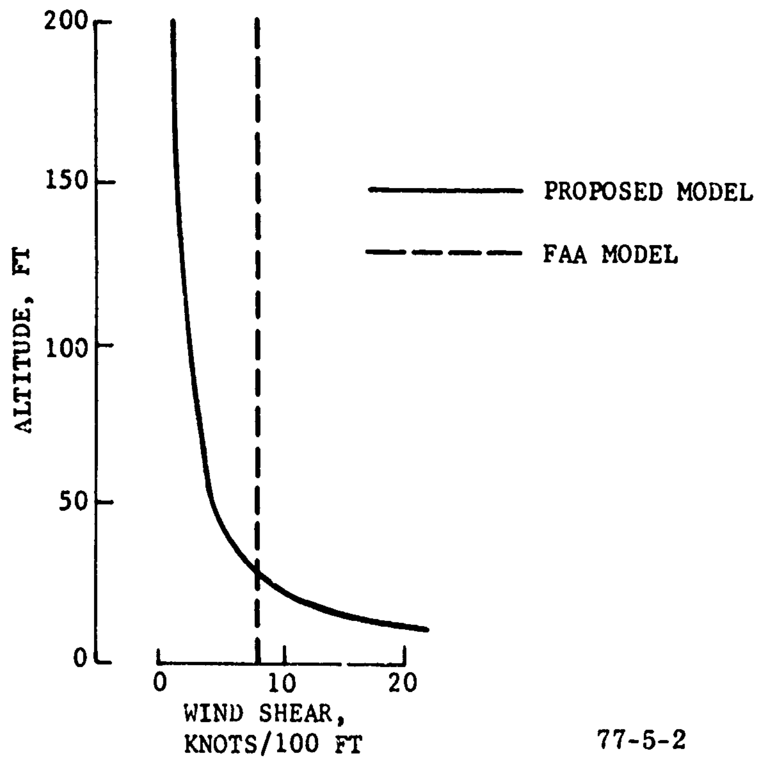

FIGURE 2. WIND SHEAR COMPARISON BETWEEN MODEL PROPOSED IN INDEX NO. 199 AND FAA-AC-20-57A

The literature search did not identify any published analytical efforts dedicated toward combining the various independent analyses of any given shear profile into a comprehensive model. This is understandable, since the local topography and heat capacity of the terrain greatly influences the surface boundary layer. Numberous reports and the variety of models in appendix B support this contention.

Some of the modeling described in the reports cited in appendix B, within category I, attempt to develop a generalized model for a given type of wind shear. This is done by allowing selected atmospheric variables to in fact vary while holding others constant. This technique enables the investigator to evaluate cause and effect, such as does the Luers' report, index No. 50, on predicting variations in aircraft touchdown, or Lowa's report, index No. 98, in forecasting potential wind shear hazards.

The principal values of wind shear characterization appear to be in the area of flight simulation for both training purposes and accident analysis. As previously noted, the FAA report FAA-RD-74-206, index No. 201, is an indepth treatment for the former, and Dr Fichtl's memorandums in December 1975 and January 1976 an example of the latter.

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In recent years, there have been several air carrier accidents in which such shears were a contributing factor. These are listed in table 1.

TABLE 1. PROBABLE WIND SHEAR ACCIDENTS

Aircraft Type	Location	Date
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In addition to these accidents, there are those aircraft accidents involving general aviation, military aircraft, and rotary-wing aircraft. The previously cited NAFEC effort will be reexamining all fixed-wing aircraft accidents from 1944 through 1975.

An excellent description of the low-level wind shear hazard as it relates to airline operations was prepared by Northwest Orient Airlines senior Meteor-oroligist, D. F. Sowa, index No. 98 and 206. Another series of articles on the problem were written by Delta Airlines W. Melvin, index Nos. 59, 60, 61, 204, and 205. While both authors have oriented their papers toward the wind shear problem as it relates to the larger aircraft, the defined hazards are applicable to all aircraft operations. Both authors concentrated their studies on the hazards which are associated with the squall lines and rapidly moving frontal systems.

The wind shear hazard and associated flight problem, from a general aviation viewpoint, are the subjects of papers by B. Schiff, index No. 213, and N. Schuyler, index No. 209, Aircraft Owners' and Pilots' Association.

As previously stated, the approach and landing or takeoff and initial climb are the most common phases of flight in which a wind shear can be hazardous. However, there are other cases in which wind shear could be or has been a factor.

In March 1964, a four-engine propeller-driven aircraft crashed in the Lake Tahoe area of Nevada. A paper by M. G. Wurtele of the Dept. of Meteorology, University of California, Los Angeles, cited the horizontal shear associated with a mountain wave as a likely contributing factor in this accident. This paper, published in June 1970, highlights another phase of flight in which a wind shear can be critical. In this case, the aircraft was attempting to climb in a mountainous terrain under icing conditions. Thus, while the wind shear alone may not have been the only factor, it may have been the critical factor in this accident.

Another phase of flight in which wind shear could be hazardous is crop dusting or other low-level aerial applications, such as fire fighting. These uses of an aircraft require slow flight and in many cases, in those areas where one may encounter wind shears or wind shifts induced by the surrounding terrain, the contribution of an encountered wind shear often goes undetected. In this type of accident, there is very little available documentation of the localized wind conditions and the aircraft resultant flightpath. As was previously noted, there is a current FAA program to reexamine existing accident/incident statistics in an effort to better identify the magnitude of the wind shear problem.

III GROUND-BASED EQUIPMENT.

During earlier FAA-supported programs in the wake vortex area, several techniques were investigated for ground-based detection of this type of atmospheric turbulence. Regardless of the success or limitations of these tests, the recent wind shear accidents prompted a reexamination of these and other techniques for wind shear detection.

A multiple-authored paper by technical personnel from the University of Wisconsin in March 1973, index No. 200, examined the use of forward scatter continuous wave radar in wind measurements. This article, which appeared in Volume 12 of the Journal of Applied Meteorology, discussed the results obtained with a radar operating at a frequency of 940 megahertz. At 1 kilometer height and up to 6.5 kilometers, the radar-derived wind, as a function of height was within 10 percent of the true (radiosonde) wind 65 percent of the time and within 20 percent of the true wind 80 percent of the time. In this article, radar-derived wind below approximately 500 meters, which covers the entire surface boundary layer, are not reported. This may, in part, be due to a ground-grazing limitation.

A paper by P. L. Smith and others in June 1974, index No. 16, discussed various potential applications of both operational and experimental radar techniques to a multiplicity of meteorological tasks including wind shear detection. In this paper, trends in the use of two or more Doppler radar systems to generate two-and three-diminsional views of the atmosphere are briefly discussed. The requirement for simultaneous scanning, "COPLAN," and other possible solutions are reviewed as are proposed techniques for reducing a single complete scan of 360° in azimuth and 20° in elevation from 53 minutes to 6 minutes. In an FAA contractor's report also in 1974 by D. Beron, index No. 142, it was indicated that while Doppler radar systems accuracies are high, the potential for continual all-weather operation is low and its costs high. A report by R. J. Donaldson Jr in 1975, index No. 129, indicated that a Doppler weather radar system offered great potential in structuring the wind field of severe storms in which precipitation or suspended moisture were present.

While there are varying degrees of limitations with microwave radar systems, these systems do offer a possibility for detecting wind shears in moisture-laden frontal systems, squall lines, and singular cell systems. This is above and beyond the current usages of weather radar for general storm and cloud-cover tracking.

At the upper range of the frequency spectrum, investigators have and are exploring the use of lasers, often called optical radars, for probing the atmosphere. The W. Viezee, R. Collis, and J. Lawrence paper in March 1973, index No. 89, reported on the use of a laser, "LIDAR," for investigating the atmospheric turbulence associated with mountain waves. It was this type of wind shear which was previously referred to in the March 1964 accident near Lake Tahoe. The test results of the LIDAR's use in 1969 and 1970 indicated that the laser system did provide data which complemented and extended the requirements for mesoscale analysis of atmospheric turbulence, (wind shear), induced by mountain waves. The paper also noted the limitations or masking effects due to clouds, high-moisture content in the atmosphere, and blowing dust. An FAA contractor's report, index No. 70, by Viezee, Oblancs, and Glaser discussed the hazards associated with high-power narrow-beam lasers which would operate under limited atmospheric moisture conditions. It suggested that regulations associated with limiting the laser power, due to the potential eye hazard, would require modification. There are current studies under way which are being sponsored by the Transportation Safety Center, TSC, that are exploring the possible use of a Doppler laser system. Such a system may offer the possibility of operating under higher atmospheric moisture conditions and not offer a potential hazard to the human eye. The Beron report, index No. 141, rates the Doppler laser's accuracy as high, its potential for continual all-weather operations as medium and relative costs as also medium.

Another paper by D. Beran in 1971, index No. 1, discusses the use of a system which operates at the lower end of the frequency spectrum, namely within the audio range. This system, which is called an acoustic Doppler system, was proposed for measuring the environment in the vicinity of an airport. It's suggested use included detection and measurement of wake turbulence and wind shear. A prototype of the acoustic Doppler was used in a wake vortex test program at NAFEC. The system showed a high sensitivity to ambient noise conditions, including automotive traffic, birds, and aircraft-generated noise in a very low air traffic environment. Other tests at New York's John F. Kennedy Airport also reflected its sensitivity to normal noise factors at an airport. The rating for such a system, as noted in index No. 142, was medium in accuracy, low in relative cost, and medium in continual all-weather operations.

Another ground-based sensing technique is the use of multiply located wind and or pressure sensors. One such system which was tested at NAFEC in 1967-68 is summarized in M. Lefkowitz and R. McCann's report in 1969, index No. 146. This mesonet network consisted of 13 stations surrounding NAFEC. The referenced document assesses the results of about 5,000,000 mesometeorological observations for providing short period aviation weather forecasting. The very limited success of this prototype system was probably due to the high dependency of the surface boundary layer on topography and the thermal absorption and radiations characteristics of the intervening terrain. L. Langweil's July 1976 paper, index No. 167, provides a brief description of four ongoing programs, two of which are the installation at Chicago O'Hare (18 micropressure and 7 surface wind measuring sites), and the tests at Dulles International (over 100 pressure jump sensors and a dual acoustic sensor/Doppler radar).

IV AIRBORNE EQUIPMENT.

There are several active or recently completed projects which are identified in the FAA's Evaluation and Development (E&D) program document of March 1976, index No. 63.

One technique under evaluation is a comparison of groundspeed and airspeed. In this procedure, groundspeed could be determind from (1) distance measuring equipment (DME), (2) inertial navigation or guidance systems (INS), or (3) a data link, either manual (voice) or automatic, using the semiautomatic existing air traffic control system, Automated Radar Terminal System (ARTS) or National Airspace System (NAS). The airspeed would be obtained from either the pilot/static aircraft system or the central air data computer (CADC). An in-house FAA letter report which evaluated the DME concept and supplemental simulator tests indicated that the current airborne DME equipment must be modified to be suitable for this purpose, in part due to its time constant.

Another technique is to evaluate the change in groundspeed or change in airspeed. In both of these concepts, only the sensing system is envolved. In the former instance, DME-derived goundspeed would suffer the same limitations previously noted. Evaluation of either of these concepts using either an INS or data link are still under study and have not been documented.

Other undocumented airborne techniques include the use of (1) change in angle-of-attack modified by a change in altitude or derivatives of these airborne-sensed parameters and (2) change in airspeed with changes in an altitude parameter.

Various aspects of airborne-sensing techniques as they relate to wind shear are at the formative stages both for simulation and flight testing at the time of this report.

V FLIGHT TEST AND SIMULATION.

One part of conducting flight simulation of wind shear encounters is defining and simulating the wind shear. R. McManus's paper, index No 67, discusses the problems associated with the testing of the autoland system for the Trident. It was indicated that while the model was producing more pessimistic results than the flight tests, in some areas it was optimistic. One of those optimistic areas was during calm or near calm conditions (at the surface) in which the model suggests no problem. Yet, experience has indicated that it is not unexpected to encounter a wind shear under such conditions.

R. Kurkowski's paper, index No. 40, discusses the modeling and simulation test results obtained at NASA AMES using their STOL simulator. These tests, designed to evaluate handling and control problems, stress the importance of modeling the atmospheric disturbances.

The Douglas Aircraft Company conducted a series of tests with a flight simulator using both a visual flight attachment system, (Redifon Terrain Model) and a computer-generated night scene image display (Vital II). Various visual presentations, with and without various types of wind shear, were flown by 20 airline pilots. Also included were induced failures and both coupled and uncoupled approach and landings. The results reported by C. Stout, index No. 145, indicated that an experienced pilot who is knowledgeable in problems associated with wind shear could safely negotiate a landing under a variety of weather conditions and induced failures. Most participants indicated in their post-flight debriefing that the training acquired from these tests was most beneficial.

Tests were conducted at Boeing for NTSB in which the apparent wind shear conditions existing during the JFK Airport Eastern 66 accidents were simulated. The unpublished results indicated that while it was marginally within the capability of the aircraft, many of the subject pilots had great difficulties during their first exposure to the wind shear.

Current flight test programs include FAA-sponsored tests using instrumented C141, DC10, and B747 flight recorder data from aircraft operated by Royal Dutch Airlines (KLM) and an instrumented FAA Aero Commander. In addition, NASA Langley is collecting wide-body jet flight recorder data from two large American air carriers in an effort to define the frequency and characteristics of wind shear encounters.

VI FORECASTING/METEOROLOGY.

A wind shear hazard forcasting technique used by Northwest Orient Airlines is described in index No. 98. This technique sets forth two criteria for frontal associated low-level wind shears, (1) a surface temperature difference, immediately across the flightpath of 5° Centigrade (10° Fahrenheit) and/or (2) the front is moving at 30 knots or more. This technique is currently under evaluation by NAFEC. Within the operating range of NAFEC's wind shear test aircraft, when either or both criteria are met, the aircraft will probe for low-level wind shears.

The "shortcasting" technique previously cited under "GROUND-BASED EQUIPMENT," namely the NAFEC MESONET, index No. 146, had very limited success in predicting weather conditions at the airport 5 minutes after observations at satellite remote weather stations. Current tests at both Chicago O'Hare and Dulles International airports will be reexamining the use of anemoneters and/or pressure sensors for wind shear hazard detection. These types of systems may be useful in detection of wind shears due to thunderstorms and single cell activity as well as frontal systems.

During a series of meetings with technical personnel at NOAA Asheville, North Carolina, the tabulation of normally documented meteorological information associated with three wind-shear-related aircraft accidents were reviewed. In two of the three accidents, there was a shifting of the wind component which was detectable 6 hours before the accident. In the discussions that followed these meetings, it was suggested that a power spectral density analysis of the wind observations may be a useful forecasting tool. Such analyses have been done with respect to relating the discrete gust and atmospheric turbulence. The literature search did not identify work using this technique for wind shear hazard forecasting.

VII FLIGHT OPERATIONAL PROCEDURES/PILOT TRAINING.

The wind shear forecasting technique noted in index No. 98, is used as an operational tool by several air carriers to alert flight crews of possible low-level wind shear encounters. As previously noted, flight simulator tests at both Boeing and Douglas indicated that prewarned pilots can manually compensate for a wind shear encounter that does not exceed the performance capability of the aircraft.

This has been supported by actual flight experience in which aircraft operating in the same wind shear environment as some of those which crashed, were able to cope with the hazard. Simulator tests also indicated that modern autopilots can also compensate for a wind shear encounter during a coupled (autopilot) approach.

An important factor which the analysis of these simulator tests and accident histories suggest is that transition from the coupled to uncoupled (autopilot to manual) approach may present an unsolvable problem to the flight crew. During a coupled approach, the aircraft's altitude or change in altitude is controlled by the elevator (pitch), and it's airspeed by throttle setting (power). In the manual mode, the opposite is true. The pilot will use throttle settings to control altitude or sink rate and elevator trim to control airspeed. In transition from coupled to uncoupled approach, the flight crew could be presented with an illusionary potential overshoot or undershoot visual reference during the transition, which could result in a use of power reverse from that required. A wind shear encounter at this time, especially a headwind to tail-wind or decreasing headwind, could result in an uncontrolled descent which could not be arrested in time before ground collision due to the spool up-time requirement.

Another important operational factor is the problem of communicating known or potential wind shear hazard information to the flight crew. In the E&O Wind Shear Program defined in index No. 63, this problem was recognized. The FAA in cooperation with the user groups are developing standard technical terminology. This operational language will be evaluated in a series of simulator tests with pilot subjects from all segments of the aviation community.

APPENDIX A

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1. ACOUSTICS: A NEW APPROACH FOR MONITORING THE ENVIRONMENT NEAR AIRPORTS
Beran, D. W. NOAA, Boulder, Colorado, Wave Propagation Lab COM-72-10726, August 12, 1971.
This note provides information on an acoustic echo sounder for use in monitoring various meteorological parameters at or near airports. The monitoring system could provide real time information on inversion heights, turbulence intensity, thermal plumes, wind profiles, and vertical wind. It could also provide information for short-range forecast input, wake turbulence advisories, low-level wind shear reports, and air pollution alerts.

2. ADDITIONAL RESEARCH OF LOW ALTITUDE TURBULENCE DATA
Gault, Joe D., Boeing of Wichita, Kansas, Wichita Division, AFFDL-TR-71-150, September 1971.
The report presents procedures, analysis methods and results pertaining to a more detailed study of several data samples recorded during the low-altitude atmospheric turbulence program (lo-locat, Phase III). Wind spectra corrected for airplane motion effects and gust velocity were calculated using filtered input parameters substantiated the original results obtained during lo-locat, Phase III.

3. AERODYNAMICS DEPARTMENT - ANNUAL REPORT 1971. SELECTED RESEARCH TOPICS.
Butler, S. F. J., Royal Aircraft Establishment, Farnborough (England), RAE-TR-72073, April 1972.
The annual report consists of a collection of abstracts based on work completed during 1971 in the Aerodynamics Department at RAE.

4. AERONAUTICAL REQUIREMENTS AND PROCEDURES FOR LOW-LEVEL TURBULENCE AND WIND SHEAR REPORTING
Nancoo, M. E., Sixth Conference on Aerospace and Aeronautical Meteorology, November 1974.
The nature and characteristics of low-level wind shears which are hazardous to aircraft during takeoff and landing are examined. The wind shear experienced by aircraft at heights up to 60 m may be caused by vertical variations in the mean flow (vertical shear), by horizontal variations in the mean flow (horizontal shear), by atmospheric turbulence, or by combinations of these factors. Specific requirements, criteria, and procedures established by ICAO for reporting vertical wind shear cannot be applied in many cases because of the lack of a reliable system for measuring vertical wind shear. The use of tethered balloons, laser Doppler, acoustic Doppler, and radar Doppler systems for this purpose is proposed.

5. AIRCRAFT ACCIDENT REPORT - DELTA AIR LINES, INC., DOUGLAS DC-9-32, N3323L, CHATTANOOGA MUNICIPAL AIRPORT, CHATTANOOGA, TENNESSEE, NOVEMBER 27, 1973.
Anonymous, National Transportation Safety Board, Bureau of Aviation Safety, Washington, D. C., NTSB-AAR-74-13, November 8, 1974.

On November 27, 1973, Delta Air Lines Flight 516, a McDonnell Douglas DC-9-32, N3323L, crashed while making an ILS approach to tunway 20 at Chattanooga Municipal Airport, Chattanooga, Tennessee. The aircraft was destroyed. The National Transportation Safety Board determines the probable cause of the accident was that the pilot did not recognize the need to correct an excessive rate of descent after the aircraft had passed decision height. The excessive rate of descent was initiated by a wind shear condition which existed in the lower levels of the approach path and a glide slope that tended toward the lower signal limit.

6. AIRCRAFT ACCIDENT REPORT - IBERIA LINEAS AEREAS DE ESPANA (IBERIAN AIRLINES), MCDONNELL DOUGLAS DC-10-30, FC CBN, LOGAN INTERNATIONAL AIRPORT, BOSTON, MASSACHUSETTS, DECEMBER 17, 1973
Anonymous, National Transportation Safety Board, Bureau of Aviation Safety, Washington, D. C., NTSB-ARR-74-14, November 8, 1974.

