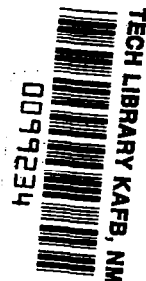


NASA Conference Publication 2270

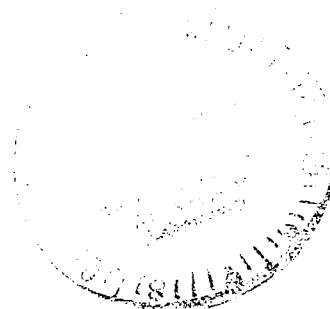
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Summary Proceedings of a Wind Shear Workshop



John H. Enders
William W. Melvin
Walter Frost
and Dennis W. Camp

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*Proceedings of a workshop held at the
University of Tennessee Space Institute
Tullahoma, Tennessee
October 25, 1982*



25th Anniversary
1958-1983





NASA Conference Publication 2270

Summary Proceedings of a Wind Shear Workshop

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NASA Marshall Space Flight Center and held at the
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National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

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TABLE OF CONTENTS

	Page
1. The Contents of a Training Film Relative to Wind Shear Hazards	1
2. Optimum Flight Procedure to Use When Encountering Wind Shear	2
3. Recommended Procedures for Determining Meaningful Wind Shear Speeds from Flight Data Recordings.	3
4. Optimum Format and Amount of Detail for Wind Shear Models to Use in Flight Training Simulators and Best Use of Wind Shear Models for Flight Crew Training	5
5. The Direction Research and Development Should Go in Warning and Detection Systems and in Forecast Problems.	7
6. Use of the Low-Level Wind Shear Alert System (LLWSAS) in its Current Form and Recommendation for Methods of Communicating the Alert to Pilots; Go/No-Go Decision Relative to Wind Shear Alerts.	9
7. Risk Level Limitation in Wind Shear Encounters	10
APPENDIX A – Participants of the Wind Shear Working Group.	12
APPENDIX B – Discussion Paper on a Proposal to Limit Risks from Wind Shear Encounters	14

CONFERENCE PUBLICATION

SUMMARY PROCEEDINGS OF A WIND SHEAR WORKSHOP

The one-day special workshop convened at The University of Tennessee Space Institute (UTSI) at Tullahoma, Tennessee, on Monday, October 25, 1982, to consider several questions concerning wind shear hazards in aviation operations and means of dealing with them effectively. Thirty-two participants, having a wide range of pertinent expertise in the subject, comprised the workshop. A summary of the discussions is presented herein, in context with the topical areas:

1. The Contents of a Training Film Relative to Wind Shear Hazards.

A 1978 vintage FAA-prepared film shown to the participants before the discussion session dealt with the meteorology of wind shear, cockpit techniques, instrumentation, and status reviews of wind shear detection and warning research and field systems. The consensus of the discussion that followed the viewing of the film was that it did not accomplish training objectives in any practical depth; however, with updating, the format lent itself to a good introductory film on wind shear for general audiences. The group agreed that a good training film (or series of films) on wind shear hazards is needed. Information considered to be essential to the content of such a film was:

- a) A clear definition of the phenomenon of wind shear.
- b) A clear definition of the threat that shear presents to aircraft operational safety.
- c) A clear technical description of wind profiles attendant to different types of wind shear, aircraft aerodynamics and performance response, and the concept of aircraft energy management.
- d) A discussion of visual clues discernible by a pilot that will alert him to the presence of wind shear, e.g., virga, cloud, blowing dust, tree and bush movement, etc.
- e) An accurate description of enabling regional meteorological factors which precede wind shear encounters, e.g., thunderstorms, cloud types and changes (acute or benign), gust fronts, frontal passage, etc.
- f) A review of currently available conventional and nonconventional cockpit instrumentation useful for detecting wind shear and discussion of proper use, pitfalls, etc.
- g) Demonstrations of proper cockpit technique (professionalism) upon an expected or unexpected wind shear encounter.
- h) A description of proper and realistic simulations of a range of shear encounters (negotiable and non-negotiable).

The film(s) should also portray the very latest in equipment and facilities to enhance credibility among a pilot audience of generally high sophistication. The film should concentrate on what is presently known to be effective in dealing with wind shear, and perhaps only briefly refer to near- and long-term potential R&D solutions. The participants also felt that the film should impress upon the viewer the desirability of reporting all wind shear encounters. The current FAA Advisory Circular 00-50A summarizes very

well the current state of understanding of wind shear; however, wind shear avoidance and encounter techniques are difficult to define precisely until more confidence is gained through experience and increased knowledge of shear occurrences.

Conclusions

- There is a strong need for a training film or series of films on wind shear.
- Such films should be periodically updated as new knowledge about both the hazard and safe operating techniques are developed.
- The 1978 FAA film is not sufficiently in-depth to be effective as a training film.

2. Optimum Flight Procedure to Use When Encountering Wind Shear.

Captain William Melvin provided a background briefing on wind shear encounter techniques in terms of performance capability and energy management. A general point brought out in the discussion was that energy in excess of that needed to maintain level flight, or glide path flight, can be traded for altitude (i.e., bleed off airspeed to approach the stall speed) if necessary. However, if a pilot sacrifices all speed down to stick shaker speed and still has not arrested the descent, there is no longer any excess energy available to convert into a flare maneuver when approaching the ground. There is also a question of timing as to when and at what rates the pilot should make this trade. At present, there does not exist a sufficient understanding of convectively driven wind shear to confidently prescribe an operational technique for handling all cases. The limited information on the phenomenon available to date indicates that this type of wind shear occurs over a broad spectrum of sizes and severity. Therefore, in real situations, a pilot may encounter severe wind shear of long duration, weak shear of short duration, or any combinations in-between. For this reason, it is very difficult to simulate a “typical” severe wind shear encounter. There were concerns expressed among the participants that a “stereotyped” simulation of wind shear could produce negative training in pilots, in that they may feel that they have learned the proper way to handle a wind shear encounter, only to find a real wind shear situation wherein their training aggravates, rather than alleviates, the encounter. Simulation to train for wind shear encounter recovery is presently frustrated by this lack of knowledge about the severity and extent of shears. Consequently, selecting a technique to deal with one of a random sample of shears may result in recovery before the pilot’s excess energy is traded, while another encounter within the same sample may use all of the excess energy before the shear is transited.

While in retrospect, one may be able to prescribe an optimal technique to deal with a particular, well-defined wind shear encounter, we must recognize that when a pilot is faced with an imminent encounter, there is currently no way for him to prospectively know how severe it will be or how long it will last. Until operational technology is devised that will provide the missing information by which a more informed judgment can be made, the group felt that a pilot should use a strategy of flying the aircraft at its optimal performance configuration (maximum L/D) until surface impact is imminent. Then, the pilot will have enough excess energy (between maximum L/D and stall) to trade in order to flare and soften ground impact. The group felt that flying at stick shaker speed before imminent ground impact deprives the pilot of this “last resort” margin of tradable energy for the impact contingency.

There was also expressed some concern that among many pilots there exists an impression that wind shears can always be safely penetrated if “proper techniques” are used. Information being developed from many sources indicates that this impression is wrong, since some extreme shears are probably non-negotiable with available power and aerodynamics.

Conclusions

- A better understanding of energy management by the pilot will help in employing the best techniques to deal with a wind shear encounter.
- Because of the unknown severity and extent of wind shears, the aircraft should be flown at maximum L/D during an encounter, and only if ground impact is imminent should the energy be traded off to stick shaker speed to flare and soften ground impact.
- Emerging knowledge about wind shears indicates that some are so severe that they cannot be safely penetrated, so known shears should be avoided.
- Projects designed to obtain information that will provide more real-time, accurate knowledge about the extent and duration of wind shears on an aircraft scale will support both the development of training techniques and detection/warning systems; such projects should be encouraged and supported if the hazard of wind shears is to be reduced.

3. Recommended Procedures for Determining Meaningful Wind Shear Speeds from Flight Data Recordings.

The problem was presented in the context of post-accident analysis of wind shear encounters.

To analyze wind shear effects upon aircraft from the information on simple four-channel flight data recorders (FDR), it should be recognized at the outset that the wind shear structure is the independent variable and the resultant aircraft performance is the dependent variable. Some analyses have operated upon assumptions that define the aircraft longitudinal motion before attempting to extract the wind shear values. Consequently, the horizontal wind component is computed as the airspeed variation from the assumed horizontal motion. Remaining variations in aircraft performance are then assigned to vertical components of the wind structure. Wind shear models derived in this manner exhibit large variations in the vertical structure of the wind quite close to the ground which are not realistic.