On December 17, 1973, Iberia Lineas Aereas de Espana Flight 933, a DC-10-30, crashed while making an instrument landing system approach to runway 33L at Logan International Airport, Boston, Massachusetts. The NTSB determined that the probable cause of this accident was that the captain did not recognize, and may have been unable to recognize, an increased rate of descent in time to arrest it before the aircraft struck the approach light piers. The increased rate of descent was induced by an encounter with a low-altitude wind shear at a critical point in the landing approach where he was transitioning from automatic flight control under instrument flight conditions to manual flight control with visual references.

7. AIRPLANE FLYING CHARACTERISTICS IN TURBULENCE
Onstott, E. D., Salmon, E. P., (Northrop Corporation, Aircraft Div.), Air Force Flight Dynamics Lab., Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, AFFDL-TR-70-143, February 1971.

A method for predicting the performance of the total pilot-vehicle system has been developed for the lateral dynamics of Class IV airplanes. This method, which is based on pilot model theory and multiloop analysis, predicts tracking errors for command tracking tasks and also for altitude hold tracking tasks in turbulence. The predictions are in terms of root mean square time domain statistics and are obtained by means of a fully automated multiloop analysis performance prediction program available from the United States Air Force. Thus, system performance can be evaluated analytically in terms of familiar time domain root mean square statistics. The validity and accuracy of this method has been ascertained by means of moving base simulation on the Northrop Large Amplitude Flight Simulator operating in five degree of freedom motion.

8. ANALYSES OF ENERGY, MOMENTUM, AND MASS TRANSFERS ABOVE VEGETATIVE SURFACES
Morgan, D. L., Pruitt, W. O., Lourence, F. J., California University Davis, Dept. of Water Science and Engineering, Final Report, AD-721-301, February 1971.

Extensive surface shear-stress and wind-profile measurements during six separate field studies at Davis, California, indicate a value for the von Larman constant, k, of 0.42. Expressions relating k sub m to the Richardson number for both stable and unstable conditions, based on the Davis data, are presented and compared favorable with the findings of several others. Expressions relating the diabatic wind profile functions to both the Richardson number and z/L are developed and compared with the results of many other researchers.

9. ANALYSIS OF ATMOSPHERIC FLOW OVER A SURFACE PROTRUSION USING THE TURBULENCE KINETIC ENERGY EQUATION WITH REFERENCE TO AERONAUTICAL OPERATING SYSTEMS FINAL REPORT
Frost, W., Harper, W. L., Tennessee University Space Institute, Tullahoma, NASA-CR-2630 M-154, December 1975.

Flow over surface obstructions can produce significantly large wind shears such that adverse flying conditions can occur for aeronautical systems. Discussion of the effects of the disturbed wind field in CTOL and STOL aircraft flightpath and obstruction clearance standards is given. The results indicate that closer inspection of these presently recommended standards as influenced by wind over irregular terrains is reruired.

10. ANALYSIS OF ATMOSPHERIC FLOW OVER A SURFACE PROTRUSION USING THE TURBULENCE KINETIC ENERGY EQUATION
Frost, W., Harper, W. L., Fichtl, G. H., (Tennessee, University, Tullahoma, Tennessee), (NASA, Marshall Space Flignt Center, Huntsville, Alabama), Boundary-Layer Meteorology, Vol. 8, April-June 1975, P. 401-417, June 1975.

Atmospheric flow fields resulting from a semielliptical surface obstruction in an otherwise horizontally homogeneous statistically stationary flow are modeled with the boundary-layer approximation of the governing equation of fluid mechanics. The turbulence kinetic energy equation is used to determine the dissipative effects of turbulent shear on the mean flow. Mean-flow results are compared with those given in a previous paper where the same problem was attacked using a prandtl mixing-length hypothesis. Iso-lines of turbulence kinetic energy and turbulence intensity are plotted in the plane of the flow. They highlight regions of high turbulence intensity in the stagnation zone and sharp gradients in intensity along the transition from adverse to favorable pressure gradient.

11. ANALYSIS OF PREDICTED AIRCRAFT WAKE VORTEX TRANSPORT AND COMPARISON WITH EXPERIMENT
Brashears, M. R., Logan, N. A., Robertson, S. J., Shrider, K. R., and Walters, C. D., Lockheed Missiles & Space Company, Inc., Huntsville Research & Engineering Center, Huntsville, Alabama, FAA-RD-74-74I, April 1974.

A unifying wake vortex transport model is developed and applied to a wake vortex predictive system concept. The fundamentals of vortex motion underlying the predictive model are discussed including vortex decay, bursting, and instability phenomena. A parametric and sensitivity analysis is presented to establish baseline uncertainties in the algorithm to allow meaningful comparison of predicted and measured vortex tracks. A detailed comparison of predicted vortex tracks with photographic and ground-wind vortex data is presented. Excellent agreement between prediction and measurement is shown to exist when sufficient wind data are available. Application of the Pasquill class criteria is shown to be an effective technique to describe the wind profile in the absence of detailed wind data. The effects of wind shear and the Ekman spiral on vortex transport are discussed. It is shown that the combination of wind shear and ground plane may be possible mechanisms underlying vortex tilting and a theoretical explanation is advanced that is somewhat supported by comparison with the experimental data. Finally, recommendations for further vortex data collection in the vicinity of an airport are presented.

12. ANALYSIS OF PREDICTED AIRCRAFT WAKE VORTEX TRANSPORT AND COMPARISON WITH EXPERIMENT VOLUME II -- APPENDIXES
Brashears, M. R., Logan, N. A., Robertson, S. J., Shrider, K. R., Walters, C. D., Lockheed Missiles & Space Company, Inc., Huntsville Research & Engineering Center, FAA-RD-74-74II, April 1974.
A unifying wake vortex transport model is developed and applied to a wake vortex predictive system concept. The fundamentals of vortex motion underlying the predictive model are discussed including vortex decay, bursting, and instability phenomena. A parametric and sensitivity analysis is presented to establish baseline uncertainties in the algorithm to allow meaningful comparison of predicted and measured vortex tracks. A detailed comparison of predicted vortex tracks with photographic and ground-wind vortex data is presented. Excellent agreement between prediction and measurement is shown to exist when sufficient wind data are available. Application of the Pasquill class criteria is shown to be an effective technique to describe the wind profile in the absence of detailed wind data. The effects of wind shear and the Ekman spiral on vortex transport are discussed. It is shown that the combination of wind shear and ground plane may be possible mechanisms underlying vortex tilting and a theoretical explanation is advanced that is somewhat supported by comparison with the experimental data. Finally, recommendations for further vortex data collection in the vicinity of an airport are presented.

13. ANALYSIS OF THE RESEARCH FLIGHT FACILITY GUST PROBE SYSTEM
Brown, W. J., Jr., McFadden, J. D., Mason, H. J., Jr., Travis, C. W., (NOAA, Research Flight Facility, Miami, Fla.), Journal of Applied Meteorology, Vol. 13, P. 156-167, February 1974.
An analysis of the frequency response of the input parameters of a gust probe system, which measures the turbulent flow of air, is presented. The results show that the system is very sensitive to noise created by aircraft structural and power plant vibrations.

14. ANALYSIS OF RESPONSE TO WIND-SHEARS USING THE OPTIMAL CONTROL MODEL OF THE HUMAN OPERATOR
Baron, Sheldon, In MIT Proc. of the 9th Ann. Conf. on Manual Control, p. 419-428, CSCL 01C, 1973.
The effects of wind-shears on the approach performance of a STOL aircraft are analyzed using the optimal-control model of the human operator. This analysis involves a time-varying situation that is more complex than is traditionally treated by human operator modelling techniques. The extensions to the time-varying case are discussed and results are presented that illustrate the effects of wind shears on category II window-performance and the effects on performance of pilot time-delay and of variations in pilot gain during approach.

15. APPLICATION OF FM-CW RADAR AND ACOUSTIC ECHOSOUNDER TECHNIQUES TO BOUNDARY LAYER AND CAT STUDIES
Bean, B. R., NOAA, Boulder, Colorado, Wave Propagation Lab., COM-72-51061-20, 1972.

Recent results are given comparing acoustic and FM-CW radar sounders with in situ measurements of atmospheric structure. The agreement of temperature and wind structure with the sounder records suggests that the two types of measurements are highly complementary, the tower data aiding in understanding the atmospheric processes traced by the sounder and the sounder aiding in selection of periods of stationarity suitable for detailed analysis of the tower data. The same conclusion can be reached for studies of exchange of energy between the mean and eddy flow. Examination of structures that appear similar to those of instability waves produced by wind shear at the stable interface of the temperature inversion indicate that such waves break when the Richardson number attains the value of 0.25. The wavelength associated with such breaking waves conforms to the theoretically predicted range of values.

16. APPLICATIONS OF RADAR TO METEROROLOGICAL OPERATIONS AND RESEARCH
Smith, Paul L., Jr. (Senior Member, IEEE), Hardy, Kenneth R. (Member, IEEE), Glover, Kenneth M. (Member, IEEE), Radar in Meteorology, Proceedings of the IEEE, June 1974 (Invited Paper).

Radar echoes from meteorological targets have existed almost from the time that radar was first used. In this paper, an equation is presented which relates the echo power to a characteristic of the cloud or precipitation particles within the radar pulse volume. Some examples of how radar has been used for operational purposes are given; these include a description of the utility of radar for storm detection, how radar can be used as an aid to weather forecasting for both the public and aviation interests, and also how radar can be applied to help solve some hydrological problems. Significant research results on the nature of atmospheric structure and processes as derived with the help of radar are presented. Doppler radar has played a prominent role in the investigation of storm dynamics, and high-power high-resolution radars have been used for studying the development and nature of clear-air. Recent trends in meteorological radars are indicated and suggestions are set forth which relate to the improved use of radar for operations.

17. ASPECTS OF THE INFLUENCE OF LOW-LEVEL WIND SHEAR ON AVIATION OPERATIONS
Kraus, K. A., (FAA Systems Research and Development Service, Washington, D. C.), In: International Conference on Aerospace and Aeronautical Meteorology, Lst, Washington, D. C., May 22-26, 1972, Preprints. (A72-28801 13-20) Boston, American Meteorological Society, 1972, p. 332, 333.

Consideration of the occasional, unusual, or extreme wind shear event that presents itself as a problem in aircraft control. This is becoming more important with the increased requirement for design precision and demand for maximum utilization of aircraft and facilities. An important aspect of wing shear occurs during a light and variabile surface wind. When such conditions exist and the controller is not aware of the low-level winds, he may not select the best active runway. The ideal system of the future would measure the vertical wind environment without requiring probes such as ballons or INS-equipped aircraft.

18. AN ASSESSMENT OF ATMOSPHERIC TURBULENCE DATA FOR AERONAUTICAL APPLICATION
Garrison, Jan N., Royal Aeronautical Society, International Conference on Atmospheric Turbulence, pp. 18-21, May 1971.
There has been a strong trend toward relating turbulence data to more of the factors which influence the data, particularly atmospheric parameters. This trend has two beneficial results: (1) confidence in statistical data is increased which should result in more realistic turbulence models for aircraft design, and (2) the statistical data are merging with out qualitative understanding of turbulence physical processes which should lead to improvements in turbulence forecasting. This paper gives a brief overview of the status of these developments.

19. ATMOSPHERIC PARAMETERS
Ehernberger, L. J., National Aeronautics and Space Administration, Flight Research Center, Edwards, California.
The objectives of this work is the definition of the atmospheric conditions in which turbulence, temperature transients, potential pressure altimetry problems, and excessive wind shears occur. The major emphasis is the atmospheric environment of supersonic aircraft. Development and acquisition of sensors needed to measure these phenomena are also included. Results of this work will be applicable to aircraft systems design as well as flight operations routing and scheduling. Observations of these phenomena are obtained from instrumented aircraft test flights. The associated meteorological conditions are analyzed and studied both in-house and on contract.

20. ATMOSPHERIC TRANSPORT AND DIFFUSION IN THE PLANETARY BOUNDARY LAYER, JULY 1971 - JUNE 1972
Van der Hoven, I., NOAA, Silver Spring, Md., Air Resources Labs., NOAA-TM-ERL-ARL-39, June 1973.
This is a review of the studies made by Air Resources Laboratories for the Environmental Safety Branch, Division of Reactor Development and Technology, U. S. Atomic Energy Commission. Air Resources Laboratories have continued their study of atmospheric transport and diffusion climatology, and the application of this micrometeorology, diffusion climatology, and the application of this work to the disposal of radioactive waste gases into the atmosphere. This report includes aspects and data on wind measurements.

21. ATMOSPHERIC TURBULENCE
Anonymous, Defense Documentation Center, Alexandria, Virginia, DDC-TAS-73-50, August 1973.
The bibliography is a selection of unclassified-unlimited distribution references on atmospheric turbulence. These citations of reports present information on clear-air turbulence, boundary layer turbulence, storm and cloud turbulence, upper air turbulence, turbulent diffusion and dispersion, turbulence interaction with electromagnetic and acoustic waves, and spectral analysis methods. The report contains indexes of corporate-author-monitoring agency: Subject, title, and personal author.

22. ATMOSPHERIC TURBULENCE FIELD PARAMETERS DETERMINATION
Neulieb, Robert L., Garrison, Jan N., Golden, Dennis J., Air Force Flight Dynamics Lab., Wright-Patterson AFB, AFFDL-TR-72-51, April 1972.
A Newton-Raphson least squares percentage error method is developed for the determination of atmospheric turbulence field parameters. A correction function is proposed to deemphasize the effects of data points with low statistical confidence. The method is used on various sets of lo-locat data to demonstrate the excellence of the curve fits obtained. Comparisons are made with other curve fits found in the literature. It is recommended that this method be adopted as the standard method for the determination of atmospheric turbulence field parameters.

23. AUTOMATIC LANDING SYSTEMS (ALS)
Anonymous, FAA, Advisory Circular AC 20-57A, January 1971.

24. AVIATION WEATHER
Anonymous, Federal Aviation Administration, AC 00-6A, 1975.
A pilot's handbook and guide to weather as it relates to flying.

25. BEHAVIOR OF SPHERICAL BALLONS IN WIND SHEAR LAYERS
Fichtl, G. H. (NASA, Marchall Space Flight Center, Huntsville, Ala.), Journal of Geophysical Research, Vol. 77, p. 3931-3935, July 20, 1972.
Analysis of the response of rising spherical ballons to a constant wind shear condition. Wind shear tends to produce a terminal rise rate that is less than the terminal rise rate in the absence of wind shear by no more than 1 percent of the wind shear and a horizontal balloon velocity defect relative to the local wind with magnitude less than or about equal to 0.2 of the wind shear for most meteorological balloons. An analysis of the behavior of a balloon in a wind field in which the wind shear varies along the vertical is also presented.

26. BEHAVIOR OF VERY LARGE AIRCRAFT DISTURBED BY WIND SHEAR AND ATMOSPHERIC TURBULENCE
deBoer, W. P., National Aerospace Lab., Amsterdam (Netherlands), (NLR-TR-72023-U), February 10, 1972.
The behavior of very large aircraft disturbed by wind shear and atmospheric turbulence (vertical gust during the landing approach) is analyzed by means of a multiloop system. The aircraft considered were a B747-like aircraft and two hypothetical aircraft, the VLAC-1A and the VLAC-4A, with weights ranging from 500,000 to 4,000,000 lbs. A combined system, consisting of an autothrottle to control airspeed and a human pilot model to control altitude was developed. It was shown that because of the decreasing value of short period value with increasing aircraft weight, a larger value of the lead time constant is needed for the larger aircraft resulting in a worse pilot rating. Results indicated that due to higher approach speeds of the larger aircraft, a higher percentage of the available thrust will be needed to cope with a given wind shear. Increased engine response lag can deteriorate altitude control.

27. BIBLIOGRAPHY OF PAPERS AND REPORTS RELATED TO THE GUST UPSET/PILOT DISORIENTATION PROBLEMS
Newberry, Clifford F., Advisory Group for Aerospace Research and Development, Paris (France), AGARD-616, February 1974.

The report is a compilation of papers and reports that have been issued relating to the problem of an airplane being upset from atmospheric disturbances and the pilot being disoriented as a result of the upset. This report lists the published papers that were known and available to the working group coordinator. The report lists the papers by title and report number and wherein a summary was available, the summary is also provided.

28. THE BUDGETS OF TURBULENT KINETIC ENERGY AND TEMPERATURE VARIANCE
Wyngaard, J. C., Cote, O. R., Atmospheric Sciences, Vol. 28, No. 2, pp 190-201, March 1, 1972.

29. CAT DETECTION SYSTEM INSTRUMENTATION - BIMONTHLY PROGRESS REPORT, 1 MAY - 30 JUNE 1973.
Jelalian, A. V., Chalot, A. A., Kawachi, D. A., Richardson, W. A., Raytheon Co., Sudbury, Mass., (Equipment Div.), NAS8-28424, July 20, 1973.

30. CIVIL AIRCRAFT ACCIDENT ANALYSIS IN THE UNITED STATES "THE JET AGE"
Anderson, Coe M., Laboratory Services Staff, National Transportation Safety Board, Bureau of Aviation Safety, July 1976, (Unpublished).

31. THE CIVIL AIRCRAFT AIRWORTHINESS DATA RECORDING PROGRAMME ACHIEVEMENTS IN RECORDING AND ANALYSIS OF CIVIL AIRCRAFT OPERATIONS
Owen, E. Margorie, Royal Aircraft Establishment, Farnborough (England), RAE-TR-71034, February 1971.

Analogue, continuous trace, multi-parameter records of airworthiness data, representing more than 65,000 flying hours, were taken from jet transport aircraft in regular airline service from 1962-1969. In Phase 1 (1962-1965) data were recorded on aircraft well proved in service, in Phase 2 (1966-1969) newer aircraft were instrumented and the records were augmented by additional parameters chiefly directed to obtaining more detailed landing data. More parameters were recorded than in any previous operational research program, and much valuable information was acquired in the fields, among others, of airworthiness, flying hazards, operating practices (including autoland) and meteorology, and of assistance for accident investigations.

32. COMMENTS ON STRATIFIED FLOW OVER EXTENDED OBSTACLES AND ITS APPLICATION TO TOPOGRAPHICAL EFFECT ON VERTICAL WIND SHEAR
Miles, John W., California Univ., San Diego La Jolla Inst. of Geophysics and Planetary Physics, AD-746-410, January 18, 1972.

Wong and Kao (1970) concluded that upstream disturbances are present whenever lee waves are present in stratified flow over obstacles. It is pointed out here that, within the hypothesis of linearized flow, that their conclusion is not valid for unseparated flow over finite obstacles.

33. COMPARATIVE TURBULENCE FOR A CANBERRA AND A VULCAN FLYING TOGETHER AT LOW ALTITUDE.
Curran, J. K., Royal Aircraft Establishment Farnborough (England), RAE-TR-71100, May 1971.
Measurements have been made of the response to turbulence of two aircraft, a Vulcan and a Canberra, while flying together over land and over the sea.

34. COMPARISON OF THE INFLUENCE OF HORIZONTAL AND VERTICAL GUST INTERFERENCES ON AIRCRAFT LONGITUDINAL MOTION.
Achaenzer, F., Scientific Translation Service, Santa Barbara, California, NASA-TT-F-15801, July 1974.
In determining the influence of gust loads on a noncontrolled longitudinal aircraft motion, it is shown to be necessary to take into account horizontal and vertical gust components, their frequencies and power spectra. At altitudes below 50 meters, the horizontal gusts have the greatest influence.

35. A COMPARISON OF WIND RECORDS FROM TWO NEIGHBOURING STATIONS IN NORTHERN ELLESMERE ISLAND
Sadler, H. Eric, Finlayson, Duncan, Defence Research Establishment Ottawa (Ontario), DREO-TN-75-25, November 1975.
The wind records from two stations in Northern Ellesmere Island are compared for 52 days. One station was only 55 km away from the other. It is shown that the winds recorded at the two locations have little or no relation to each other but are largely governed by the local topography.