To explore more reasonable alternatives, one should first consider that a four-channel recorder provides aircraft heading, airspeed, pressure altitude, and vertical acceleration (g). One can, with first and second integration of the g trace, derive altitude rate, inertial vertical velocity, and inertial altitude. All parameters are recorded at 1-sec intervals except g, which is recorded at 0.1-sec intervals.

An aircraft's excess thrust (net thrust margin) can be used to increase its kinetic energy (accelerate aircraft inertially), to increase its potential energy (increase its altitude), or combinations thereof. Net thrust margin and resultant performance can be negative or positive. This can be expressed by

$$T - D = W \sin \gamma + WV/g ,$$

where

T = thrust

D = drag

W = weight

g = gravitational acceleration

V = acceleration or rate of change of inertial acceleration

γ = flight path angle.

This formula is usually expanded into component parts of the two factors on the right side. It is necessary to assume a thrust level when using simple four-channel recorders. Although this is not difficult in takeoff, it is a very uncertain assumption in landing.

Wind shear effects on an aircraft can be assigned either to vertical components of the wind, where the aircraft must climb in a downdraft, or to horizontal wind changes, where the aircraft must accelerate inertially (positively or negatively) in order to maintain its flying qualities. For example, in the takeoff case, if the all-engine climb gradient of the aircraft is known for still air, wind shear effects can be determined from the net changes in climb gradient capability and the net change in airspeed rate, if power settings are equivalent.

If a takeoff accident analysis attempts to start the aircraft at the initial takeoff point and terminates flight at the impact site with assumptions of wind velocity during takeoff, etc., one must be aware that small errors made over the longer time span will mask the significant inertial acceleration that quantifies the wind shear effects in the last few seconds.

Figure 1 shows an assumed distance versus time plot for takeoff. The solid curve represents the longitudinal path of the aircraft for a no-wind condition. Ideally, for the no-wind case, the curve from lift-off should be a straight line as kinetic energy is converted to altitude. In a wind shear case with strong increasing tailwinds requiring inertial acceleration (net excess thrust) to maintain flying qualities, the shape of the curve is that of the dashed line.

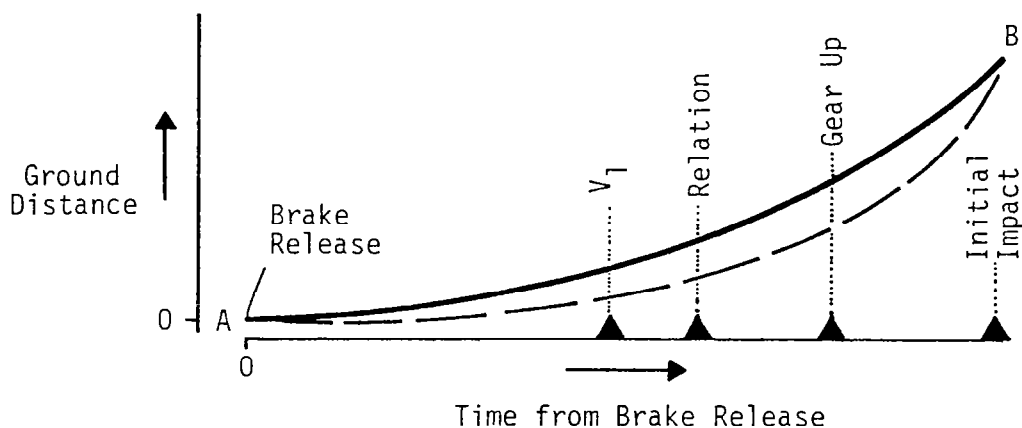


Figure 1. Illustrates distance versus time plot for takeoff.

Considering the many unknown variables such as rolling friction, thrust variations, etc., initial ground acceleration could be less than one might otherwise assume. Such small errors, integrated over the takeoff roll and into flight could mask a rather strong shear during the last few seconds. Wind shear effects might be more accurately determined by calculating the net performance decrement and assuming some reasonable relationship between downdraft and horizontal wind component.

Discussion led to digital flight data recorders' (DFDR) data. These newer recorders provide several more variables with which analyses can be carried out, whereas the older four-channel accident recorders are limited in information. Any definitive estimation of wind shear requires ground-referenced velocity. This information is available on DFDR's used for routine maintenance and operational effectiveness by several airlines. Typical sources are Inertial Navigation Systems, or Doppler Velocity Systems. The British Royal Aircraft Establishment (RAE) has a program looking at wind shears from British Airways FDR data for B-747 operations around the world (about 70 airports). Data from over 9000 landings have clearly demonstrated the ability to identify wind shear without requiring any changes to the usual parameters that are recorded on the DFDR. The analysis has identified about 100 wind shears of significant size.

Conclusions

- Care must be exercised in analyzing crash recorder data for wind shear by ensuring that assumptions themselves are reasonable and lead to reasonable conclusions.
- Older, four-channel crash recorders do not provide the desired accuracy or number of parameters to permit a high level of confidence in wind shear analysis.
- Inclusion of ground referenced velocity from inertial or Doppler velocity systems, when available, provides clear identification of wind shear.

4. Optimum Format and Amount of Detail for Wind Shear Models to Use in Flight Training Simulators and Best Use of Wind Shear Models for Flight Crew Training.

Current wind shear models are not adequate for simulation. A problem is that the input shear is not dynamically representative of real shears. The Joint Airport Weather Studies (JAWS) program is generating definitive high-resolution three-dimensional time-dependent data that will help to resolve the inadequacies of the current models, which are based on very limited data. The wind shear models should be useful not only for driving the simulator but also in conceptualizing wind shear processes for pilot training in understanding shear. These technical issues must be addressed to ensure that the JAWS data are compatible with simulator requirements. However, it is recognized that today's simulation technologies may not be ready to assimilate the new data bases and models. The problem of obtaining realistic turbulence models was also discussed, and it was recognized that there was a need for improvement here as well as in the specialized wind shear case. The need for improvement in visual display cues and understanding external cues that reflect weather dependence was noted. Visual cues can be critical to the pilot in timing his recovery actions.

There developed some discussion about the purpose of wind shear simulation training: What do we want to show the pilot? A shear that will cause him to crash? If not, what? The group reached no decision on this inasmuch as there was a great deal of uncertainty regarding the ability to definitively present "survivable" and "nonsurvivable" shear situations in a consistent manner. There was concern that an element of negative training may result; i.e., a pilot may be trained so effectively in recovering from simulated shear and believing that all shears can be safely penetrated that proper respect for avoiding severe conditions may

erode. The value of demonstrating nonsurvivable shears in the simulator was discussed, and the group felt that if such a nonsurvivable shear could be credibly modeled, it should be presented hand-in-hand with other training aids such as visual clues, generic information about downbursts, microbursts, etc. The JAWS program is providing much information that will help to improve the fidelity of wind shear models. Further, it was felt that, in check-rides in training simulators, it would be instructive to provide the pilots with "surprise" realistic wind shear profiles that can be safely penetrated if proper energy management techniques are used.

The question of adequacy of simulator fidelity was discussed. How much is enough? Factors such as the model and data base, visual representation, motion, and others affect fidelity. It was questioned whether requisite levels of fidelity can be quantified, and if so, at what cost. Also, methods of validation or verification need to be developed.

Given the limited amount of time that a pilot has for simulator training, the question was raised how best to incorporate wind shear experience. This could not be answered due to the general feeling about the inadequacy of the present wind shear models. It was suggested that a standard wind shear data format needs developing to furnish data to the interdisciplinary simulator-user community.

It was further noted that in some cases it may not be emphasized strongly enough to newer crews during training that all available engine power should be used in an emergency. There are situations where some pilots do not call for maximum available thrust when given strong wind shears in a simulator, and some of the group felt this to be because of preoccupation with "flying" the simulator. If this is the case, the group felt that there should be training to compensate for this factor, so that in an actual encounter the crew is conditioned to make most effective use of all available engine power.

There was discussion of the need for manufacturers to establish wind shear reference speeds or angles of attack for each drag configuration that will optimize performance with respect to drag while ensuring adequate energy margin to flare the aircraft in the event that the aircraft cannot escape the shear and ground contact becomes inevitable. The effect on lift and drag of heavy rain is being researched presently by government and university teams, and should analytical predictions be verified in practice, due consideration should be given to lift and drag penalties.