36. CONFERENCE SUMMARY: INTERNATIONAL CONFERENCE ON AEROSPACE AND AERONAUTICAL METEOROLOGY
Quiroz, R. S., Kellogg, W. W., Bromley, Edmund Jr., National Meteorological Center, Washington, D. C., COM-73-10006, 1972.
The conference was divided into three sections: aerospace, air quality, and aviation. In the aviation section about 40 papers and 3 panel discussions provided the stimulus for the attendees to talk about terminal weather, turbulence, icing, hail, CAT, wind shear, and other atmospheric phenomena as they relate to safe and efficient movement of aircraft.

37. CROSS-SPECTRAL FUNCTIONS BASED ON VON KARMAN SPECTRAL EQUATION
Houbolt, John C., Sen, Asim, NASA Contractor Report, NASA CR-2011, March 1972.

38. CUMULUS CONVECTION AND LARGER-SCALE CIRCULATIONS. PART III. BROADSCALE AND MESO SCALE CONSIDERATIONS
Gray, William M., Colorado State Univ., Fort Collins Dept. of Atmospheric Science, Paper-190, July 1972.
The magnitude and implications of vertical circulation patterns during the summer in tropical atmospheric regions is discussed. Large-scale observations indicate that significant extra up and down local motion occurs exceeding that prescribed by mean or synoptic scale flow patterns.

39. DESIGN AND INVESTIGATION OF A WIND-SHEAR-PROOF CONTROL SYSTEM FOR AUTOMATIC LANDING

Trivett, Louis G., Air Force Institute of Tech., Wright-Patterson AFB, Ohio School of Engineering, GGS/MA/73/4, June 1973.

An analog computer simulation of the longitudinal portion of an all-weather landing system is presented. The linearized longitudinal equations of motion of a DC8 aircraft during landing approach are converted to state-variable form to facilitate the analog simulation. An advanced automatic flight control system is added and the approach phase of an automatic landing is simulated. A severe turbulence atmospheric environment consisting of wind gusts and wind shears is an integral part of the simulation. A systematic method is presented for developing a Kalman filter based wind-shear-proofing system to reduce deviations from glide slope caused by wind shears.

40. DEVELOPMENT OF TURBULENCE AND WIND SHEAR MODELS FOR SIMULATION APPLICATION

Kurkowski, R. L., Fichtl, G. H., Gera, J., NASA Aircraft Safety and Operating Problems, Vol. 1, NASA SP-270-1971, 1971.

The purpose of this paper is to present information on some continuing studies aimed at producing realistic models of turbulence and wind shears for handling qualities studies. These studies include an evaluation of analytical models of turbulence which have non-Gaussian gust distributions, a statistical analysis of wind shear, and a brief evaluation of the effects of wind shear on aircraft operations.

41. A DIGITAL CALCULATION OF THE RESPONSE OF A PILOTED SUBSONIC JET-TRANSPORT AIRPLANE TO SEVERE VERTICAL GUSTS

Strong, K. L., PH.D Thesis, Texas University, Arlington, 1973.

A digital computer investigation has been made to study the response characteristics of a four-engine subsonic jet transport airplane flying through severe vertical gusts. The simulation includes the pertinent factors suspected of contributing to the turbulence-induced jet-upset problem. The analysis is confined to the three-degree-of-freedom, longitudinal, rigid-body dynamics.

42. DOPPLER RADAR INVESTIGATION OF FLOW PATTERNS WITHIN THUNDERSTORMS

Kraus, Michael J., Air Force Cambridge Research Laboratories (LYW), Hanscom AFB, Mass., AFCRL-TR-74-0290.

Information of airflow in six New England Thunderstorms was obtained from quasi-horizontal observations by a single Doppler radar. Radial velocity fields in four of the storms showed well organized patterns throughout an appreciable range of height. Vertical cross sections of the horizontal component field, coupled with some reflectivity information, provided a basis for inferring regions where vertical motion was strong. Computed horizontal flow fields consistent with the observed component fields showed environmental flow basically through the storm except at mid-levels. The radial velocity patterns in the fifth storm showed no organization and little variation from the environmental wind field. Computed vector velocity fields at two low elevation angles showed environmental flow through the echo except for a small area where flow around an obstacle was indicated. Comparisons are made between these and other Doppler radar observations.

43. DOPPLER RADAR MEASUREMENTS OF TURBULENCE, SHEAR, AND DISSIPATION RATES IN A CONVECTIVE STORM
Strauch, R. G., Frisch, A. S., Sweezy, W. B., (NOAA, Wave Propagation Laboratory, Boulder, Colo.), Radar Meteorology Conference 16th, Houston, Texas, April 22-24, 1975.

44. DOPPLER AND REFLECTIVITY MORPHOLOGY OF A SEVERE LEFT-MOVING SPLIT THUNDERSTORM
Achtemeier, G. L., Preprints, 16th Cong. on Radar Meteorology, elsewhere in this volume, 1975.

45. DOPPLER RADAR STUDIES OF BOUNDARY LAYER WIND PROFILE AND TURBULENCE IN SNOW CONDITIONS
Wilson, Dean A., ESSA Research Labs., Boulder, Colorado, COM-73-10119-38.
The paper proposes a method of measuring the rate at which the turbulent kinetic energy grows at the expense of wind shear. The study illustrates how Doppler radar techniques are applicable to the evaluation of the turbulent kinetic energy budget in the boundary layer. Experimental results were derived from observations of space motion variability of snowflakes.

46. DROPSONDE MEASUREMENTS OF VERTICAL WINDS IN THE COLORADO THUNDERSTORM OF 22 JULY 1972
Bushnell, R. H., (National Center for Atmospheric Research, Boulder, Colorado.), Journal of Applied Meteorology, Vol. 12, p. 1371-1374, June 15, 1973.
In connection with the National Hail Research Experiment vertical winds were measured in a thunderstorm by 10 special dropsondes dropped side-by-side over a distance of 4 km. The measurements, made at the northern edge of a weak-echo region, showed updrafts up to 13 m sec. at middle levels with much variability.

47. EASTERN AIRLINES FLIGHT 66 WIND PROFILES AS DETERMINED FROM FLIGHT RECORDER
Anonymous, Boeing Company, November 1975.

48. THE EFFECT OF AIRCRAFT FLIGHT CONDITIONS ON LOW ALTITUDE CRITICAL AIR TURBULENCE/LO-LOCAT
McCloskey, J. W., (Dayton, University, Dayton, Ohio), International Conference on Aerospace and Aeronautical Meteorology, 1st, Washington, D. C., May 22-26, 1972.
Development of an analytical procedure for relating turbulence parameters to a wide range of low-level flight conditions recorded for each leg of 5 1/2 minutes duration. The gust velocity time history was recorded, filtered to eliminate drift and aircraft motion from the data, and finally decomposed into three orthogonal, space-oriented gust velocity components. A linear model is established in an attempt to identify various flight conditions which will be useful in the prediction of clear-air turbulence.

49. EFFECT OF GROUND WIND SHEAR ON AIRCRAFT TRAILING VORTICES
Burnham, D. C. (U. S. Department of Transportation, Transportation Systems Center, Cambridge, Mass.) AIAA Journal, Vol. 10, p. 1114, 1115, August 1972.
In order to understand the observed asymmetry in vortex height, a self-consistent two-dimensional calculation was made of the vortex motion for a simple model in which all the vorticity of the ground shear layer is concentrated into a series of evenly spaced line vortices at a particular altitude. The model gives a reasonable description of winds at distances larger than the vortex spacing. The phenomenon described pertains to relatively low crosswinds.

50. EFFECT OF SHEAR ON AIRCRAFT LANDING
Luers, James K., Reeves, Jerry B., National Aeronautics and Space Administration, Washington, D. C., NASA CR-2287, July 1973.
A simulation study was conducted to determine the effect of wind shear on aircraft landings. The landing of various type of commercial and military aircraft was digitally simulated starting from an initial altitude of 300 feet. Assuming no pilot feedback during descent, the deviation in touchdown point due to vertical profiles of wind shear was determined. The vertical profiles of wind shear are defined in terms of surface roughness, Z_0, and stability, L, parameters. The effects on touchdown due to Z_0 and L have been calculated for the different type aircraft. Comparisons were made between the following types of aircraft: C-130E, C-135A, C-141, DC8, Boeing 747, and an augmentor-wing STOL. In addition, the wind shear effect on touchdown resulting from different locations of the center of gravity and weights was also analyzed.

51. EFFECT OF SURFACE FRICTION ON THE STRUCTURE OF PARATROPICALLY UNSTABLE TROPICAL DISTURBANCES
Williams, R. T., Schminke, T. K., Newman, R. L. Naval Postgraduate School, Monterey, California, COM-71-50333-10-07, June 9, 1971.
The structure of barotropically unstable disturbances in the Tropics is studied with a two-level quasi-geostrophic model. An Ekman layer is attached to the lower boundary. The equations are linearized and the most unstable mode is found numerically by using the initial value technique. Computations are made for a shear-zone wind profile and a jet profile, these fields are independent of height. The disturbance structure is found to be critically dependent on the absolute vorticity gradient in the mean flow. The predicted disturbance structures contain a number of features that are observed in tropical wave disturbances.

52. EFFECT OF WIND SHEAR ON ATMOSPHERIC WAVE INSTABILITIES REVEALED BY FM/CW RADAR OBSERVATIONS
Gossard, E. E., Righter, J. H., Jensen, D. R., (NOAA, Wave Propagation Laboratory, Boulder, Colo.), (NOAA, Wave Propagation Laboratory, Boulder Colo.), (U. S. Naval Material Command, Naval Command and Control Communications Center, San Diego, California), Boundary-Layer Meteorology, Vol. 4, p. 113-131, April 1973.

53. EFFECT OF WIND SHEAR ON ATMOSPHERIC WAVE INSTABILITIES REVEALED BY FM/CW RADAR OBSERVATIONS
Gossard, E. E., Richter, J. H., Jensen, D. R., NOAA, Boulder, Colorado, Wave Propagation Lab., COM-73-11818/4, August 8, 1972.
An FM/CW radar sounding system reveals atmospheric wave structure in detail. Features evident in the record are: internal gravity waves; features resembling Kelvin/Helmholtz instability structures, and multiple layering, often with lamina only a few meters thick. The paper shows a variety of atmospheric structural patterns and compares them with several hypothetical models of internal waves to obtain insight into the atmospheric processes at work. Attention is given to the distribution of the Richardson number in trapped and untrapped gravity waves. It is proposed that the multiple layers result from untrapped internal gravity waves whose propagation vector is directed nearly vertically within very stable height regions. It is argued that the layers are caused by dynamic instability resulting from reduction in the Richardson number due to wave induced shear and to some background wind shear when the amplitude-to-wavelength ratio grows during propagation into thermally stable regions of the atmosphere.

54. THE EFFECTS OF ATMOSPHERIC STABILITY, TURBULENCE, AND WIND SHEAR ON AIRCRAFT WAKE BEHAVIOR
Beran, D. W., Hall, F. F., Willmarth, B. C., Keller, R. J., Hunter, D. (NOAA, Wave Propagation Laboratory, Boulder, Colorado.), Conference on Aerospace and Aeronautical Meteorology, 6th, El Paso, Texas, November 12-15, 1974.
A full-scale operational test of an experimental acoustic Doppler wind measuring system was conducted at Denver's Stapleton International Airport between October 1973 and March 1974. The system involved a bistatic configuration with one main vertically pointed transmitter, two smaller tilted transmitters, and two receivers located at points along two orthogonal legs intersecting at the main transmitter. An on-line computer was used for real time data processing and output. Questions of system design are discussed along with problems of test site selection and aspects of Stapleton system performance.

55. THE EFFECTS OF SHEAR AND TEMPERATURE DISTRIBUTION ON LOW-LEVEL CONVECTION
Suchman, David, Young, John A., Wisconsin University, Madison, Space Science and Engineering Center, NOAA-E-230-68 (G), September 1971.
It is found that a constant wind shear exerts a stabilizing effect on the thermal instabilities, as does a variable wind shear. The dependence on mean thermal stratification appears to be much stronger than the wind shear dependence. The most ideal conditions for the production of convection instabilities was found to be a zero mean wind shear and static thermal instability.

56. THE EFFECTS OF STABILITY AUGMENTATION ON THE GUST RESPONSE OF A STOL AIRCRAFT DURING A CURVED MANUAL APPROACH
Porter, Milton B., Air Force Flight Dynamics Lab Wright-Patterson AFB, Ohio, AFFDL-TR-75-63, June 1975.
Manually piloted STOL aircraft will be particularly sensitive to atmospheric turbulence during precision tracking. In this study a parametric variation of the open loop poles of a STOL aircraft was made using stability augmentation system (SAS) gains, and the gust response of the manually piloted aircraft was analyzed at points on an MLS approach path. Both the SAS and pilot gains calculation yielded reasonable low gains for all cases.

57. EFFECTS OF SURFACE WINDS AND GUSTS ON AIRCRAFT DESIGN AND OPERATION
Anonymous, Advisory Group for Aerospace Research and Development Paris (France), AGARD-R-626, November 1974.
The three papers that comprise this report deal with recent studies done in the U. S. and U. K. on the subject of surface winds and gusts. Considerable experiemental data are presented and useful equations and mathematical models are derived. An analysis of present and projected research in the area of gusts analysis and alleviation in the U. K. is presented.

58. EFFECTS OF SURFACE WINDS AND GUSTS ON AIRCRAFT DESIGN AND OPERATION---ANALYSIS OF METEOROLOGICAL PARAMETERS FOR IMPROVED AIRCRAFT FLIGHT CHARACTERISTICS
Anonymous, Advisory Group for Aerospace Research and Development, Paris (France), AGARD-R-626, November 1974.
An analysis of the effects of surface winds and gusts on aircraft stability and control is presented. The analysis is applied to the development of airframes, improvement of basic airworthiness, better flight characteristics through gust load alleviation, and methods for avoiding atmospheric turbulence. The subjects discussed are as follows: (1) The wind characteristics in the planetary boundary layer, (2) Research on aeronautical effects of surface winds and gusts, and (3) The use of radiosonde data to derive atmospheric wind shears for small shear increments. Graphs and tables of wind characteristics, wind speed dispersion, and statistical analyses of gust load conditions.

59. EFFECTS OF WIND SHEAR ON APPROACH
Melvin, W. W., Pilots Safety Exchange Bulletin 70-103/105, April/June 1970.

60. EFFECTS OF WIND SHEAR IN THE BASE AREA OF DOWNDRAFTS
In Draft, W. W. Melvin, Air Lines Pilots Association Dallas, Texas.
The effects of wind shear under the base of a thunderstorm are discussed from a pilot's view.

61. EFFECTS OF WIND SHEAR ON APPROACH WITH ASSOCIATED FAULTS OF APPROACH COUPLERS AND FLIGHT DIRECTORS
William W. Melvin (Air Line Pilots Association, Dallas, Tex.), American Institute of Aeronautics and Astronautics, Aircraft Design and Operations Meeting, Los Angeles, Calif., Paper 69-796. 8p, July 14-16, 1969.
Examination of the effects of wind shear on approach to determine the requirements necessary to maintain airspeed and glide path position during a shear. Two distinct and opposite effects then become evident which require thrust corrections to counteract. The first effect is a function of energy and is dependent upon the rate of wind shear, while the second effect is a function of flight path angle and is dependent upon the magnitude of the shear. Of importance to the problem is the approach technique used by approach couplers and directed by flight directors whereby pitch controls glide path position and thrust controls airspeed. The theory and practice of flying an approach are examined to explain how this technique is unsatisfactory during reasonably high wind shears.

62. EIGHTH AIR NAVIGATION CONFERENCE--PROPOSED U. S. REPLY TO ICAO REQUEST FOR RESULTS OF ANY STUDIES ON SURFACE WIND AND VERTICAL WIND SHEAR (RECOMMENDATIONS 12/2 AND 12/7)

Anonymous, Department of Transportation, IGIA 72/1.82, April 5, 1976.

Subject: The Eighth Air Navigation Conference - Recommendations 12/2 and 12/7, Surface Wind and Vertical Wind Shear Studies, are in reply to the ICAO Letter AN 10/11.9 - 75/67 dated 24 April 1975.

63. ENGINEERING AND DEVELOPMENT PROGRAM PLAN - WIND SHEAR

Wind Shear Systems Program Staff, Department of Transportation, Federal Aviation Administration, FAA-ED-15-2, March 1976.

This is a development plan for solutions to aviation hazards created by low-level wind shear in the terminal area. It describes the 4-year development program to satisfy National Airspace System user needs for current and predicted information concerning wind shear at the Nation's airports. Included in the plan are (1) efforts to better characterize low-level wind shear, (2) plans to define the hazards of wind shear for the aviation community, (3) tasks required to develop ground-based devices for hazardous wind shear detection and movement, (4) investigations into the use of airborne equipment to detect hazardous wind shear and then either warn the pi ˋt of its presence or assist him in coping with it, (5) an outline of how the data collected on wind shear will be processed, analyzed, and reported, and (6) provisions for integrating wind shear data into the NAS by developing data formats and displays suitable to users (air traffic control systems, pilots, and the National Weather Service).

64. ESTIMATES OF WIND VARIABILITY BETWEEN 100 AND 900 METERS

Monahan, H. H., Armendariz, M., V. D., United States Army Electronics Command, April 1969.

The temporal wind variability between 100 and 900 meters above ground level was estimated from wind measurements made with an Automatic Pilot Balloon Wind Measuring System. One-hundred-gram balloons were released simultanerously from four observational sites on White Sands Missile Range, New Mexico, at 6-minute intervals, for a period of 180 minutes on 3 consecutive days. These data indicate tha. wind variability increases with increasing time lag, the relationship between wind variability and time lag interval being described by a power curve. In addition, a linear relationship between wind variability and mean wind speed is suggested.

65. EVALUATION OF THE ATLANTIC CITY MESONET FOR SHORT-RANGE PREDICTION OF AVIATION TERMINAL WEATHER

Entrekin, H., Wilson, J., Final Report, (Contract No. FAA66WA-1536, Project No. 150-535-01A, SRDS Report No. 68-40) Unclassified Report, August 1968.

Two years of mesoscale weather data collected from the Federal Aviation Administration's Atlantic City mesometeorological network (mesonet) were used for the development and testing of techniques for 15-, 30-, and 60-minute predictions of runway visual range, cloud-base height, and wind. The primary purpose of this work was to evaluate the utility of the mesonet for improved prediction of aviation terminal weather. The results showed, in general, that none of the techniques which used mesonet data provided forecasts significantly better than those provided by persistence. It is therefore concluded that the mesoscale data provided from the Atlantic City mesonet are not adequate for providing significantly improved short-range terminal weather forecasts.

66. EXAMPLES OF VARIABLE DENSITY FLOWS COMPUTED BY A SECOND-ORDER CLOSURE DESCRIPTION OF TURBULENCE
Lewellen, W. S ., Teske, M. E., Donaldson, Coleman duP., AAIA 8th Fluid and Plasma Dynamics Conference, Hartford, Connecticut, June 16-18, 1975.
An incompressible fluid, with the influence of the variable density coming through a Boussinesq buoyancy term, is considered turbulent flow. This technique successfully incorporates the strong influence of stratification for a number of flows. Particular flows which are computed and compared with experimental data are, (1) stratified shear flow with homogeneous turbulence, (2) free convection bounded by a stable density gradient, (3) wakes in a medium with a stable density gradient, and (4) the atmospheric boundary layer where the flow oscillates from stable to unstable conditions in a typical day.

67. EXPERIENCE WITH A LOW ALTITUDE TURBULENCE MODEL FOR AUTOLAND CERTIFICATION
McManus, R. M. P., AGARD Conference Proceedings No. 140 on Flight in Turbulence.
Early testing of the autoland system for the Trident indicated that turbulence would be the major external factor affection landing performance. Analysis of all available data showed that little work had been done for the very low altitude (below 200 feet) band. The autoland development aircraft was, therefore, instrumented to obtain three axis gust time histories for each landing made. From these time histories a gust model was built up and was used for the initial certification of automatic landing on the Trident. Although the model produces a pessimistic statistical result it appears optimistic in some other respects. During the development flying several events have occurred which were not predicted by the model. These are of the nature of either sharp edged gusts or of a particular sequence of events. The former occurs in strong winds and indicates a deficiency in detail of the model, whereas the latter often occurs in calm conditions where the model suggests there is no turbulence.