Stick shakers used in a stall warning mode should be regarded from a maintenance point of view as a flight instrument and kept to appropriate standards. Also, pilots should know how far away from stick shaker speed they are operating (if it is to be used as a stall warning), taking into account calibration errors usually found in airspeed indicators at high angles of attack.

If manufacturers establish wind shear reference performance as noted earlier in the discussion, the group noted that it would ease the pilot's task in flying maximum performance while reserving an energy margin for contingency flare purposes.

Recognizing that some shears are near or beyond the performance capability of the aircraft, the pilot must be prepared to divert or to skillfully manage the energy at his disposal. However, pilots are generally predisposed to go (i.e., takeoff or land) so that an actual wind shear encounter is a surprise. The few seconds it takes for him to judge the situation and react may cost him success. The group felt that the best policy to follow is to try to avoid a wind shear encounter rather than to try to penetrate a meteorological condition when it is reported that severe wind shears exist in the local area. However, should a pilot be caught in a wind shear by surprise, he must be able to respond instantly from previous training by maintaining the best possible aerodynamic (maximum L/D) performance.

The uncertainties surrounding simulator models thus become critical obstacles in determining an effective training program to deal with shear encounters. Some of the current “stratified” models likely permit some techniques to work that will not work in a real 3-D shear situation.

Conclusions

- Better models (3-D) of shear for simulation need to be developed before training confidence can be established and improved.
- Critical shear encounters are rare events; training for rare events is difficult and expensive.
- Training must be conducted to avoid “negative” training.
- Simulator technologies and input data format must be compatible.
- Questions of simulator fidelity adequacy need to be addressed.
- Aircraft manufacturers should establish wind shear performance reference needs (or angles of attack) for each drag configuration that will optimize performance with respect to drag while ensuring adequate energy margin to flare the aircraft in the event the aircraft does not overcome the shear and ground impact is imminent.
- Pilots must be trained in proper energy management techniques and be prepared to use everything available to recover in an extreme emergency. Enough energy to flare should be conserved if ground contact is inevitable.
- If procedures are developed that utilize stall warning devices (e.g., stick shakers), then such devices must give adequate warning and the performance must be assured by the manufacturer.
- Pilots should be trained to recognize microbursts, and to avoid deliberate encounters.

5. The Direction Research and Development Should Go in Warning and Detection Systems and in Forecast Problems.

The current systems available for wind shear forecasting, detection, and warning are:

- In situ surface detection
- Airborne detection/warning
- Remote sensing
- Short-period forecasting

These systems, or approaches to dealing with wind shear, prompted the question of what combination of them is needed. A definitive picture of wind shear in operational engineering terms is elusive, so there was no consensus reached, except that the discussion appeared to favor a combination of approaches, e.g., Doppler radar on ground with an airborne sensor.

There was recognition of the high perishability of wind shear information, given the sudden and transitory nature of the phenomenon, and therefore the rapid acquisition and processing of data and dissemination of information is critical. A risk model should be developed to process diverse data and to accelerate recognition of the existence of a severe wind shear.

It was observed that wind shear detection and measurement efforts to date assumed a conventional straight-in approach to landing, while substantial effort is being devoted to microwave landing systems that will permit close-in curved approaches. Wind-shear-oriented R&D and engineering efforts should therefore keep this potential requirement in mind.

Regarding cockpit warning of wind shear encounters, researchers were asked to carefully consider the mode of warning to the pilot. Visual cues of wind shear are very important if such cues are part of the flight reference system, such as, for example, a heads-up display. Otherwise, an aural warning is most satisfactory since a pilot is not likely to see a warning light if it is not part of the instrument display he is using at the time.

As a help in developing warning and forecast techniques, it was noted that many aircraft are now equipped to record parameters that also can measure wind shear. Therefore, it would be relatively easy to accumulate a lot of information on wind shear encounters and aircraft response. The RAE in the United Kingdom (and NLR in Holland) have been measuring wind shear from routine flight data recorders to determine the probability of encountering severe wind shear so that realistic certification requirements can be formulated and to study the character of a wide range of strong wind shear.

The RAE have developed an analysis technique (the Discrete Gust Method), which provides rapid and relevant analysis of the DFDR data. (NLR, Holland are using this same method following its successful application by the RAE.) Alan Woodfield of RAE, Bedford, presented a summary of the U.K. analysis of over 9000 landings by British Airways B-747 aircraft at 70 airports around the world, including several major U.S. airports. The strongest wind shears identified so far have been losses of headwind of about 35 kts in 1500 m air distance and downdrafts of up to 1500 ft/min. Among the 100 significant wind shears recorded are examples of low-level jets, storm fronts, on-shore winds, topographically induced wind shear and hard landings due to wind shear close to the ground.

It is planned to include the RAE method as a means of identifying strong wind shear for the U.K. CAADRP special event program, a joint U.K. CAA, airline, RAE program which looks at a wide range of special events identified from routine DFDR data to assess any significant airworthiness implications.

No thunderstorm microbursts have been found in the 9000 landings, although airports with high probabilities of thunderstorms (e.g., Kuala Lumpur, Singapore, and Miami) are included. However, the RAE is participating in the JAWS program, and several microbursts have been measured with its HS-125 Research Aircraft. Norm Crabill reviewed similar DFDR data gathered during the NASA/Langley Storm Hazards Program from TWA 747's and L-1011's. Information from these programs can complement the JAWS data with routine operations occurrence data.

A concern was raised about the trend toward automating many cockpit functions as potentially limiting the pilot's flexibility in dealing with a wind shear encounter. Some discussion ensued about appropriate logic for auto-pilot and auto-throttle in wind shear situations where conventional speed command logic may not be desirable.

It was noted that the ground speed/airspeed wind shear detection concept is highly dependent upon accurate ground speed and ground wind data. Storage of energy beforehand is very important in counteracting the effects of strong wind shears. Ground speed sensing is an effective clue to alert a pilot to the need to store energy. The Doppler radar on new aircraft does very well for ground speed determination.

Conclusions

- JAWS project results will aid in determining the best sensing methods or combinations for detection and warning, as well as offering insight into optimal training and simulation models.
- Model development is critical to effective warning systems.
- All efforts should bear in mind the need for rapid gathering, processing, and transmitting data to the cockpit.
- Basic data on wind shear (JAWS), improved sensing, model development, human-engineered warning systems are needed
- Non-U.S. data sources where available (such as the U.K. and Holland) should be integrated into a total wind shear experience information base to provide researchers with the widest possible window on wind shear encounters.

6. Use of the Low-Level Wind Shear Alert System (LLWSAS) in its Current Form and Recommendation for Methods of Communicating the Alert to Pilots; Go/No-Go Decision Relative to Wind Shear Alerts.

The evolution of the current system was described. Located at 57 U.S. airports, the LLWSAS consists of six anemometers (1 center field and 5 surrounding the airport complex 20 to 30 ft above ground). Processed information is telemetered to the tower and updated every 8 sec. A vector difference of 15 knots wind velocity is the warning threshold. Comments from five air carrier pilots in the group indicated that the quality and usefulness of the system data depended upon the controller and cockpit crew workload. The variance in data quality poses a credibility problem. Accurate information in a consistent manner will develop confidence in the information. The communications link appears to be the weakest – the controller is required to prioritize in favor of traffic separation first. He may not be able to pass along wind shear information if his workload is heavy. The problem of getting pilots to report airspeed gain or loss was noted. It was pointed out that wind shear cannot always be indicated by airspeed gain or loss – a thrust change may stabilize airspeed in many shear encounters.

A discussion on go/no-go decision resulted in consensus that it is a pilot responsibility and should be treated in the same way as RVR (Runway Visibility Range) data – a pilot judgment call.

Another problem was noted – that of scale in the LLWSAS sampling. The critical scale of microburst horizontal distance is 1 to 3 km, but the LLWSAS systems towers have an average spacing of 3 (up to 5) km. There is, therefore, a basic inadequacy in sampling on this scale of motion.

Conclusions

- At present LLWSAS data may be useful only if communicated to crew in a timely and complete fashion.
- The FAA's NASPLAN for upgrading the ATC system should ensure the inclusion of a means of immediately transmitting hazardous wind shear data to pilots likely to be affected.
- The variance in quality of information now relayed to aircrew can cause a credibility problem, and quality should be standardized.
- ATC workload will affect the quality of wind shear information reaching the cockpit; crew workload will determine the crew's ability to assimilate and act effectively on the wind shear information.
- Go/no-go decisions should be pilot judgments, based upon accurate information of the highest quality.
- There appears to be a basic inadequacy in sampling by the LLWSAS.