68. EXTRACTION OF FLOW ENERGY BY GLIDING IN A WIND WITH UNIFORM VERTICAL SHEAR
Hendriks, Ferdinand, California Univ. Los Angeles School of Engineering and Applied Science UCLA-ENG-7324, April 1973.
Gliding in nonuniform wind offers the opportunity of energy extraction by a glider. It has long been suggested that albatrosses in particular use this form of locomotion. The main problem is how to control a glider to maximize the energy gained. For three-dimensional motion, circling in a uniform shear flow, the solution of the equations of motion by a perturbation method indicates that a synchronization of turning and phugoid frequency is required to stay aloft. For purely two-dimensional motion, it is shown that small periodic variations of the lift coefficient leads to a deterioration of glide performance. An example based on numerical integration suggests that dynamic soaring by albatrosses in the atmospheric boundary layer is not an impossibility.

69. FAA SYMPOSIUM ON TURNBULENCE, 22-24 MARCH 1971, WASHINGTON, D.C.
Anonymous, Federal Aviation Administration, Washington, D. C., Final Report, AD-732-117, March 24, 1971.
The symposium covered wake turbulence, clear-air turbulence, wind shear, upsets, thunderstorms, and turbulence plotting. The final report of the Symposium includes a highlight summary of each presentation.

70. FEASIBILITY OF LASER SYSTEMS FOR AIRCRAFT LANDING OPERATIONS UNDER LOW VISIBILITY CONDITIONS
Viezee, W., Oblanas, J., Glaser, M. (Stanford Research Institute, Menlo Park, California), FAA Contractor's Report FAA-RD-74-190, October 1974.
The efforts of atmospheric scattering on the potential application of lasers to low-visibility aircraft approach and landing operational environment are assessed.

71. A FIRST COURSE IN TURBULENCE
Tennekes, H., Lumley, J. L., MIT Press, Cambridge, Massachusetts, 1972.

72. FLIGHT INVESTIGATION OF THE INFLUENCE OF TURBULENCE ON LATERAL-DIRECTIONAL FLYING QUALITIES
Franklin, James A. (Princeton University, Princeton, New Jersey), J. Aircraft, Vol. 8, No. 10, October 1971.
Flight evaluations using a variable stability airplane were made to determine the independent and interacting effects of simulated turbulence disturbances and lateral-directional dynamics on flying qualities associated with a precision heading control task. Turbulence was described in terms of rms roll and yaw disturbance magnitude, correlation between roll and yaw disturbances, and the bandwidth of the turbulence power spectrum. Variations in dynamics included roll damping, directional stability, and Dutch roll dampling. Trends in pilot rating obtained in the test program with variations in turbulence disturbances and airplane dynamics are explained in terms of measures of precision of task performance, pilot control workload, and pilot compensatory behavior derived from time histories of the flight evaluations.

73. FLIGHT IN TURBULENCE
Aiken, William S., Jr., Advisory Group For Aerospace Research and Development Paris (France), AGARD-CP-140, November 1973.
Although a number of international symposia have been held on atmospheric turbulence, the desired emphasis in the one reported is flight through turbulent air rather than on turbulence as encountered in flight. Two aspects of the problem have received attention: Analysis of data on atmospheric phenomena as related to measurable or forecastable meteorological parameters, and the magnitude and distribution of turbulence in space and time. The sessions involved medium and low-altitude flight, mathematical models, aircraft operational problems, conventional civil transports, STOL aircraft, high-speed low-level military flight, design criteria, and means of alleviating turbulence effects.

74. FLUX-PROFILE RELATIONSHIPS IN THE ATMOSPHERIC SURFACE LAYER
Businger, J. A., Wyngaard, J. C., Izumi, Y., Bradley, E. F., Journal of Applied Meteorology, Vol. 28, pp. 181-189, 1971.
Wind and temperature profiles for a wide range of stability conditions have been analyzed in the context of Monin-Obukhov similarity theory. Direct measurements of heat and momentum fluxes enabled determination of the Obukhov length L, a key independent variable in the steady-state, horizontally homogeneous, atmospheric surface layer. The behavior of the gradients under neutral conditions is unusual, however, and indicates that von Karman's constant is ≈ 0.35, rather than 0.40 as usually assumed, and that the ratio of eddy diffusivities for heat and momentum at neutrality is ≈ 1.35, compared to the often suggested value of 1.0. The gradient Richardson number, computed from the profiles, and the Obukhov stability parameter z/L, computed from the measured fluxes, are found to be related approximately linearly under unstable conditions. For stable conditions the Richardson number approaches a limit of ≈ 0.21 as stability increases. A comparison between profile-derived and measured fluxes shows good agreement over the entire stability range of the observations.

75. FORMATION CONDITIONS FOR STRONG VERTICAL WIND SHEARS IN THE ATMOSPHERIC GROUND LAYER
Glazunov, V. G., Analysis and Prediction of Meteorological Conditions for Aviation, Leningrad, Gidrometeoizdat, 1975, pp. 19-33, 1975.
Combinations of velocity differences and wind directions at various wind speeds in the 30-meter atmospheric layer are determined which give rise to strong vertical wind shears in the layer. Wind-measurement data obtained on a tall meteorological mast are used to show the recurrence period of wind shears, velocity differences, and wind directions in the layer from 8 to 25 meters under different conditions. Characteristic vertical wind profiles to a height of 300 meters are presented which reveal the presence of strong wind shears in the lowest layer of the atmosphere (below 25 meters). A generalized synoptic analysis of these cases is conducted, and formation conditions for a vertical wind shear that would affect aircraft takeoffs and landings are pointed out.

76. GENERALIZATION OF THE KEYPS FORMULA IN DIABATIC CONDITIONS AND RELATED DISCUSSION ON THE CRITICAL RICHARDSON NUMBER---WIND SHEAR FUNCTIONS IN ATMOSPHERIC BOUNDARY LAYER
Yamamoto, G. (Tohoku University, Sendai, Japan), Meteorological Society of Japan, Journal, Vol. 53, pp. 189-195, June 1975.
Dimensionless shear functions are obtained as a function of a specific dimensionless length on the basis of the method leading to the Keyps formula. under assumptions of stable conditions. The Richardson Number is expressed through dimensionless quantities. The discussion covers the generalization of the Keyps formula, its modification in the case of stable conditions, and the evaluation and probable existence of the critical Richardson Number. It is shown that the existence of a unique critical Richardson Number corresponds to the realization of log-linear profiles, or more accurately, of linear profiles with increasing values of the specific dimensionless length.

77. GRAVITY CURRENT MODEL APPLIED TO ANALYSIS OF SQUALL-LINE GUST FRONT
Charba, J. P., Ph.D Thesis, Oklahoma University, Norman, 1972.
The structure of a severe gust front which led the squall line of 31 May 1969 was examined from analysis of measurements from the National Severe Storm Laboratory (NSSL) Network of Surface Stations located in central Oklahoma. The mechanics of motion of the gust front were investigated. The gust front was found to be in approximate dynamic similarity to theoretical and experimental gravity currents.

78. HAZARD AVOIDANCE AND ELIMINATION
Chiarito, P. T., National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio.
The objective is to provide basic data for the improvement of the operational safety of civil and military aircraft. Through NASA-supported research, which complements researches conducted by other segments of the aviation community, provide devices and techniques which overcome operational problems. These problems are presented by the desire to improve the safety of airplane operations while extending the mission of the airplane and improving the economics of its operation. Commercial and general aviation aircraft, including V/STOL, subsonic and supersonic, will be considered. Specific areas of current interest include lightning hazards to aircraft avionics, rotor burst protection, detection of incipient structural failure, ozone hazard in high-altitude aircraft, wind shear effects, and icing tests.

79. INDIRECT SENSING OF METEOROLOGICAL ELEMENTS IN THE TERMINAL AREA
Paulsen, W. H. (USAF, Aerospace Instrumentation Laboratory, Bedford, Massachusetts), Societe Meterorologique Francaise and American Meteorological Society, Paris and Orly, France, May 24-26, 1971, Paper. 19 P., May 1971.
A survey is made of current techniques of indirectly sensing meteorological elements that are of concern in the terminal area. The conventional weather radar and its range of capabilities are presented along with the additional meteorological information that can be obtained with the use of a vertically pointing cloud-detecting radar. Other available indirect sensing techniques for determining ceiling heights and warning of approaching thunderstorms are discussed and new techniques that are being investigated and developed for measuring slant range visibility. Low-level winds and turbulence, and wind shear zones are presented.

80. INFLIGHT DATA COLLECTION FOR RIDE QUALITY AND ATMOSPHERIC TURBULENCE RESEARCH FINAL REPORT
Kadlec, P. W., Buckman, R. C., Continental Airlines, Inc., Los Angeles, California, NASA-CR-127492, December 1974.
A flight test program to investigate the effects of atmospheric turbulence on passenger ride quality in large, wide-body commercial aircraft was conducted. Data were collected on a series of flights on a Boeing 747 aircraft. Atmospheric and aircraft performance data were obtained from special sensors, as well as conventional instruments and avionics systems normally available. Visual observations of meteorological conditions encountered were manually recorded during the flights.

81. INFLUENCE OF PILOT AND AIRCRAFT CHARACTERISTICS ON STRUCTURAL LOADS IN OPERATIONAL FLIGHT

Sturgeon, J. R., Advisory Group for Aerospace Research and Development Paris (France), AGARD-R-608-73, May 1973.

Some handling problems met in operational conditions are described and compared with flight test conditions. It is concluded that errors in flight instrumentation and physiological cues have a substantial influence on control capability. A unified strategy for flight in all operational conditions is required to reduce these problems. A strategy, aimed at minimizing structural loads and aerodynamic problems in all flight conditions, is proposed that will restore to pilot- and autopilot-controlled flying the positive stability in pitch and yaw which is a classic requirement for aircraft operating in the "stick free" mode. Proposals are made for improving the requirements of flight instruments to reduce control problems during complex maneuvers and flight in severe wind shear conditions.

82. THE INFLUENCE OF VERTICAL WIND GRADIENTS ON THE LONGITUDINAL MOTION OF AIRPLANES

Gera, Joseph, NASA Langley Research Center, Hampton, Virginia National Aeronautics and Space Administration, Washington, D. C. NASA TN D-6430, Septmember 1971.

The present study is an attempt to make an assessment of the influence of wind shear on the longitudinal motion of airplanes. It was assumed that the wind is completely horizontal and its speed varies linearly with altitude. It is shown quantitatively that both glide and climb performance are influenced by wind shear and that trimmed flight at constant airspeed, altitude, and with fixed controls is along a parabolic path relative to the ground. The problem of the landing approach in a wind shear is examined in some detail. Small-disturbance theory indicates no wind-shear effect on the short-period motion and the time for the phugoid to damp to half amplitude but the phugoid frequency and damping ratio vary considerably with wind shear. A nondimensional quantity which depends on the wind shear and airspeed is shown to be a fundamental parameter influencing the longitudinal dynamic behavior of the airplane.

83. THE INFLUENCE OF WIND SHEAR ON AERODYNAMIC COEFFICIENTS

Frost, W., Hutto, E. (Tennessee, University, Tullahoma, Tennessee), Conference on Aerospace and Aeronautical Meteorology, 6th, El Paso, Texas, November 12-15, 1974, NAS8-27387, 1974.

The purpose of this study is to investigate the influence of wind shear on the lift, drag, roll and yaw moments of a wing in a horizontal wind gradient at various elevations and roll angles. The models of wind shear considered are those proposed by Leurs (1973) for atmospheric flow over horizontally homogeneous and uniform terrain, indicate that wind shear can have a significant effect on the rolling and yawing moments of the wing of an aircraft flying with one wing low in the atmospheric boundary layer.

84. AN INITIAL TEST OF THE APPLICABILITY OF INVARIANT MODELING METHODS TO ATMOSPHERIC BOUNDARY LAYER DIFFUSION

Donaldson, Coleman duP., Hilst, Glenn R., Aeronautical Research Associates of Princeton, Inc., New Jersey, ARAP-169, October 1971.

The study concerned the movement of air pollution in the atmosphere. With only prior knowledge of the mean wind and temperature profiles and using a relationship between the macroscale and the dissipation scale derived for laboratory scale flow, the structure of turbulence and the diffusion of matter were simulated well within an order of magnitude of observed values. In most cases, the verification is within a factor of two. Perhaps most importantly all of the classical requirements for asymptotic behavior of the diffusion were met. The predictions were somewhat more exact for neutral and unstable temperature stratification than for stably stratified atmospheres. A greater understanding of the physics of turbulent transport has been achieved and has led directly to further improvement and refinement of the model. The dependence of the scale on stability has been clarified.

85. THE INTERACTION OF INTERNAL GRAVITY WAVES AND ATMOSPHERIC WINDS WITH SHEAR

Bekofske, K. L., Ph.D Thesis, Michigan University, Ann Arbor, 1972.

The interaction between an atmospheric internal gravity wave and a mean horizontal wind with shear is investigated. A two-dimensional, monochromatic internal gravity wave propagating in a linear shear flow is considered. The atmosphere is assumed to be isothermal and incompressible and to satisfy the boussinesq approximation. The resulting model equation of interaction is nonlinear and an iterative technique is used to obtain numerical solutions.

86. INVARIANT MODELING OF TURBULENCE AND DIFFUSION IN THE PLANETARY BOUNDARY LAYER

Lewellen, W. S., Teske, M., Contillano, R., Hilst, G., Donaldson, C. duP., Aeronautical Research Associates of Princeton, Inc., Princeton, New Jersey, Office of Research and Development, U. S. Environmental Protection Agency, Washington, D. C., EPA-650/4-74-035, September 1974.

Significant progress has been made at A.R.A.P. over the last year toward the goal of developing a viable computer model based on second-order closure of the turbulent correlation equations for predicting the fate of nonchemically reacting contaminants released in the atmospheric boundary layer. The invariant turbulent model discussed in previous reports has been modified both by extending its capabilities and by developing approximations to the full system of equations which may be used in complicated flow geometries where economy of computing time justifies some compromise in accuracy. Sample calculations of several flow problems of current practical interest are included. These are: that of the diurnal variations in the turbulence distributions in the planetary boundary layer induced by the unsteady surface hear flux, the spatial variation of turbulence occurring when the wind blows over an abrupt change in surface roughness, and the dispersal of a plume released at different heights, under different stability conditions, and over different terrain.

87. AN INVESTIGATION OF THE APPLICATION OF TAYLOR'S HYPOTHESIS TO ATMOSPHERIC BOUNDARY LAYER TURBULENCE
Oiwell, D. C., Elderkin, C. E. (Battelle Pacific Northwest Laboratories, Richland, Washington), Journal of the Atmospheric Sciences, Vol. 31, pp. 990-1002, May 1974.
The application of Taylor's hypothesis to atmospheric boundary layer turbulence at heights of 15, 30, and 58 m has been investigated. The eddy structure travels slightly faster than the mean value of the longitudinal wind at the same height. As predicted by Taylor's hypothesis, for space lags up to 252 m, the agreement for the lateral component is inferior for lags greater than about 32 m.

88. AN INVESTIGATION OF EXTREME LOW-LEVEL WIND SHEAR AT SELECTED STATIONS IN THE CONTERMINOUS UNITED STATES
Grossman, R. L., Beran, D. W. (NOAA, Wave Propagation Laboratory, Boulder, Colorado) Journal of Applied Meteorology, Vol. 14, p. 506-512, A75-33104, June 1975.
The study considered provides a statistical background on the climatological aspects of extreme low-level wind shears at various points in the conterminous U. S. and explores the applicability of such information to aircraft operations. Models of wind shear and its extremes are considered along with the effect of wind shear on aircraft. A description is given of the method of analysis, taking into account the frequency distributions of vector fields, a criterion for extreme wind shear, and the use of the bivariate frequency table.

89. AN INVESTIGATION OF MOUNTAIN WAVES WITH LIDAR OBSERVATIONS
Viezee, W., Collis, R. T. H., Lawrence, J. D., Jr. (Stanford Research Institute, Menlo Park, Calif.) (Stanford Research Institute, Menlo Park, Calif.) (Langley Research Center, Hampton, Virginia), Journal of Applied Meteorology, Vol. 12, p. 140-148, June 7, 1972.
In March and April of 1969 and 1970, lidar (laser radar) observations of the atmospheric structure were made in the lee of the Sierra Nevada during the occurrence of mountain lee waves. Rawinsonde ascents and, on some occasions, research aircraft flights supported the lidar observations. The objective of the program was to explore the applicability of the lidar technique to atmospheric turbulence detection. The observations demonstrate that a ground-based lidar can delineate significant features of the atmospheric flow pattern by monitoring echoes from concentrations of particulate matter that characterize the airflow structure in the form of either visible or subvisible clouds and dust.

90. INVESTIGATION OF THE TURBULENT WIND FIELD BELOW 500 FEET ALTITUDE AT THE EASTERN TEST RANGE, FLORIDA
Blackadar, A. K., Panofsky, H. A., Fiedler, F., Pennsylvania State Univ., University Park, Dept. of Meteorology, NASA-CR-2438, M 131, June 1974.
A detailed analysis of wind profiles and turbulence at the 150 m Cape Kennedy Meteorological Tower is presented. Various methods are explored for the estimation of wind profiles, wind variances high-frequency spectra, and coherences between various levels, gives roughness length and higher low-level wind and temperature data, of geostrophic wind and insolation. The relationship between planetary Richardson number, insolation, and geostrophic wind is

explored empirically. Techniques were devised which resulted in surface stresses reasonably well correlated with the surface stresses obtained from low-level data. Finally, practical methods are suggested for the estimation of wind profiles and wind statistics.

91. AN INVESTIGATION INTO WIND SHEAR AT HELSINKI AIRPORT
Immonen, E., Finnish Meteorological Institute, Helsinki, TR-3, June 1972.
Vertical wind shear measurements were made using a balloon rising with the average rate of 180 m/min and optical theodolites to measure the angle at 10 sec. intervals and to check the rate of ascent. Weather permitting, soundings were carried out on three days of the week at four synoptic times from the beginning of April 1967 through March 1968. The annual, seasonal, and diurnal distributions are discussed and are graphed.

92. KNOWLEDGE OF ATMOSPHERIC PROCESSES
Ehernberger, L. J., National Aeronautics and Space Administration, Flight Research Center, Edwards, California.
The objective of this work is the definition of the atmospheric conditions in which turbulence, temperature transients, potential pressure altimetry problems and excessive wind shears occur. The major emphasis is the atmospheric environment of supersonic aircraft. Development and acquisition of sensors needed to measure these phenomena are also included. Results of this work will be applicable to aircraft systems design as well as flight operations routing and scheduling. Observations of these phenomena are obtained from instrumented aircraft test flights. The associated meteorological conditions are analyzed and studied both in-house and on-contract.

93. THE LIFE CYCLE OF A THUNDERSTORM IN THREE DIMENSIONS
Wilhelmson, R. (Illinois, University, Urbana, Illinois), Journal of the Atmospheric Sciences, Vol. 31, p. 1629-1651, DAHCO4-71-0016, September 1974.
The results of an isolated three-dimensional thunderstorm simulation are reported.

94. LIMITED SHEAR ZONES: A HAZARD TO AVIATION
Becker, R. J., Gage, K. S., International Conference on Aerospace and Aeronautical Meteorology - American Meteorological Society, pp. 347-352, May 1972.
A discussion of the dual hazard to aviation posed by turbulence and wind shear in a stably stratified environment is considered. Principal emphasis is placed on the horizontal wind shear hazard.

95. LOCAL FREE CONVECTION, SIMILARITY, AND THE BUDGETS OF SHEAR STRESS AND HEAT FLUX
Wyngaard, J. C., Cote, O. R., Izumi, Y., Journal of Atmospheric Sciences, Vol. 28, No. 7, pp. 1121-1182, October 1971.
Equations for the conservation of Reynolds shear stress and the two components of heat flux (velocity-temperature covariance) in the homogeneous atmospheric surface layer are derived. The behavior of the production and turbulent transport (flux divergence) terms in each budget is determined directly from measurements obtained over a wide range of stability conditions during the 1968 Kansas field program of AFCRL. The data are presented in the dimensionless

form suggested by Monin-Obukhov similarity theory, and follow universal functions quite well. The theory is extended to the "local free convection" regime which exists under very unstable conditions, and specific power law forms are predicted. Several of these are verified and values are given for the proportionality factors in the power laws.

The flux divergence terms are small, implying that in each budget the local production and destruction rates are in balance. The third moments which represent the vertical fluxes of stress and heat flux are small under stable conditions, but are large on the unstable side and indicate that turbulence transfers shear stress and heat flux upward at a velocity u_*.

96. LONGITUDINAL AND LATERAL SPECTRA OF TURBULENCE IN THE ATMOSPHERIC BOUNDARY LAYER AT THE KENNEDY SPACE CENTER
Fichtl, G. H., McVehil, G. E., Journal of Applied Meteorology, Vol. 9, No. 1, pp. 51-63, February 1971.

An engineering spectral model of turbulence is developed with horizontal wind observations obtained at the NASA 150 m meteorological tower at Cape Kennedy, Florida. Spectra, measured at six levels, are collapsed at each level with $[nS(n)/U_{*o}^2, f]$ -coordinates, where S(n) is the longitudinal or lateral spectral energy density at frequency n(Hz), U_{*o} the surface friction velocity, and $f=nz/\bar{u}$,$\bar{u}$ being the mean wind speed at height z. A verical collapse of the dimensionless spectra is produced by assuming they are shape-invariant in the vertical.

An analysis of the longitudinal spectrum in the inertial subrange, at the 18 m level, implies that the local mechanical and buoyant production rates of turbulent kinetic energy are balanced by the local dissipation and energy flux divergence, respectively.

97. LOW-ALTITUDE ATMOSPHERIC TURBULENCE AROUND AN AIRPORT
Scoggins, James R., Chevalier, Howard L., Cass, Stanley D., Texas A and M Univ. College Station, Journal of Aircraft, Vol. 10, No. 3 p. 157-163, March 1973, January 1973.

A small airplane was used to measure vertical accelerations due to atmospheric turbulence around an airport surrounded by large buildings, trees, and other objects. The vertical and lateral extent and the intensity of turbulence in the wake of buildings and at other locations around the airport were measured. Results are presented which indicate that the vertical accelerations of the airplane are related to gust intensities measured by conventional anemometers, and that reasonable forecasts of atmospheric turbulence which an airplane could expect to encounter near an airport surrounded by buildings, etc., may be made from wind data appropriately measured and analyzed.

98. LOW-LEVEL WIND SHEAR - ITS EFFECTS ON APPROACH AND CLIMBOUT
Sowa, Daniel F., DC Flight Approach No. 20 June 1974, pp. 10-17

99. A MATHEMATICAL EXAMINATION OF THE PRESS MODEL FOR ATMOSPHERIC TURBULENCE
Sidwell, Kenneth, NASA Langley Research Center, Hampton, Virginia, National Aeronautics and Space Administration, Washington, D. C., NASA TN D-8038, October 1975.

The random process used to model atmospheric turbulence in aircraft response problems is examined on a mathematical basis. The first, second, and higher order probability density and characteristic functions are developed. The concepts of the Press model lead to an approximate procedure for the analysis of the response of linear dynamic systems to a class of non-Gaussian random processes. The Press model accounts for both the Gaussian and non-Gaussian forms of measured turbulence data. The nonstationary aspects of measured data are explicitly described by the transition properties of the random process. The effects of the distribution of the intensity process upon calculated exceedances are examined. It is concluded that the Press model with a Gaussian intensity distribution gives a conservative prediction of limit load values.

100. MATHEMATICAL WIND GUST MODEL AND COMPUTER PROGRAMS FOR USE WITH AIRCRAFT SIMULATIONS
Campagna, Robert W., Army Electronics Command Fort Monmouth, New Jersey, ECOM-3479, September 1971.

A description is given of atmospheric turbulence and its spectral characteristics with emphasis placed on the application of this information to the aircraft equations of motion. The gust model developed accounts for not only the effect of body axis gust velocities applied at the center of gravity, but also includes the effect of gust gradients along the length and span of the aircraft. The latter effect is usually neglected but can be quite significant with small aircraft at high speeds. Thus, the model varies as a function of both aircraft size and velocity. An analog and digital model is developed for use with large-scale aircraft simulations or less sophisticated linearized aircraft models.

101. MEASURED EFFECT OF SHEAR ON PLUME DISPERSION
Brown, R. M., Michael, P., Brookhaven National Lab., Upton, New York, BNL-18951 CONF-740922-1, November 1974.

Multiple plume traversing was studied by aerial measurements at the Long Island Lighting Company's electric power generating plant. It has three 183-m stacks located 60 m apart and the plumes merge within 1 m downwind. Data analyses indicate that for point source releases from tall stacks, the crosswind standard deviations were found to be greater during stable conditions than during neutral conditions. The larger wind shears associated with increased stability are a dominant factor in plume dispersion at great distances downwind during stable conditions.

102. MEASUREMENT AND ANALYSIS OF PILOT SCANNING BEHAVIOR DURING SIMULATED INSTRUMENT APPROACHES
Weir, David H., Klein, Richard H., J. Aircraft, Vol. 8, No. 11, November 1971.

Experimental measurements of pilot scanning and control response in a simulated instrument approach are reported. Airline pilot subjects flew ILS approaches in a six degree-of-freedom mixed base DC8 simulator at the NASA Ames Research Center. A conventional instrument panel and controls were used, with simulated vertical gust and glide slope beam bend forcing functions. Pilot eye fixations and scan traffic on the panel were measured using a recently developed eye point-of-regard (EPR) system. Simultaneous recordings were made of displayed signals, pilot response, and vehicle motions. The EPR data were reduced for 31 approaches with a cross section of subjects to obtain dwell times, look rates, scan rates, and fractional scanning workload. Flight director (zero reader) approaches as well as standard localizer/glide slope (manual) approaches were made. The scanning results showed the altitude and glide slope/localizer instruments to be primary in a manual ILS approach, sharing 70-80 percent of the pilot's attention. The glide slope/localizer instrument required shorter dwell times with a fixed instrument sensitivity. Differences in dwell time between pilots occurred mainly on the altitude instrument. With the flight director, glide path deviation errors were reduced and the flight director instrument dominated pilot attention (about 80 percent). There were no apparent circulatory scanning patterns in any of the approaches. These EPR results were generally consistent with prior data where meaningful comparisons could be made.

103. MEASUREMENTS OF HORIZONTAL WINDSPEED AND GUSTINESS MADE AT SEVERAL LEVELS ON A 30 M MAST
Colmer, M. J., Royal Aircraft Establishment Farnborough (England) RAE-TR-71214, November 1971.

The horizontal component of atmospheric turbulence has been measured at heights up to 30 m above ground. The data from 17 runs were analyzed to obtain mean windspeed, root mean square of the fluctuations and power spectral density at several heights. This was used to determine the values of parameters in mathematical models which describe the variation of mean windspeed and RMS with height. The power spectral densities do not fit the usual models, typified by the Von Karman spectrum, at long wavelengths, and a new model is postulated which fits the measurements at all wavelengths, from 20 m to 10,000 m.

104. MEASUREMENTS AND GRAPHS OF TURBULENCE AUTOCORRELATIONS IN SPACE AND IN TIME
Elderkin, C. E., Battelle Pacific Northwest Labs. Presented at the Symposium on Air Pollution Turblence and Diffusion, Las Cruces, New Mexico, BNWL-SA-4086, December 7-9, 1971.

105. MEASUREMENTS OF THE STATISTICAL PROPERTIES OF ATMOSPHERIC TURBULENCE AT ALTITUDES BELOW 1000 FEET
Gould, D. G., MacPherson, J. I., National Aeronautical Establishment Ottawa (Ontario), NAE-LR-567, January 1973.
Measured statistical properties of the three components of turbulence are presented for research flights at four altitudes below 1000 feet over flat terrain and two altitudes below 1000 feet over hilly terrain. The measured power spectral density distributions were closely approximated by the Von Karman spectral shape. The derived scales of the three components were all about the same, being approximately proportional to height over the flat terrain. The derived scales at the higher altituded appeared to be related to the terrain a considerable distance up-wind from the track along which the measurements were made.

106. MECHANICAL ENGINEERING SERIES, CHEMICAL ENGINEERING SERIES AND INDUCTRIAL DATA FOR ENGINEERING APPLICATION. FLUID MECHANICS, EXTERNAL FLOW SUBSERIES. VOLUME 1.
Anonymous, Engineering Sciences Data Unit Ltd., London (England), 1974.
The report, relative to mechanical, chemical and industrial engineering, consists of 7 engineering data item packages pertaining to fluid flow on non-streamlined bodies, around stranded cables around cylindrical bodies, and over flat plates. Wind loads of buildings and structures are analyzed.

107. METEOROLOGICAL CONDITIONS SURROUNDING THE PARADISE AIRLINE CRASH OF 1 MARCH 1964.
Wurtele, Morton G. (Dept. of Meteorology, University of California, Los Angeles), Journal of Applied Meteorology, Vol. 9, p. 787-795, December 31, 1969.
The Paradise Airline crash of 1 March 1964 occurred under conditions reconstructed, according to observational and theoretical evidence, that included a strong mountain lee wave with fully developed foehn and hydraulic jump. For a pilot attempting to ascend from an upwind valley and clear the lee crest, these conditions are extremely hazardous.

108. METEOROLOGICAL INFORMATION FOR VERTICAL AND SHORT TAKE-OFF AND LANDING (V/STOL) OPERATIONS IN BUILT-UP URBAN AREAS - AN ANALYSIS
Ramsdell, J. V., Powell, D. C., Battelle Pacific Northwest Laboratories, Richland, Washington, FAA Contractor's Report FAA-RD-72-135, September 1973.
An analysis was conducted to identify potential meteorological problems of V/STOL aircraft terminal operations in urban areas. Present data do not permit quantitative assessment of wind and turbulence in urban areas.

109. METEOROLOGICAL MEASUREMENTS FROM SATELLITE PLATFORMS
Suomi, V. E., Wisconsin Univ., Madison, Space Science and Engineering Center, NASA-CR-130246, December 1972.
Quantitative exploitation of meteorological data from geosynchronous satellites is starting to move from the laboratory to operational practice. Investigations of the data applications portion of the total meteorological satellite system include: (i) tropospheric wind shear and the related severe storm circulations, (2) kinematic properties of the tropical atmosphere as

derived from cloud motion vectors, (3) application of a geostationary satellite rake system to measurements of rainfall, and (4) pointing error analysis of geosynchronous satellites.

110. MICROSTRUCTURE OF RADAR ECHO LAYERS IN THE CLEAR ATMOSPHERE
Metcalf, James I., Air Force Cambridge Research Labs., Hanscom AFB, Massachusetts, Office of Naval Research, Arlington, Virginia, Army Research Office, Durham, North Carolina, Environmental Protection Agency, Washington, D. C., AFCRL-TR-75-0195, July 9, 1973.

Previous observations of clear air echo layers by high-resolution radar are reviewed briefly and compared with theoretical models. Quantitative radar reflectivity records reveal a variety of features common to these echo layers. In particular some of the records show that the backscatter from layers only a few meters thick is strongly anisotropic with maximum reflectivity at 0° incidence angle, although these 0° echoes are not specular in the strict sense. The anisotrophy is consistent with the presence of large shears across the thin layers. The data leave open the question of whether or not microscale (1m) instability always or necessarily precedes the occurrence of large-amplitude (10-100m) breaking waves.

111. A MODEL OF ATMOSPHERIC BOUNDARY-LAYER FLOW ABOVE AN ISOLATED TWO-DIMENSIONAL "HILL" - AN EXAMPLE OF FLOW ABOVE "GENTLE TOPOGRAPHY"
Taylor, P. A., Gent, P. R., (Southampton University, Southampton, England), Boundary-Layer Meteorology, Vol. 7, p. 349-362, NERC-GR/3/1932, November 1974.

112. A MODEL OF WIND SHEAR AND TURBULENCE IN THE SURFACE BOUNDARY LAYER
Luers, James K., University of Dayton, Research Institute, Dayton, Ohio, NASA, Washington, D. C., NASA CR-2288, July 1973.

A model of wind and turbulence has been described for the surface boundary layer. The wind structure in the surface layer is considered to be a function of the surface parameters, stability, and height. The surface parameters considered are Z_0, the surface roughness length, U^*, the surface friction velocity, and d, the zero plane displacement height. The stability parameter Z/L, where L is the Monin-Obukhov stability length, describes the thermal effect on the wind profile. The logarithmic wind profile is used to describe the mean wind field in the neutral boundary layer, and a logarithmic profile with a stability defect is used to describe the stable and unstable atmospheric conditions. For the very stable conditions, the logarithmic wind law does not hold. Under this condition, the layers of the atmosphere become disconnected and large scale frontal motions are the predominate factor in defining the wind profile. Figures are presented which represent some typical wind profiles in the very stable condition. The Dryden spectral function was chosen to represent the statistical properties of turbulence. The parameters of the Dryden model, σ and L (scale length), are specified as functions of stability, height, and surface conditions for each component of turbulence. The interrelationship between the components of σ and L are constrained to satisfy a condition of local isotropy at large wave numbers.

113. A MODEL OF WIND SHEAR IN THE LOWER 50-METER SECTION OF THE GLIDE PATH, FROM DATA OF LOW-INERTIA MEASUREMENTS
Glazunov, V. G., Cverava, V. G., National Lending Library for Science and Technology, Boston Spa (England), 1973.
Requires making measurements of wind speed at a high rate of data intake and with averaging over a few seconds. It was determined that strong wind shears (> 4 m/sec. 30m) are hazardous for the piloting of aircraft in the lower part of their glide paths.

114. MODIFICATION OF V/STOL INSTRUMENT APPROACH GEOMETRY AS A MEANS OF COMPENSATING FOR ALONG-TRACK WIND EFFECTS
Hindson, W. S., Gould, D., National Aeronautical Establishment, Ottawa (Ontario), NRC-LR-573, January 1974.
The influence of wind on the low speed approach and landing considerations for V/STOL aircraft poses new problems which, although neglected for conventional aircraft, may require specific solutions for these new designs. A novel method to allow for significant along-track wind effects, including shears, is proposed whereby the approach geometry relative to the earth is modified according to the ambient wind condition.

115. THE MOTION OF THUNDERSTORM CELLS IN RELATION TO THE MEAN WIND AND MEAN WIND SHEAR
Fenner, J. H. (Berlin, Freie Universitaet, Berlin, West Germany), Royal Meteorological Society, Quarterly Journal, Vol. 102, p. 459-461, April 1976.
In this paper the relation of the motion of 24 severe local storms and of a large number of non-severe thunderstorms to both the mean wind and mean wind shear is presented. In addition, the speeds expected by Moncrieff and Green's method, as modified by Fenner, are compared with the observed motion of severe thunderstorm cells. The mean wind shear gives a much improved forecast of the direction severe storms move, the observed speed also agrees fairly well with that predicted.

116. MOUNTAIN LEE WAVES AT WHITE SANDS MISSILE RANGE
Lamberth, Roy L, Reynolds, Ralph D., Wurtele, Morton G., (U. S. Army Electronics Research and Development Activity WSMR, N. Mex.), (U. S. Army Electonics Research and Development Activity, WSMR, N. Mex.), (University of California at Los Angeles), Bulletin American Meteorological Society, Vol. 46, No. 10, October 1965.

117. A NOTE ON TURBULENCE PROBLEMS ASSOCIATED WITH TAKE-OFF AND LANDING
Burnham, J., Royal Aircraft Establishment Technical Report 67240, September 1967.
The effects of turbulence on the take-off and landing of conventional and V/STOL aircraft are briefly described. The adequacy and relevance of existing knowledge of the atmosphere is discussed, together with plans for further research.

118. THE NSSL SURFACE NETWORK AND OBSERVATIONS OF HAZARDOUS WIND GUSTS
Anonymous, National Severe Storms Lab., Norman, Oklahoma, NOAA-TM-ERL-NSSL-55, June 1971.

The NSSL network of surface stations for measurement of meteorological parameters is described. Examples of severe wind conditions recorded with intense thunderstorms are presented in detail, and analyzed wind fields are related to the contoured display of the NSSL WSR-57 radar. The design of an operational system for real time monitoring of wind gust lines is discussed.

119. A NUMERICAL INVESTIGATION OF SEVERE THUNDERSTORM GUST FRONTS
Mitchell, Kenneth E., National Aeronautics and Space Administration, Washington, D. C., NASA CR-2635, December 1975.

A numerical model is developed to simulate the temporal evolution and structure of the severe thunderstorm gust front. The model is a non-hydrostatic, fine resolution, cross-sectional primitive equation model. The numerical calculations are derived from the two-dimensional horizontal and vertical equations of motion, the continuity equation, and the thermodynamic energy equation. The unfiltered forms of these equations are approximated by finite differences of second order accuracy centered in time and space.

The effect of evaporative cooling in producing a vigorous downdraft is parameterized by a local cooling function. This function is applied in a unique manner that sustains a steady cold downdraft, which drives the cold outflow and associated gust front.

It is shown that two dominant factors influencing gust front configuration are surface friction and the solenoidal field coincident with the front. The circulation theorem is invoked to suggest that solenoidal accelerations oppose the deceleration of surface friction. After a downdraft is initiated in the model, it turns out that these opposing tendencies soon reach a balance and the gust front achieves a quasi-steady configuration. Thus, the experiments indicate that surface friction does not induce a cycle of front formation and collapse as limited observational evidence has previously suggested.

The magnitude of cooling in the downdraft and the ambient air stability are found to be important variables. Greater cooling in the downdraft results in a more intense gust front that exhibits stronger wind maximums and greater shears. The ambient air stability is shown to be an important factor influencing the depth of the cold outflow.

120. A NUMERICAL MODEL FOR PREDICTION MESOSCALE WINDS ALOFT
Cornett, John S., NOAA, Las Vegas, Nevada, Air Resources Lab. ARLV-351-22, 1971.

The report describes the initial effort to develop a simple numerical model which could eventually satisfy economical restraints and yet yield a usable product in terms of prediction the three-dimensional wind field for operational requirements on the Nevada Test Site. The model is limited in horizontal extent to 160 n. mi by 160 n. mi and was formulated in a cartesian coordinate system. Ten cases were used to verify the model's prediction. One case is described in detail as an illustration. In general, there was excellent agreement between the observed amd predicted winds except at the 7000 and 8000 ft. levels. Modifications needed to improve predictions are identified.

121. NUMERICAL SIMULATION OF WIND, TEMPERATURE, SHEAR STRESS AND TURBULENT ENERGY OVER NONHOMOGENEOUS TERRAIN
Huang, Chin-hua, Nickerson, E. C., Colorado State Univ. Fort Collins, Fluid Dynamics and Diffusion Lab., CER71-72CH-ECN23, THEMIS-CER-TR-12, March 1972.

Airflow in the atmospheric surface layer over nonhomogeneous surfaces with discontinuities in surface roughness and temperature is investigated by numerical techniques. A computational scheme is developed for solving the steady state two-dimensional boundary layer equations. Several theorems of convergence are proved. A successful numerical test, which has been compared to the exact solution, is achieved. Some iterative schemes, which have already enjoyed considerable success without theoretical support are here shown to be convergent. The variations in pressure and buoyancy force associated with changes in surface roughness have been neglected by previous investigators whose work is included in the present study. The numerical results of velocity and shear stress are compared with wind tunnel and field data. The roughness and temperature discontinuities are shown to have an effect on the upstream as well as the downstream flow conditions.

122. AN OBJECTIVE EVALUATOR OF TECHNIQUES FOR PREDICTING SEVERE WEATHER EVENTS
Donaldson, Ralph J., Jr., Dyer, Rosemary M., Kraus, Michael J., Air Force Cambridge Research Laboratories, Bedford, Massachusetts, 1975.