7. Risk Level Limitation in Wind Shear Encounters.

Captain Melvin distributed copies of a discussion paper (Appendix B) proposing a methodology for limiting risks from wind shear encounters. There was not time for the group to study the proposal and offer a critique, but great interest was shown in the paper.

Other Topics

Dr. Caracena briefly described a vortex ring model of microbursts. A vortex ring is a mechanism in nature that makes possible a very efficient mass-momentum transfer in the downdraft. A strong, narrow jet model of a microburst fails to account for this transfer because diffusion tends to broaden, dilute, and weaken the jet. A vortex ring, however, tends to decouple from the ambient flow and deliver a relatively unmixed parcel of air over a long distance. A vortex ring descending in a thunderstorm downdraft would therefore tend to be closest to an unmixed parcel descent and would so achieve the most energy due to negative buoyancy. It was further noted that Dr. Caracena's vortex ring model offers a possible explanation for Dr. Fujita's documentations of microbursts whose damage paths are confined to narrow swaths.

Dr. McCarthy informed the group of a recent Senate amendment to the Transportation Appropriations Bill directing the National Academy of Sciences (NAS) to study the wind shear alert standards for denying takeoff and landing clearances and appropriating funding to double the number of sensors at Moisant Airport in Louisiana. The group discussed this amendment and concluded that the recommendation as worded to the NAS led to a conclusion (i.e., denying clearances) in a nonobjective manner and that merely doubling the LLWSAS sensors at Moisant would not clearly reduce the likelihood of dangerous wind shear encounters. In fact, it could create a nonstandard sensing system that might in fact degrade the rapid and efficient gathering, processing, and transmission of critical wind shear information. Accordingly, the group

endorsed the drafting of a letter to J. Lynn Helms, FAA administrator, which expressed these concerns, asking that careful reconsideration be made to ensure that wind shear hazards be reduced in the most rapid and effective manner as recommended by the best scientific, engineering, and operational expertise available.

JOHN H. ENDERS

Chairman

Special Workshop on Wind Shear

APPENDIX A

PARTICIPANTS OF THE WIND SHEAR WORKING GROUP

SIXTH ANNUAL WORKSHOP ON METEOROLOGICAL AND ENVIRONMENTAL INPUTS TO AVIATION SYSTEMS

October 25, 1982

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APPENDIX B

DISCUSSION PAPER ON A PROPOSAL TO LIMIT RISKS FROM WIND SHEAR ENCOUNTERS

Transport category aircraft accidents are rather rare, and taken altogether, prove an impressive safety record. Many would use gross statistics to argue that no new regulation, or system or standard, should ever be imposed because the costs would not justify the benefits. However, when accidents and incidents are evaluated according to the risks that were being taken at the time of each operation, there is overwhelming evidence that limiting the highest risk operations would in fact prove to be very cost effective.

In almost all wind shear related accidents and incidents, there was evidence before the event that, in retrospect, should have prevented the accident/incident if the evidence had been collected and disseminated in a timely manner to the flight crews and if the flight crews had recognized the risks involved.

According to the above rationale, it is proposed for discussion a system to rate the wind shear risks for various meteorological conditions which could limit the highest risk operations while not imposing an undue economic burden upon operators such that the limits would be ignored.

What is proposed is to establish levels of risks along the following lines:

Level 1. Meteorological conditions not conducive to wind shear. Basically clear and nearly calm winds – 5 knots or less. This level would not be transmitted to pilots unless there was a pilot request for the wind shear level.

Level 2. Some wind shears. Surface winds from 5 to 20 knots. Orographic shears, nocturnal jet stream, general gustiness. Well within capability of aircraft performance. There would probably be some wind shears reported at this level. Level 2 would not be transmitted unless there was a report of a wind shear and then only to inform pilots that the risks of encountering a shear that would exceed their aircraft performance would be very small.