123. ON THE CLIMATOLOGY AND MECHANISMS OF COLORADO CHINOOK WINDS
Riehl, H., Freie University, Berlin (West Germany), November 1973.

About 100 Chinook situations occur within ten years in the foothills of Northern Colorado. Of these, one-third affect the growing season. At Fort Collins, peak speeds in the range from 40 to 60 MPH were common, the ratio of peak gust to 5-minute mean wind averaged near 1.55. Most events took place during fastward passage of upper troughs ahead of the attendant cold fronts.

124. ON THE COMPUTATION OF THE SURFACE DIVERGENCE FIELD
Schaefer, Joseph T., National Severe Storms Lab., Norman, Oklahoma, COM-73-113337/5, January 9, 1973.

The note suggests that although improved surface wind sensors will undoubtedly be of value, accurate computation of derived parameters, such as divergence, will require precise measurement of the vertical shear. Remote sensing techniques will provide this capability.

125. ON THE CHARACTER OF THUNDERSTORM GUST FRONTS
Colmer, M. J., InternationalConference on Atmospheric Turbulence Royal Aeronautical Society, May 18-21, 1971.

This paper describes some of the characteristics of thunderstorm gust fronts based on an analysis of a special network of meteorological stations with an average spacing of 8 km. The results show that the vertical profile has very little relationship between any of the measured profiles or that of Simpson's closed loop model.

126. ON LARGE AND RAPID WIND FLUCTUATIONS WHICH OCCUR WHEN THE WIND HAD PREVIOUSLY BEEN RELATIVELY LIGHT
Burnham, J., Colmer, M.J., Royal Aircraft Establishment Technical Report 69261, November 1969.
Examination of anemometer records obtained at Bedford Airfield for the years 1962-66 shows that, on about 40 occasions per year, large and rapid changes in windspeed and direction occur in relatively light wind conditions. Such events are associated with convection and do not follow the usual relationship between the size of fluctuations and the mean windspeed.

127. ON THE LOG-LINEAR WIND PROFILE AND THE RELATIONSHIP BETWEEN SHEAR STRESS AND STABILITY CHARACTERISTICS OVER THE SEA
Hsu, Shih-Ang, Louisiana State Univ. Baton Rouge, Coastal Studies Inst., Office of Naval Research, Arlington, Virginia, TR-168, December 1974.
Wind and stability characteristics in the atmospheric surface boundary layer at a height, Z, less than 20 m above the sea were examined in nine oceanic investigations. The analysis lends further support to the utility of the log-linear wind-profile law.

128. ON THE RELATIONS BETWEEN WIND SHEARS OVER VARIOUS ALTITUDE INTERVALS
Adelfang, S. I., Journal of Applied Meteorology, Vol. 10, p. 156-159, NAS8-30165, February 1971.

129. OPERATIONAL BENEFITS OF METEOROLOGICAL DOPPLER RADAR
Donaldson, Ralph J., Jr., Dyer, Rosemary M., Kraus, Michael J., Air Force Cambridge Research Laboratories, Hanscom AFB, Massachusetts AFCRL-TR-75-0103, February 21, 1975.
A comparison is made between Doppler and conventional radar as a tool in operational forecasting of hazardous weather. Estimates are given of the cost increment of Doppler capability above the basic radar cost. The advantages and limitations of dual-Doppler and multi-Doppler networks are also considered. The evidence leads to the firm conclusion that, for operations in areas subject to the threat of tornadoes, hurricanes, and other damaging windstorms, the cost increment of single-Doppler radar capability is more than justified by its advantages over conventional radar. On the other hand, dual-Doppler capability is not recommended for operational use, although it is an excellent research tool.

130. PLAN SHEAR INDICATOR AND AIRCRAFT MEASUREMENTS OF THUNDERSTORM TURBULENCE - EXPERIMENTAL RESULTS
Lee, J. T., Kraus, M. (NOAA, National Severe Storms Laboratory, Norman, Oklahoma), (USAF, Cambridge Research Laboratories, Bedford, Massachusetts), Radar Meteorology Conference, 16th, Houston, Texas, p. 337-340, April 22-24, 1975.
The plane shear indicator is an instrument that will graphically depict shear. The range resolution is 855 m, while the 0.8-degree beam width provides an azimuthal resolution of about 1.1 km at 80 km. The maximum wavelength resolvable is equipment-dependent and is about 1,500 m. In the experiments described, a Doppler radar was modified to operate in either the standard mode (pulse repetition frequency of 1302 Hz) or the plan-shear-indicator mode (pulse repetition frequency of 917 Hz). When a storm with intensity greater than

30 DBZ approached aircraft were launched and vectored to the storm areas. Moderate or severe turbulence was encountered in all cases where the plan shear indicator displayed "wiggles" along the aircraft flight path, however, wiggles were not present in all the turbulence encounters. It appeared that turbulence below 9.1 m/sec may escape detention by the indicator. At turbulence above 9.1 m/sec, the indicator showed transient shear areas along the flight path.

131. PREDICTION OF THE MONIN-OBUKHOV SIMILARITY FUNCTIONS FROM AN INVARIANT MODEL OF TURBULENCE
Lewellen, W. S., Teske, M., Journal of the Atmospheric Sciences, Vol. 30, June 1973.

The second-order invariant modeling technique for turbulent flows as developed by Donaldson is applied to the atmospheric surface layer. The steady, high-Reynolds-number equations reduce to a universal set when the variables are scaled by the shear stress and vertical heat flux as suggested by Monin and Obukhov. Numerical integration of these equations yields results for the mean velocity gradient, mean temperature gradient, Richardson number, rms vertical velocity and temperature fluctuations, and horizontal heat flux which agree favorably with experimental observations over the complete range of stability conditions.

132. PRELIMINARY ANALYSIS OF CANADIAN WIND-SHEAR DATA
Muller, F. B., Mushkat, C. M., WMO Vertical Wind Shear in the Lower Layers of the Atmosphere p. 31-36, 1969.

Three wind and temperature records from Canadian instrument towers have been selected for analysis of some of the information they can provide concerning the frequency distribution of wind shears between upper and lower levels. Some details concerning the towers, their locations, and the nature of their wind records are provided, coupled with overall distributions of the wind shears measured at these stations over the usable period of record. A discussion of the interpretation of the results is provided, and recommendations given for further study of the problem from the point of view of aviation. The preliminary distributions were obtained in the course of editing the data into a suitable form. This edited form will greatly facilitate further analysis, This analysis includes frequency distributions under many combinations of conditions of season, time of day, vertical temperature difference, upper and lower wind directions, and speeds.

133. PROBABILITY DISTRIBUTION OF VERTICAL LONGITUDINAL SHEAR FLUCTUATIONS
Fichtl, G. H., Journal of Applied Meteorology, Vol. 11, pp. 918-925, 1972.

This paper discusses some recent measurements of third and fourth moments of vertical differences (shears) of longitudinal velocity fluctuations obtained in unstable air at the NASA 150 m meteorological tower site at Cape Kennedy, Florida. Each set of measurements consisted of longitudinal velocity fluctuation time histories obtained at the 18, 30, 60, 90, 120, and 150 m levels, so that 15 wind-shear time histories were obtained from each set of measurements. It appears that the distribution function of the longitudinal wind fluctuations at two levels is not bivariate gaussian. The implications of the results relative to the design and operation of aerospace vehicles are discussed.

134. PROBLEMS IN THE SIMUALTION OF ATMOSPHERIC BOUNDARY LAYER FLOWS
Fichtl, George H., AGARD Conference Proceedings No. 140 on Flight in Turbulence.

The realistic simulation of flow in the atmospheric boundary layer (heights $\leq$ 2km) is a major goal of the meteorological/aerospace community. This paper reviews the presently available information concerning horizontally homogeneous and statistically stationaly atmospheric boundary layer flows, discusses the problems related to the incorporation of this information into atmospheric wind simulation programs, and suggests the information that the meteorologist must acquire in the future in order to provide a basis for advancing the state-of-the-art in the simulation of atmospheric boundary layer flows.

135. PROGRESS IN THE MATHEMATICAL MODELLING OF FLIGHT IN TURBULENCE
Gerlach, O.H., van de Moeadijk, G. A. J., van der Vaart, J. C., Department of Aeronautical Engineering, Delft University of Technology, Delft, The Netherlands, AGARD Conference Proceedings No. 140 on Flight In Turbulence.

This paper deals with two problems of mathematical modelling of flight in turbulence. Both themes are closely related to recent activities of the Flight Mechanics Panel's working group on the simulation of approach and landing. As a consequence they deal with aspects of the simulation of flight in the lower atmosphere during the approach and landing in particular.

The first subject, to be discussed in Section 2, is the discrepancy between the usual Gaussian representation of atmospheric turbulence and the actual non-Gaussian atmosphere, the latter often being termed "patchy" by pilots. A parameter is introduced to characterize the patchiness of actual or simulated turbulence, as sensed by the pilot. Furthermore a method is described to generate simulated non-Gaussian turbulence having a prescribed power spectral density and probability density function as well as a chosen value of the patchiness parameter.

The second subject, discussed in Section 3, is inspired by the present - and perhaps perennial - uncertainty as to the best values to be assigned to intensity and scale length of turbulence at various heights near the ground. A method is discussed to find the range of altitudes at which the most significant disturbances are encountered during the approach influencing the aircraft's state at e.g. decision height. Application of this method provides and insight into the importance of differences between the various proposed models of atmospheric urbulence for approach and landing.

136. THE PROFILES OF STRONG WINDS IN THE BOUNDARY LAYER ACCORDING TO EXPERIMENTAL DATA
Shkliarevich, O. B., Physics of the Atmospheric Boundary Layer, Leningrad, Gidromet Teoizdat, 1975, p. 109-121, 1975.

The profiles of strong winds in the boundary layer under different physical and geographical conditions are analyzed on the basis of temperature and wind sounding data from a network of aerological stations. The winds are classified according to their advection characteristics and subdivided with regards to the stratification and position of the inhibiting layers. The maximum wind velocities are found in the region of the upper boundary of a ground inversion.

Regardless of the advection characteristics an increased stability of the boundary layer leads to an increase in the rate of wind rise with altitude.

137. PROPOSAL FOR WIND MODEL(S) FOR COMPUTER SIMULATED APPROACH AND LANDING
Anonymous, Lockheed-California Co., Burbank, LR-25023, January 1972.
A program of work to accomplish the requirements specified in DOT-FAA request for proposal No. WA 5M-2-0349 is described. A documented investigation of presently available wind models will be performed. Documentation shall be assembled on the major wind environment for approach and landing. An evaluation of the models will be performed to determine their suitability for use in computer studies of aircraft approach and landing systems from the surface to 1000 ft. A statistical analysis will be provided of available wind, wind shear, gusts and turbulence data that are representative of the airport environment from the surface to 1000 ft. The analysis will be aimed toward establishment of the probability distributions of the independent variables in the wind model recommended at the completion of Task B. This will permit estimation of the dependent variables of the wind model for a specified probability of occurrence.

138. PULSED-DOPPLER VELOCITY ISOTACH DISPLAYS OF STORM WINDS IN REAL TIME
Sirmans, D., Doviak, R. J., (National Severe Storms Laboratory NOAA, Norman, Oklahoma)
First results derived from an NSSL effort to develop a real-time Plan Position Indicator (PPI) display of Doppler isotachs are described. The mean Doppler velocity is estimated for multiple range locations by measuring the phase change of the complex echo envelope over time intervals equal to the pulse repetition period. This technique, phase change per pulse pair, provides velocity from samples of the Doppler time record to circumvent spectrum computation.

139. RADAR OBSERVATIONS OF THE TURBULENT STRUCTURE IN SHEAR ZONES IN THE CLEAR ATMOSPHERE
Ottersten, Hans, ESSA Research Labs., Boulder, Colorado, COM-73-10119-33, 1972.
The author examines how radar observations of the structure in the clear atmosphere may be used to infer the structure of streamlines in order to follow the progression of a turbulent breakdown. A new concept of turbulence generation is suggested. The overturning is observed to occur initially at small scales and to be oriented in rows of laterally extended roll-instabilities (billows). In increasing turbulence the breakdown repeats itself at discrete scales in successively larger vortex-rolls. The vortices also appear to lose their energy in discrete steps by transfer to smaller, secondary instabilities.

140. THE RELATIONSHIP BETWEEN THE DISCRETE GUST AND POWER SPECTRA PRESENTATIONS OF ATMOSPHERIC TURBULENCE, WITH A SUGGESTED MODEL OF LOW-ALTITUDE TURBULENCE
Zbrozek, J. K., Ministry of Aviation, London (England), RAE-IN-AERO-2682, 1972.
The relation between the discrete gust and the spectral presentations of atmospheric turbulence is discussed, and the limitations of the discrete gust approach are explained. The available measurements of low altitude turbulence are analyzed. The relationships between the three components of turbulence at low altitude and the effect of wind are considered.

141. A RELATIONSHIP OF THE REYNOLDS STRESS TO LOCAL SHEAR AND HEAT FLUXES IN THE PLANETARY BOUNDARY LAYER
Mahrt, L. J., (Oregon State University, Corvallis, Oregon), Journal of the Atmospheric Sciences, Vol. 30, November 1973, pp. 1577-1583, NSF GA-37571, November 1973.
The steady Reynolds Stress and turbulent energy equations for steady, horizontally homogeneous mean flow are used to relate the Reynolds Stress to the mean wind shear and heat fluxes in the planetary boundary layer. The resulting Reynolds Stress demonstrates a 3/2 power dependence on the stress Richardson number and 1/2 power dependence on the flux Richardson number. Numerical results of Deardorff are used to estimate vertical profiles of a heat flux function which results from the derivation. Such calculations and certain observations suggest that the stress depends mainly on the flux Richardson number in the upper part of the strongly heated boundary layer but more on the stress Richardson number in the lower part of the weakly heated stable boundary layer.

142. REMOTE SENSING WIND AND WIND SHEAR SYSTEM
Beran, Donald W., NOAA/ERL, Wave Propagation Laboratory, Boulder, Colorado, DOT/FAA Aviation Weather Systems Branch, Federal Aviation Administration, Washington, D. C., FAA-RD-74-3, January 1974.
The background for, and developmental history of acoustic Doppler is followed by a detailed study of winds that effect landing operations. A climatology of critical boundary layer wind shear and a study of optimum averaging times for reported winds show that the occurrence of severe wind shear is regional and not to be expected more than a small percentage of the time. Analysis of several ground based remote wind sensing devices suggests that the acoustic Doppler system is presently optimum. Weaknesses in any given device may, however, dictate that a joint sensor approach must be used to insure continual real time operation. The selection of an optimum antenna configuration and details of the hardware used during experimental tests at Stapleton International Airport are discussed in Chapter 4. Calibration of the Acoustic Doppler Wind System was accomplished by comparison with winds taken by anemometers suspended beneath balloons, tower mounted anemometers and slow ascent radiosondes. Agreement with all of these wind measurements was very good. Results from the operational tests at Stapleton indicate the Acoustic Doppler System can perform in the high noise environment of an airport. The effect of the high noise environment of an airport. The effect of the high noise in terms of percentage of lost record has not yet been determined.

143. THE REPRESENTATION OF LOW-ALTITUDE ATMOSPHERIC TURBULENCE IN PILOTED GROUND-BASED SIMULATORS
Jones, J. G., Royal Aeronautics Establishment.

144. RESEARCH ON AERONAUTICAL EFFECTS OF SURFACE WINDS AND GUSTS---APPLICATION TO IMPROVING AIRCRAFT HANDLING QUALITIES UNDER TURBULENT CONDITIONS
Jones, J. G., Royal Aircraft Establishment, Farnborough (England), November 1974.
An outline of topics concerning aeronautical effects of surface winds and gusts currently under investigation in the UK or planned for future research is presented.

145. RESULTS OF SIMULATOR EXPERIMENTATION FOR APPROACH AND LANDING SAFETY
Stout, C. L., Stephens, W. A., Douglas Aircraft Company, McDonnell Douglas Corporation, Douglas Paper 6395A, November 10-15, 1975.
The study of approach and landing accident/incident information has shown the frequent presence of certain environmental factors, in particular, with the undershoot accident. An experimental program was developed and performed with airline flight crews and supervisory pilots in a flight simulator to investigate the effect on pilot performance of certain of these factors which can be hypothesized to present potential for accident. Such situations as low and varying visibility, "scud" or patchy fog restrictions to visibility, illusory, windshear, and combinations of these were included in the simulator test.

146. REVIEW OF THE ATLANTIC CITY MESONET
Lefkowitz, Matthew, McCann, R. J., U. S. Department of Commerce, Environmental Science Services Administration, Weather Bureau, Sterling, Virginia, Final Report, March 1969, (Inter-Agency Agreement FA66WAI-151, SRDS Report No. RD-69-20.)
The Atlantic City, N J., mesometeorological network was a prototype system used in experiments of totally automated surface weather observations. This report describes each element of the 13 station system, and highlights the limitations, deficiencies, and assets of the installation which has since been disassembled. Included is an extensive list of references containing analyses of the mesoscale data, and details concerning the data acquisition periods which comprise about 5 million mesometeorological observations.

147. REVIEW OF DATA AND PREDICTION TECHNIQUES FOR WIND PROFILES AROUND MAN-MADE SURFACE OBSTRUCTIONS
Frost, Walter, The University of Tennessee Space Institute, Tullahoma, Tennessee, AGARD Conference Proceedings No. 140 on Flight in Turbulence.
A review of experimental data and analytical models related to flow over bluff obstacles is presented with the object of providing a survey of basic flow theory available to an understanding of atmospheric wind patterns around man-made surface obstructions. Primary emphasis is on the distortion of shear flows approaching and passing over buildings or block models of rectangular geometry and over bluff surfaces such as fences or steps. The various physical phenomena of pressure and velocity variation in the separated flow regions surrounding the body, velocity profiles in the displaced flow over the body and the origin and decay of induced turbulence along the boundaries of the separated regions

are described. Most of the reviewed experimental data for flow around bluff structures are obtained in low turbulence wind tunnels where the boundary layer nature of the wind is simulated with properly designed screens or with boundary layers formed on long plane surfaces preceding the test model. Extrapolation of these data to extremely turbulent and gusty real winds introduces unavoidable uncertainties in our knowledge of flow around full scale buildings, nevertheless, wind tunnel tests continue to be the principal source of data and to provide physical insight into the flow near structures. Analytical models are summarized and provide some useful calculational procedures for estimating characteristics of the separated flow and mean wind profiles. Finally, the limited experimental results available from full scale studies on actual buildings in natural winds are discussed.

148. RICHARDSON NUMBER PROFILES THROUGH SHEAR INSTABILITY WAVE REGIONS OBSERVED IN THE LOWER PLANETARY BOUNDARY LAYER
Emmanuel, C. B., (NOVA, Wave Propagation Laboratory, Boulder, Colorado), Boundary-Layer Meteorology, Vol. 5, April 1973, pp. 19-27, April 1973.

149. SEVERE WEATHER WARNING BY PLAN SHEAR INDICATOR
Donaldson, Ralph J., Jr. (Air Force Cambridge Research Laboratories, Bedford, Massachusetts), Preprint of a paper prepared for the 14th Radar Meteorology Conf., Tucson, Arizona, 17-20 November 1970.
The Plan Shear Indicator is a device for obtaining a rough measure of wind variability in real time over the entire range of echoes detected by a scanning Doppler radar. PSI display in use at AFCRL obtains velocity data from a C-band Porcupine Doppler radar, processed by a coherent memory filter. Range resolution is 855 meters and half-power beamwidth of the radar is 0.9° in both directions. The radar antenna scans in azimuth over a sequence of elevation angles. Photographs of the PSI display have been taken in a number of convective storm situations during three summers. Disturbed PSI patterns, indicating regions of intense shear and turbulence, are frequently observed in storm situations with reports of severe weather events at the ground. An investigation of the height and time of appearance and vertical development of the disturbed PSI patterns may suggest their use in short-term warning of damaging surface winds and hail as well as the more obvious job of identifying a hazardous flight environment.

150. SHEAR CONVECTION
Zilitinkevich, S. S. (Akademiia Nauk SSSR, Institute Okeanologii, Leningrad, USSR), Boundary-Layer Meteorology, Vol. 3, March 1973, pp. 416-423, March 1973.
Discussion of convection in the presence of wind shear. An attempt is made to develop a consistent analysis from the basic hypothesis of a very weak interaction between the vertical convective motions and mechanical turbulence, employing a new similarity model of the turbulent regime. In contrast to earlier work on this subject, this regime is termed "Shear Convection" rather than "Free Convection." The latter is traditionally regarded as synonymous with the terms "Pure" or "Fully Developed Convection."

151. SIMULATION OF ATMOSPHERIC TURBULENCE, IN PARTICULAR ITS INFLUENCE ON AIRCRAFT
Schattenmann, W., Scientific Translation Service, Santa Barbara, California, NASA-TT-F-15802, July 1974.
The atmospheric turbulence model used in American flight worthiness literature is discussed. The model must be extended to extremely slow flight and to flight conditions near the ground.

152. THE SIMULATION OF TURBULENCE AND ITS INFLUENCE ON THE PILOT
Tomlinson, B. N., International Conference on Atmospheric Turbulence, Royal Aeronautical Society, London, May 1971.

153. SINGLE-DEGREE-OF-FREEDOM ROLL RESPONSE DUE TO TWO-DIMENSIONAL VERTICAL GUSTS
Houbolt, John C., Sen, Asim, NASA CR-111966, July 1971.

154. SMALL-SCALE WIND SHEAR DEFINITION FOR AEROSPACE VEHICLE DESIGN
Fichtl, G. H. (NASA, Marshall Space Flight Center, Huntsville, Alabama), Journal of Spacecraft and Rockets, Vol. 9, pp. 79-83, February 1972.
Rawinsonde wind profile data provide adequate wind shear information for vertical height intervals greater than 1 km to specify wind shears for intervals below 1 km for space vehicle design, detailed wind-profile information like that provided by the FPS-16 radar-jimsphere system or an extrapolation precedure is required. This paper is concerned with the latter alternative.

155. SOME ASPECTS OF BOUNDARY LAYER DESCRIPTION
Pasquill, F., Quarterly Journal of the Royal Meteorological Society, Vol. 98, July 1972.
The basis and recent developments of the flux-profile relations have been fully reviewed elsewhere, notably by Sheppard (1958, 1970). In this address I turn to certain other features which must also be of major concern in the construction of a basic description of the boundary layer. I shall begin by looking briefly at the problems raised by inhomogeneities in the surface properties, and then go on to an examination of the information now available on the scales and intensities of boundary-layer turbulence.

156. SOME ASPECTS OF THE STRUCTURE OF CONVECTIVE PLANETARY BOUNDARY LAYERS
Wyngaard, J. C., Arya, S., Air Force Cambridge Research Labs, L. G., Hanscom Field, Massachusetts, ARCRL-TR-74-0262, December 1973.
It is shown that although coriolis forces cause large production rates of stress in a convective planetary boundary layer, there is a control mechanism involving mean wind shear which prevents stress levels from becoming large. Higher-order-closure model calculations are presented which show that the stress profiles are essentially linear, regardless of wind direction, providing the geostrophic wind shear vanishes and the wind speed jump across the capping inversion is negligible. It is shown that it will be very difficult to verify these predicted stress profiles experimentally because of averaging time problems. A simple two-layer model is developed which leads to geostrophic drag and heat transfer expressions in fairly good agreement with Wangara Data.

157. SOME MEASUREMENTS OF THE FINE STRUCTURE OF LARGE REYNOLDS NUMBER TURBULENCE
Wyngaard, J. C., Pao, Y. H., Symposium on Statistical Models and Turbulence, La Jolla, California, 1971

158. SPECIAL STUDY OF FATAL, WEATHER-INVOLVED, GENERAL AVIATION ACCIDENTS
Anonymous, National Transportation Safety Board, Washington, D. C., NTSB-AAS-74-2, August 28, 1974.
Weather is the most frequently cited causal factor in fatal, general aviation accidents. This study examines, in detail, circumstances surrounding those accidents over a 9-year period. Observations are made and conclusions drawn about: Pilot time, time-in-type, time last 90 days, pilot certificate held, geographical location, pilot age, actual and simulated instrument time. Also examined are: Weather phenomena as a cause or factor, accuracy of weather forecasts, source and adequacy of weather briefings, time of day, type of flight plan, and time of year.

159. SPECTRAL CHARACTERISTICS OF SURFACE-LAYER TURBULENCE
Kaimal, J. C., Wyngaard, J. C., Izumi, Y., Cote, O. R., Air Force Cambridge Research Laboratories, Bedford, Massachusetts; Journal of Royal Meteorological Society, February 1972.
The behavior of the spectra and cospectra of turbulence in the surface layer is described and, with appropriate normalization, reduced to a family of curves. The resultant analysis is compared to the results obtained by other investigators as a means of validating the curves contained in the report.

160. SPORADIC-E AND WIND-PROFILE INTERRELATION OVER HAWAII
Smith, Lawrence B., Wright, J. W., NOAA, Boulder, Colorado, Environmental Research Labs., COM-72-10771, November 4, 1971.
Principal qualitative and semiquantitative expectations of the wind-shear theory of sporadic-E are stated, with special emphasis on the significance of observed time variations in deciding whether the theory is operative and whether the vertical-shear mechanism is dominant. Nine wind profiles and twenty-two sporadic-E observations made in Hawaii are examined in the light of these expectations and are judged to behave consistently with the wind-shear theory.

161. SQUALL LINE STRUCTURE AND MAINTENANCE NUMERICAL EXPERIMENTATION
Hane, C. E., Florida State University, Tallahassee, REPT-72-5, June 1972.
The conditions favorable for squall line development and maintenance include a convectively unstable air mass in the area, strong vertical shear of the horizontal wind, and some lifting mechanism in the area capable of releasing the instability. These are used in specifying initial and boundary conditions for a time-dependent, two-dimensional numerical model designed to simulate the squall line thunderstorm. The results using a 96 x 33 grid reveal that although the original system in each case loses its organization and decreases in intensity, a new system develops possessing the same basic internal structure as the first.

162. THE SQUALL LINE THUNDERSTORM - NUMERICAL EXPERIMENTATION
Hane, C. E., (Florida State University, Tallahassee, Florida), Journal of the Atmospheric Sciences, Vol. 30, pp. 1672-1690, NSF GJ-367, November 1973.

A two-dimensional time-dependent numberical model is developed for studying the structure and the mechanism of maintenance of the Great Plains squall line thunderstorm. The environmental conditions known to favor squall line development and maintenance include a convectively unstable air mass whose motion is characterized by strong vertical shear of the horizontal wind. These conditions are used to specify an environment in X-Z plane upon which a disturbance is superposed. The appropriate physical equations are integrated forward in time to study changes in the motion, thermal, and moisture fields in and around the squall line thunderstorm.

163. STABILITY OF A TROPICAL MODEL INCLUDING SHEAR, SURFACE FRICTION AND CISK HEATING
Robertson, Terry G., Naval Postgraduate School, Monterey, California, AD-764-090, March 1973.

The structure of barotrophically unstable disturbances in the tropics is studied with a two-level quasi-geostrophic model. An Ekman layer is attached to the lower boundary. The equations are linearized and the most unstable mode is found numerically by use of the initial value technique. CISK heating, horizontal friction and shear are introduced to give more realistic solutions. Computations are made for two shear zone wind profiles.

164. STANDARD DEVIATION OF VERTICAL TWO-POINT LONGITUDINAL VELOCITY DIFFERENCES IN THE ATMOSPHERIC BOUNDARY LAYER
Fichtl, G. H., (NASA, Marshall Space Flight Center, Aero-Astrodynamics Laboratory, Huntsville, Alabama), Boundary-Layer Meteorology, Vol. 2, pp. 137-151, December 1971.

Statistical estimates of wind shear in the planetary boundary layer are important in the design of V/STOL aircraft, and for the design of the space shuttle. The data analyzed in this study consist of eleven sets of longitudinal turbulent velocity fluctuation time histories digitized at 0.2 sec. intervals with approximately 18,000 data points per time history. The longitudinal velocity fluctuations were calculated horizontal wind and direction data collected at the 18-, 30-, 60-, 90-, 120-, and 150-M levels. The data obtained confirm the result that eulerian time spectra transformed to wave-number spectra with Taylor's frozen eddy hypothesis possess inertial-like behavior at wave-numbers well out of the inertial subrange.

165. STATISTICAL ANALYSIS OF LO-LOCAT TURBULENCE DATA FOR USE IN THE DEVELOPMENT OF REVISED GUST CRITERIA
McCloskey, John W., Luers, James K., Ryan, John P., Engler, Nicholas A., Dayton University Ohio Research Institute, GIDEP-344.20.00-C4-01 (AD-731 139), April 1971.

Lo-Locat is an extensive low level turbulence program utilizing statistically representative samples of turbulence data obtained over a wide range of meteorological, topographical, seasonal, and time of day conditions. UDRI has attempted to identify which of the various meteorological and environmental conditions affect the turbulence as reflected through a number of turbulence parameters. The turbulence parameters considered were: Sigma, the standard deviation of the gust velocity, B, the turbulence intensity, L, the scale of turbulence, and N(0), the characteristic frequency. The basic method of mathematical analysis was a stepwise regression scheme which related the environmental conditions to the various turbulence parameters based upon statistical priority. It is felt that the regression scheme provides a detailed outline of statistical relationships which can be used as a guide for further investigation.

166. STATISTICAL PROPERTIES OF VERTICAL SHEAR OF LATERAL VELOCITY
Kumar, P., Journal of applied Meteorology, Vol. 13, pp. 237-241, March 1974.
The statistical properties of two-point differences, Delta V Prime, along the vertical of the lateral component of turbulent (horizontal component perpendicular to mean wind vector) in the first 150 m of the unstable atmospheric boundary layer are analyzed with experimental data. The analysis shows no systematic dependence of the noted moments on the Monin-Obukhov stability parameter.

167. THE STATUS AND DIRECTION OF THE FEDERAL AVIATION ADMINISTRATION WIND SHEAR PROGRAM
Langweil, L., AIAA 9th Fluid and Plasma Dynamics Conference, Session 17, San Diego, California, Paper No. 76-386, July 16, 1976.
A high priority R&D program designed to alleviate the hazards created by wind shear in the terminal area is presently being carried out by the FAA. The program investigates solutions to the wind shear hazard in three general categories (A) through the use of ground-based sensor equipment (B) through the use of avionics and (C) by providing localized wind shear forecasts on a terminal-by-terminal basis. A description of the program and its status is presented.

168. A STUDY OF THE BAROCLINIC INSTABILITY PROBLEM AND THE LOWER BOUNDARY CONDITION
Wiln-Nielsen, A., (Michigan U., Ann Arbor, Michigan), Journal of Geophysical Research, Vol. 76, pp. 6497-6505, NSF GA-16166, September 9, 1971.

169. STUDY OF LESSONS TO BE LEARNED FROM ACCIDENTS ATTRIBUTED TO TURBULENCE
Anonymous, National Transportation Safety Board, Washington, D. C., NTSB-AAS-71-1, December 15, 1971.
The study deals with 97 turbulence-involved U. S. air carrier accidents occurring from 1964-1969. Based on the detailed investigation of those accidents, there is discussed lessons to be learned primarily from the point of view of the meteorologist, the air carrier and the pilot. Observations are made and conclusions drawn in regard to such factors as the adequacy of CAT (clear air turbulence) versus thunderstorm-associated turbulence forecasts, the use of airborne weather radar as a thunderstorm avoidance tool, airborne weather radar maintenance problems, the requirement for real-time data in the cockpit, CAT detectors, turbulence associated losses, the nuisance problem and information derived from cockpit voice recorders and flight data recorders.

170. A STUDY OF SOME EFFECTS OF VERTICAL SHEAR ON THUNDERSTORMS
Connell, J., Tennessee Univ. Space Inst., Tullahoma, NASA-CR-2647, January 1976.

Evidence is presented for the existence of vortices and vortex pairs in thunderstorms. A preliminary parameterized model of the nonthernal generation of thunderstorm vortices derived from field observations of storms and laboratory observations of a jet in crossflow is reported, together with an explanation of how such a model might be used to guide analysis of mesoscale rawinsonde, radar, and satellite data toward an improved capability for prediction of thunderstorm motion and growth. Preliminary analyses of radar and satellite data from atmospheric variability experiment IV are used with available rawinsonde data to develop a correlation between wind shears, instability and thunderstorm motion and development. Specific studies are recommended for best development of concepts and utilization of data from atmospheric variability and atmospheric variability severe storms experiments.

171. A SUMMARY OF ATMOSPHERIC TURBULENCE RECORDED BY NATO AIRCRAFT
Peckham, Cyril G., Technology Inc., Dayton, Ohio, AGARD-R-586-71, September 1971.

The document describes 150,000 hours of turbulence data collected from seven participating NATO countries, the instruments used to measure the data, and the methods of processing the data and of separating the turbulence data from the maneuver data. In addition, it details the power spectral density methods used to derive gust velocities which are presented by altitude.

172. SURVEY ON EFFECT OF SURFACE WINDS ON AIRCRAFT DESIGN AND OPERATION AND RECOMMENDATIONS FOR NEEDED WIND RESEARCH
Houbolt, John C., Aeronautical Research Association of Princeton, Inc., National Aeronautics and Space Administration, Washington, D. C., NASA CR-2360, December 1973.

Results are presented of a survey of the effect of environmental surface winds and gusts on aircraft design and operation. A listing of the very large number of problems that are encountered is given. Attention is called to the many studies that have been made on surface winds and gusts, but development in the engineering application of these results to aeronautical problems is pointed out to be still in the embryonic stage. Control of the aircraft is of paramount concern. Mathematical models and their application in simulation studies of airplane operation and control are discussed, and an attempt is made to identify their main gaps or deficiencies. Key reference material is cited. The need for better exchange between the meteorologist and the aeronautical engineer is discussed. Suggestions for improvements in the wind and gust models are made. Needed research effort that was indicated by the survey is recommended. Key deficiencies are: a lack of knowledge of spatial correlation functions that are critical to aircraft response, lack of development or understanding of unusual and severe wind shear and cross winds, and inadequate modeling.

173. A SYSTEM MODEL FOR LOW-LEVEL APPROACH
Johnson, W. A., McRuer, D. T., Journal of Aircraft, Vol. 8 No. 12, December 1971.

174. TAKE-OFF AND LANDING CRITICAL ATMOSPHERIC TURBULENCE (TOLCAT) - EXPERIMENTS AND ANALYSIS
Elderkin, C. E., Powell, D. C., Dunbar, A. C., Horst, T. W. (Batelle Memorial Institute Pacific Northwest Laboratories), Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, AFFDL-TR-71-172, April 1972.

Measurements of turbulence were made from various arrays of tower mounted sensors to demonstrate methods of describing the temporal and spatial character of turbulence pertinent to Take-Off and Landing Critical Atmospheric Turbulence (TOLCAT) problems of the Air Force.

Results were obtained from analyzing measurements made from several arrays utilizing both 62-meter fixed towers and 30-meter expandable portable towers. Power spectra from 15, 30, and 58-meter heights show characteristics at frequencies above those where the micrometeorological peak energies occur, or the region of greatest interest for aircraft applications. These are reasonably predictable from a knowledge of the near-surface stress, wind speed, and stability.

175. TEMPERATURE INVERSIONS. AN INVESTIGATION OF THE ORIGIN, THE BEHAVIOR AND THE OCCURRENCE IN THE LOWEST LAYERS OF THE ATMOSPHERE ABOVE THE NETHERLANDS
Daan, H., Royal Netherlands Meteorological Inst., De Bilt, KNMI-WR-74-6, 1974.

The temperature inversions observed in 1971 are classified according to the following types, (1) radiation inversions, (2) convection inversions, (3) subsidence inversions, (4) turbulence inversions, (5) cold front, (6) warm front inversion, (7) "sticking layer" inversion, and (8) warm sector inversions, frequency distributions are given for each type, and tables are presented which show the occurrences as functions of season, time of day, and certain meteorological parameters. Remarks are on the representativity in space and time of observations, and an attempt is made to relate temperature inversions to the occurrence of air pollution.

176. THEORETICAL RESEARCH ON THE STABILITY OF THERMALLY STRATIFIED VISCOUS PARALLEL FLOW. FINAL REPORT
Gage, K. S., Maryland Univ., College Park Inst. For Fluid Dynamics and Applied Mathematics, BN-778, August 1973.

For abstract, see NSA 29 05, number 12477.

177. THIRD AND FOURTH MOMENTS OF VERTICAL TWO-POINT DIFFERENCES OF TURBULENT VELOCITY FLUCTUATIONS IN THE ATMOSPHERIC BOUNDARY LAYER
Fichtl, G. H., (NASA, Marshall Space Flight Center, Aero-Astrodynamics Laboratory, Huntsville, Alabama), International Conference on Aerospace and Aeronautical Meteorology, 1st, Washington, D. C., Preprints, May 22-26, 1972.

Results of recent measurements of the distribution function of wind shear and the associated third and fourth standardized moments. Emphasis is placed on the vertical variation of the longitudinal component of turbulence, i.e., the component of turbulence along the mean wind vector. The data source consists of 11 sets of longitudinal turbulent velocity fluctuation time histories digitized at 0.2-sec intervals with approximately 18,000 data points per history.

178. THUNDERSTORM OUTFLOW KINEMATICS AND DYNAMICS
Goff, R. Craig, NOAA Technical Memorandum, ERL NSSL-75, National Severe Storms Laboratory, Norman, Oklahoma, December 1975.

Tall tower and conventional radar sensors at the National Severe Storms Laboratory detected twenty cases of cold air outflow from thunderstorms during 1971 through 1974. Tower data have resolved many small details of thunderstorm outflow not previously observed.

The data were objectively analyzed, each case plotted in 10 min, 450 m deep time-height sections and the cases arranged in an evolutionary sequence based on outflow and storm intensity criteria. Four stages of cold air outflow were established and variations in outflow character were discussed in terms of these stages. Most outflow observations were associated with solid or broken squall lines, two parent thunderstorms were of the supercell type and two others were left-moving cells following a thunderstorm split.

The data show that strong updrafts precede the leading edge of the outflow (the gust front). The gust front is a zone of sharp contrasts in wind, temperature, pressure, and moisture.

Gust fronts often move far ahead of associated precipitation. Secondary cold air surges are observed in about half the cases, confirming earlier observations of mature thunderstorm pulsation. Gust front shape, pre-gust front vertical motion and strength of frontal discontinuities appear to be functions of storm age.

For most of the outflow life history, a near balance is apparent between pressure gradient forces and drag forces but toward the end of the life cycle, Coriolis forces may be significant.

179. TROPOSPHERIC WAVE MOTIONS WITH BAROCLINIC BASIC FLOW IN EQUATORIAL LATITUDES
Berkofsky, Louis, Air Force Cambridge Research Labs. L. G. Hanscom Field, Massachusetts, AFCRL-72-0676, March 1, 1972.

The theoretical investigation of tropospheric wave motions in equatorial latitudes carried out by Rosenthal (1965) is extended to include the vertical shear of the basic current. It is shown that with the inclusion of the effect, the divergence decreases with increasing wavelength, in agreement with the scale analysis of Charney (1963). In addition, the inclusion of shear leads to maximum values of divergence which are in much closer agreement with the divergences in Palmer waves (L approximately 2000 km) than when the basic current is invariant with height. The propagation speeds of meteorological waves are also in closer agreement with observations when the shear is included than when it is absent.

180. TURBULENCE IN AN ATMOSPHERE WITH NON-UNIFORM TEMPERATURE
Obukhov, A. M., Boundary Layer Meteorology, Vol. 2, pp. 7-29, 1971.