Level 3. Surface winds 20 to 40 knots. Wind shears approaching limit of 1 knot per second in horizontal plane. Greater than 10-knot variations in airspeed reported by pilots. Shears associated with frontal conditions. Although these shears are within the capability of aircraft performance, they can be hazardous if not immediately identified and corrected for. Level 3 and subsequent levels should be transmitted on the ATIS and given as advisory information by the tower.

Level 4. Wind shears beyond the capability of jet transport aircraft to correct for without an energy trade are a possibility. Vertical development of clouds with cell activity within 10 nm of an airport. Reasonable expectation of a downburst or microburst. Excess energy recommended for all aircraft. At this level all persons should be keenly tuned to search for further evidence which would confirm the presence of a microburst or downburst. Surface winds in excess of 40 knots should also be classified as Level 4 because there is a high probability that orographic shears could exceed aircraft performance capability.

Level 5. Vertical development with presence of microbursts or downbursts confirmed by (1) ground instrumentation, (2) aircraft instrumentation, (3) aircraft encounter (missed approach, hard landing, etc.), (4) visual sighting (ring of dust, etc.), (5) other information. Level 5 should be automatically assigned if a cell is within 5 nm of the airport unless the airport has an approved ground detection system that is capable

of identifying microbursts, in which case operation could be continued as long as arriving and departing aircraft could remain more than 3 nm from any cell while below 1000 feet agl. At Level 5, operations should be suspended until observations indicate the level can be downgraded to 4.

No prudent pilot should attempt to take off or land at Level 5 unless other risks are predominant, such as low fuel state, etc.

Levels 1 through 4 should be assigned by a meteorologist. Level 5 would be automatic if any source of information indicates the presence of a microburst or downburst.

Consideration should be given to an automatic "Wind Shear Alert – Level 5" transmitted on tower frequency when Level 4 has been assigned and grounded instrumentation confirms the presence of microbursts/downbursts or if an air traffic controller activates the automatic transmission. "Wind Shear Alert" should not be transmitted to pilots just because the alert system in the tower alerts the controllers to the fact that there is a 15 knot variation in wind. In this case, the actual wind values should be transmitted to pilots. A higher value than 15 knots should be used for an automatic alert. Otherwise, pilots will tend to ignore the warnings as they will occur frequently when they do not indicate the presence of microbursts or downbursts.

An automatic alert feature could possibly be transmitted to ACARS for transmission by data line to all aircraft so equipped in the area. ACARS could activate a voice alert in the cockpit.

The foregoing is intended to stimulate discussion on this matter. Critical review is invited. Please send comments to:

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16. Abstract A special one-day workshop on wind shear was sponsored by the NASA Marshall Space Flight Center and hosted by The University of Tennessee Space Institute (UTSI) before the annual NASA/FAA/NOAA-funded "Workshop on Meteorological and Environmental Inputs to Aviation Systems." The workshop was organized to address a number of recent program results and current issues: <ol style="list-style-type: none"> 1) The data collection phase of the highly successful Joint Airport Weather Study (JAWS) Project and the NASA B-57B Gust Gradient Program. 2) The use of these data for flight crew training through educational programs (e.g., films) and with manned flight training simulators. 3) Methods for post-accident determination of wind conditions from flight data recorders. 4) The microburst wind shear phenomenon which has been positively measured and describe the ring vortex as a possible generating mechanism. 5) The optimum flight procedure for use during an unexpected wind shear encounter. 6) Evaluation of the low-level wind shear alert system (LLWSAS). 7) Assessment of the demonstrated and viable application of Doppler radar as an operational wind shear warning and detection system. <p>The Workshop brought together a variety of disciplines concerned with the wind shear problem, represented by airline pilots, meteorologists, flight safety investigators, NASA/FAA/NOAA personnel, aeronautical engineers, flight simulator operators, radar scientists, educators, and aircraft manufacture personnel. The degree of expertise relative to wind shear hazard to aviation operations was extremely high among the group, many of whom are internationally recognized and are leading authorities in their specific phases of the wind shear problem. The major issues relative to avoidance of further wind shear accidents were addressed.</p> <p>Mr. John H. Enders, President of Flight Safety Foundation, chaired the committee and documented the discussions. The document summarizes the committee's major recommendations for the direction of future research and development.</p> <p>This paper concisely states the research and development needs, as seen by key members of the aviation and atmospheric science community, for improving the safety of aircraft operations in severe wind shear.</p>					
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