181. TURBULENCE AND LATERAL-DIRECTIONAL FLYING QUALITIES
Franklin, James A., NASA CR-1718, April 1971.

182. TURBULENCE MODELS FOR THE ASSESSMENT OF HANDLING QUALITIES DURING TAKE-OFF AND LANDING
Jones, J. G., AGARD Flight Mechanics Meeting on Flight Handling Qualities, Ottawa, Canada, October 1971.

183. TURBLENCE SPECTRA WITH TWO SEPARATED REGIONS OF PRODUCTION
Roth, R., Journal of Applied Meteorology, Vol. 10, No. 3, pp. 430-432. June 1971.

184. TURBULENCE STRUCTURE NEAR THE GROUND
Neuendorffer, A. C., Pries, T. H. (U. S. Army, Atmospheric Sciences Laboratory, White Sands Missile Range, N. Mex.), IN: Symposium on Air Pollution, Turbulence and Diffusion, Las Cruces, N. Mex., December 7-10, 1971, Proceedings, (A73-22326 09-20) Albuquerque, N. Mex., Sandia Laboratories, pp. 175-182, 1972.

Six independent, long duration wind temperature records from a 32-meter mast at White Sands Missile Range, N. Mex., were examined using simple spectral techniques in time alone. Aspects of turbulent fluctuations are considered. Horizontal, and basically lateral mechanical rolls are produced by wind shear under conditions of shear instability. Not all measured fluctuations can properly be described as turbulent. Two simple types of gravity waves of importance to the lower troposphere are discussed.

185. A UNIFIED DISCRETE GUST AND POWER SPECTRUM TREATMENT OF ATMOSPHERIC TURBULENCE
Jones, J. G., International Conference on Atmospheric Turbulence, Royal Aeronautic Society, London, May 1971.

186. USE OF APPROXIMATING POLYNOMIALS TO ESTIMATE PROFILES OF WIND, DIVERGENCE, AND VERTICAL MOTION
Schmidt, Phillip J., Johnson, Donald R., Wisconsin Univ., Madison, Dept. of Meteorology, COM-72-50079-05-04, October 5, 1971.
"Least-squares" approximating polynomials are used to suppress bias and random errors in estimating vertical profiles of winds, divergence, and vertical motion. A quadratic polynomial is used to filter each wind profile. Profiles of divergence and vertical motion computed from a linear, a cross-product, and a quadratic two-dimensional (horizontal) approximating polynomial model and from the Bellamy technique are compared. The random-error variance component of the wind observations is estimated from the filtering polynomial prediction errors. In turn, the random-error variance component of the filtered wind, divergence, and vertical motion is determined from the wind observational error variance for the various models.

187. USE OF INVARIANT MODELING
Lewellen, W. S., A.R.A.P. Report No. 243, Aeronautical Research Associates of Princeton, Inc., Princeton, New Jersey.
A method for the calculation of turbulent shear flows based on closure of the equations for second-order correlations of fluctuating quantities is reviewed. Various model possibilities for closure are described and detailed evaluation of coefficients for a simple model is outlined. Comparisons of model predictions and experimental data for a wide variety of laboratory and atmospheric flows are presented.

188. USE OF RADIOSONDE DATA TO DERIVE ATMOSPHERIC WIND SHEARS FOR SMALL SHEAR INCREMENTS
Essenwanger, O. M., Army Missile Research, Development and Engineering Lab, Redstone Arsenal, Alabama, November 1974.
The wind vector shear in the lowest 3000 feet for the 90, 95, and 99 percent threshold of the annual cumulative distribution and the maximum shear from 14 stations of the climatological ringbook and 27 stations of unpublished vector shear distributions are derived. All data were normalized to a 100 M shear interval by a formula. The outcome of the analysis confirms that the vector shear decreases from the surface to a minimum at around 2 KM.

189. VARIATION OF LATERAL GUSTINESS WITH WIND SPEED
Skibin, D., (Atomic Energy Commission, Nuclear Research Centre, Beer-sheba, Israel), Journal of Applied Meteorology, Vol. 13, September 1974, pp. 654-657, September 1974.
The variations of lateral gustiness with wind speed were studied. Results show

a decreasing trend of lateral direction fluctuations with increasing wind speed, for speeds gr than 2 M/Sec. For winds less than 2 M/Sec, direction fluctuations increas h increasing wind speed, both during stable and unstable conditions.

190. VARIATION OF THE LOW LEVEL WINDS DURING THE PASSAGE OF A THUNDERSTORM GUST FRONT
Sinclair, R. W., Anthes, R. A., Panofsky, H. A., NASA Contractor Report NASA CR-2289, July 1973.
The structural properties of six gust fronts were analyzed in an effort to develop a statistical prediction technique for the wind speed from the surface to about 150 m during the passage of a gust front.

191. THE VARIATION OF THE STATISTICS OF WIND AND HUMIDITY FLUCTUATIONS WITH STABILITY
McBean, G. A., Boundary Layer Meteorology, Vol. 2, pp. 438-457, 1971.

192. VERIFICATION OF A MESOSCALE WIND-PREDICTION MODEL DERIVED FROM A HORIZONTAL VORTICITY THEOREM
Cornett, J. S., Randerson, D., (NOAA, Air Resources Laboratory, Las Vegas, Nevada), Conference on Weather Forecasting and Analysis, 5th, St. Louis, Missouri, Preprints, March 4-7, 1974.

193. VERTICAL WIND SHEAR IN THE BOUNDARY LAYER
Pettitt, R. B., Root, R. G., In WMO Vertical Wind Shear in the Lower Layers of the Atmosphere, pp. 1-30, 1969.
The results of a short study on boundary-layer vertical wind shear, i.e., the rate of wind velocity with height in the first 200 feet above the ground are given. Vertical wind shear was investigated at two towers: one in Montreal, Quebec, the other at Whiteshell, Manitoba. Following a discussion of relevant theory, the data, for both sites, are examined separately. A comparison of the two sets of results are given.

194. WANTED - A WAY TO MEASURE LOW LEVEL WIND SHEAR
Glines, C. V., Airline Pilot, July 1975.

195. WEATHER EFFECTS ON AIRPORT CAPACITY
Bromley, E., Jr., Stoliar, A.P., (FAA Communications Development Div., Washington, D. C.) (Sperry Rand Corp., Sperry Div., Great Neck, New York), Sperry Rand Engineering Review, Vol. 24, No. 3, pp. 2-10, 1971.
Discussion of the key role weather plays in airport capacity, and review of the impact of individual weather factors such as wind, wind shear, turbulence, precipation, temperature, visibility and ceiling. It is shown that reductions in airport capacity due to weather factors can be minimized by integrating tailored weather information into an upgraded air traffic control system and making this information available to pilots.

196. WEATHER HAZARDS TO SAFE FLIGHT
Morss, M. N., (International Federation of Air Line Pilots Associations, London, England), In: Outlook on safety, Proceedings of the Thirteenth Annual Technical Symposium, London, England, November 14-16, 1972, (A73-34076 17-02) Hayes, Middx., England, British Air Line Pilots Association pp. 149-167, Discussion, pp. 168-177, 1973.

With the increasing pressure on airlines to improve the reliability and regularity of their schedules, it has become increasingly important to understand in detail why the atmosphere assumes certain forms, so that accurate and timely forecasts can be made of their occurrence. Major attention is given to low level wind shear and clear air turbulence (CAT). Various accidents and incidents attributable to wind shear are discussed. There is a need for better information on vertical wind shear in the terminal area. At present, pilot reports are the most immediate means of obtaining this information. In the case of CAT, it is evident that as traffic increases and is compressed in the same airspace, the frequency of encounters will increase. It is suggested that when there are sufficient reports of CAT to warrant it, the affected airspace should be blocked off. Aspects of fog are considered in some detail, and some suggestions for a better weather service are made.

197. WIND CHARACTERISTICS IN THE PLANETARY BOUNDARY LAYER AT WHITE SANDS MISSILE RANGE, NEW MEXICO
Rachele, Henry, U.S. Army Electronics Command, White Sands Missile Range New Mexico, March 1974.

Equations, graphs and tabulated results describing wind shear, gust factors, wind variability, time and space correlation (including coherence), and turbulent characteristics are presented. Data were collected in the planetary boundary layer at White Sands Missile Range (WSMR), New Mexico. Results, when possible, are compared with those obtained by other investigators.

These data indicate that a simple power law relationship exists between (1) layer thickness and the magnitude of vector shear, (2) layer thickness and the magnitude of the extreme vector shear, and (3) magnitude of the mean shear and standard deviation of shear for given layers.

198. WIND CHARACTERISTICS IN THE PLANETARY BOUNDARY LAYER---ANALYSIS OF WIND CONDITIONS AT WHITE SANDS MISSILE RANGE, NEW MEXICO
Rachele, H., Armendariz, M., Atmospheric Sciences Lab., White Sands Missile Range, N. Mex., November 1974.

Equations, graphs, correlation coefficients, and tabulated results describing wind shear, gust factors, wind variability, and the turbulent characteristics of the atmosphere are presented. Data were collected in the planetary boundary layer at White Sands Missile Range (WMSR), New Mexico. When possible, results were compared with those cases, it was found that simple mathematical models could be used to describe the meteorological parameter as a function of stability.

199. WIND GRADIENTS AND VARIANCE OF DOPPLER SPECTRA IN SHOWERS VIEWED HORIZONTALLY

Battan, Louis J., Theiss, John B., (Institute of Atmospheric Physics, The University of Arizona, Tucson), Journal of Applied Meteorology, Vol. 12, pp. 688-693, November 15, 1972.

An X-band pulsed Doppler radar having its beam fixed at an elevation angle of 3°, has supplied new data on radial velocity spectra in two showers. It was found that the mean Doppler velocity, variance of the Doppler spectrum. and radar reflectivity varied markedly over distances of less than about 1 m sec in more than 80 percent of the observations and exceeded 3 m sec in about 4 percent of the cases. An analysis of $\Delta \bar{V} / \Delta r$, the radial gradient of the radial wind apparently can explain less than about 15 percent of the observed variance of the Doppler spectrum. It appears that a major part of the variance is attributable to scales of motion smaller than the dimensions of the sampling volume.

200. WIND MEASUREMENTS USING FORWARD-SCATTER CW RADAR

Birkemeier, W. P., Fontaine, A. B., Gage, K. S., Gronemeyer, S. A., Jasperson, W. H., Sechrist, F. S., (University of Wisconsin, Madison) Journal of Applied Meteorology, Vol. 12, pp. 1044-1053, March 13, 1973.

The ability of a forward-scatter CW radar to measure cross-path wind speed profiles is demonstrated from the results of a two-week observation period in Hune 1971. Radar-measured simultaneously by radiosondes and pibals. It is concluded that forward-scatter CW radar is a sensitive atmospheric probe which can accurately measure atmospheric winds.

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

Barr, Neal M., Dagfinn, Gangsaas, Schaeffer, Dwight R., U. S. Department of Transportation, Federal Aviation Administration Systems Research and Development Service, Washington, D. C., FAA-RD-74-206, December 1974.

Analytic and probablistic descriptions of low-altitude mean wind and turbulence have been investigated and a description selected. The effects of wind and turbulence on aerodynamics and aircraft motion have been analyzed. A model of wind and turbulence, suitable for the certification of landing and approach guidance and control systems by flight simulations, has been developed, and consideration has been given to implementation.

202. WIND SHEAR

Anonymous, Flight Safety Committee, No. 4/76.

203. A WIND SHEAR ACCIDENT AS EVIDENCED BY INFORMATION FROM THE DIGITAL FLIGHT DATA RECORDER

Laynor, W. G., Roberts, C. A., NTSB, SASI International Seminar, Ottawa, Canada, October 1975.

The evidence indicated that immediate recognition of the wind shear effect and positive pilot action were required to prevent landing short of the runway. Tests indicated that restricted visual cues hindered prompt recognition of the developing descent role and accurate assessment of pitch change requirements.

204. WIND SHEAR ON THE APPROACH
Melvin, W. W., (Delta Air Lines, Inc., Atlanta, Georgia), Shell Aviation News, No. 393, pp. 16-20, 1971.

205. WIND SHEAR ON THE APPROACH
Melvin, W. W., (Deltal Air Lines), Flight Safety Foundation, Inc., Arlington, Virginia, March 1974.
Vertical wind shears result from variations in wind levels with altitude. The gradients of these shears (wing change per 100 feet of altitude) and the magnitudes (total velocity change) are of primary importance to the pilot flying an approach.

206. WIND SHEAR ON APPROACH AND CLIMBOUT
Sowa, Daniel, Flight Operations, October 1975.
In low-level wind shear, the most important thing to know is wind direction on both sides of the front. Next in importance is its height in relation to where you'll penetrate the frontal surface. The worst possible condition in a shear is to fly into a sudden tailwind. Here's an analysis of problems to expect and techniques to minimize their effect.

207. WIND SHEAR (A BIBLIOGRAPHY WITH ABSTRACTS)
Habercom, Guy E., Jr., National Technical Information Service, December 1975.
The phenomena of wind profiles and shear effects on aircraft, spacecraft launchings, atmospheric turbulence, and air/water interactions are among the topics reviewed. (Contains 200 abstracts) See also NTIS/PS-75/870, Wind Effects. Part 1. Buildings and Bridges and NTIS/PS-75/871, Wind Effects. Part 2 General Structures.

208. WIND SHEAR EFFECTS ON LANDING TOUCHDOWN POINT
Luers, J. K., Reeves, J. B., University of Dayton Research Institute, Ohio, Conference on Aerospace and Aeronautical Meteorology, NAS8-26600, November 1974.
In the study reported, an investigation was conducted concerning the shape of wind shear profiles during aircraft landings, taking into account also the values of the meteorological parameters which describe the wind shears. Attention is also given to the variation of wind shear effects in the case of different aircraft types. The study was conducted for commercial, military, and STOL aircraft. A digital landing simulation model was used in the investigations.

209. WIND SHEAR - THE INVISIBLE ENEMY
Schuyler, N., Plane and Pilot, pp. 26-28, November 1975.

210. WIND SHEAR: "A LOT TO LEARN"
Anonymous, Pilot, Vol. 15, No. 9, September 1975.

211. WIND SHEAR - NASA LITERATURE SEARCH
Anonymous, NASA Scientific and Technical Information Facility, # 30693.

212. WIND SHEAR NEAR THE GROUND AND AIRCRAFT OPERATIONS
Fichtl, G. H., (NASA, Marshall Space Flight Center, Huntsville, Alabama), Journal of Aircraft, Vol. 9, pp. 765-770, November 1972.
The variance of wind shear in the first 150-200 M of the atmosphere is a function of the direction of the mean wind relative to the flight path, the zenith angle of the flight path, the standard deviation of the three components of the turbulence velocity vector, the surface friction velocity, the stability properties of the atmospheric boundary layer, and the heights above natural grade of the beginning and end points of the portion of the flight path over which the shear is to be calculated. The results are interpreted in terms of the ICAO interim shear criteria for reporting wind shear in qualitative terms.

213. WIND SHEAR: THE MYSTERY OF THE VANISHING AIRSPEED
Schiff, Barry, The AOPA Pilot, pp. 30-33, November 1975.

214. WIND SHEAR PROBLEMS IN TERMINAL OPERATIONS
Vickers, T. K., The Controller, pp. 65-68, December 1972.
The wind shear problem as it influences the aircraft's operational performance and the associated problems with respect to air traffic control in the terminal area is presented.

215. WIND SHEAR - A REPORT BIBLIOGRAPHY
Anonymous, DDC # 035842, Cameron Station Alexandria, Virginia.

216. WIND SHEAR - THE SUPER HAZARD
Anonymous, Business and Commercial Aviation, August 1975.

217. WIND SHEAR - THERMAL WIND RELATIONSHIPS ON THE MESOSCALE
Eddy, Amos, McDonald, Philip A., Oklahoma University Norman, ARO-12813.1-R-GS, May 1975.
Space-time relationships between the wind and temperature fields have been examined using rawinsonde observations taken over White Sands Missle Range and nearly locations during the period 21 August 1973 - 1 March 1974. This required the bringing into operation of multivariate analysis of variance (MANOVA) and regression computer programs.

218. WIND STRESS ON NEARSHORE AND LAGOONAL WATERS OF A TROPICAL ISLAND
Hsu, S. A., Louisiana State University, Baton Rouge, Coastal Studies Inst., TR-192, April 1974.
Wind profiles were measured over a windward lagoon and a quasi-leeward area in Barbados, West Indies, under the prevailing trade winds. Relationships between shear and wind velocities for these environments were determined. Under average wind conditions the shear stress on these coastal waters is about 72 percent of that of an oceanic region.

219. WIND STRUCTURE IN THE ATMOSPHERIC BOUNDARY LAYER
Pasquill, F., Philosophical Transactions Society, London, A 269, 1971.

220. WIND AND TURBULENCE INFORMATION FOR VERTICAL AND SHORT TAKE-OFF AND LANDING (V/STOL) OPERATIONS IN BUILT-UP URBAN AREAS - RESULTS OF METEOROLOGICAL SURVEY

Ramsdell, J. V., Battelle, Pacific Northwest Laboratories, Battelle Boulevard, Richland, Washington, FAA-RD-75-94, June 1975.

Winds and turbulence have been measured at typical urban STOL and VTOL port sites and at a conventional rural airport during a 9-month period. These measurements have been used to develop a set of turbulence models for use in: design of V/STOL aircraft stability and control features, development of airworthiness criteria for certification of V/STOL aircraft, and simulation of the turbulence in the urban terminal environment of V/STOL aircraft. The model set includes spectral models, rms gust velocity models and turbulence length scale models. Probability distributions are given for gust velocities and length scales. The data obtained during the study and the models derived therefrom are compared with conventional, flat-terrain turbulence models and data.

In addition, the report contains a review of atmospheric boundary layer theory and descriptions of the measurement sites, instrumentation and data processing. There is a discussion of spatial aspects of turbulence and an evaluation of the standard airport cup anemometer.

The appendices contain extensive summaries of the collected. These summaries include: wind roses, wind and turbulence spectra, gust velocity distributions, and length scale distributions.

APPENDIX B

SUBJECT INDEX

GROUPING

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SUPPLEMENTARY

INFORMATION

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WIND SHEAR: A LITERATURE SEARCH, ANALYSIS, AND ANNOTATED BIBLIOGRAPHY

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The principal values of wind shear characterization appear to be in the area of flight simulation for both training purposes and accident analysis. As previously noted, the FAA report FAA-RD-74-206, index No. 201, is an indepth treatment for the former, and Dr Fichtl's memorandums in December 1975 and January 1976 an example of the latter.

II HAZARD DEFINITION/ACCIDENT ANALYSIS.

The primary hazard to an aircraft by a wind shear encounter is during low-altitude operations at reduced airspeed. These are the normal operational conditions of the approach and landing or takeoff and initial climb phases of flight operations.

In recent years, there have been several air carrier accidents in which such shears were a contributing factor. These are listed in table 1.

TABLE 1. AIRCRAFT ACCIDENT IN WHICH WIND SHEARS WERE A CONTRIBUTING FACTOR

Aircraft Type	Location	Date
DC8	Naha Air Base, Okinawa	July 27, 1970
B727	New Orleans, LA	July 26, 1972
B707	JFK Airport, NY	December 12, 1972
DC3	LaGuardia Airport, NY	January 4, 1974
B707	Pago Pago, American Samoa	January 30, 1974
B727	JFK Airport, NY	June 24, 1975
B727	Denver, CO	August 7, 1975
B727	Raleigh, NC	November 12, 1975

It should be noted that the above list is not necessarily all-inclusive. In fact, the National Aviation Facilities Experimental Center (NAFEC) is currently reexamining all aircraft accidents from 1964 thru 1975 in an attempt to identify other accidents in which low-level wind shears could have been a factor. The purpose of the reexamination is to evaluate various aspect of the wind shear program identified in the FAA program plan of March, 1976, index No. 63.

A review of the World Airline Accident Summaries for both underrun and overrun landing accidents identifies four known wind shear accidents, 16 additional accidents in which wind shear could have been a potential factor, and 16 other accidents which may have had an associated wind shear factor. In addition, there are wind shear related air carrier accidents which have occurred during takeoff, such as the United Airlines B727 accident in Denver, which was noted in table 1.