Session VII. 2nd Generation Reactive Systems

N91-24184

Temperature Lapse Rate as an Adjunct to Wind Shear Detection
Terry Zweifil, Honeywell Sperry

TEMPERATURE LAPSE RATE

AS AN

ADJUNCT TO WINDSHEAR DETECTION

TERRY ZWEIFEL
HONEYWELL, INC.

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HONEYWELL, INC.

ABSTRACT

As airborne windshear detection systems evolve, an increasing sophistication is required to assure more reliable and timely detection of hazardous windshears. As part of an on-going study by the University of Oklahoma and Honeywell, Inc., several meteorological parameters are being examined to determine if measurable atmospheric conditions can improve windshear detection devices.

Lapse rate, the temperature change with altitude, shows promise as being an important parameter in the prediction of severe windshears. It is easily measured from existing aircraft instrumentation, and it can be an important indicator of convective activity including thunderstorms and microbursts. This presentation briefly reviews the meteorological theory behind lapse rate measurement and describes an FAA certified system that is currenty implemented in the Honeywell Windshear Detection and Guidance System.

LAPSE RATE AND MICROBURSTS

- THERE IS A SUBSTANTIAL BODY OF EVIDENCE INDICATING A CORRELATION BETWEEN TEMPERATURE LAPSE RATE (THAT IS THE CHANGE IN TEMPERATURE WITH ALTITUDE) AND THE PROBABILITY OF MICROBURST FORMATION.

- THIS RELATIONSHIP WAS FIRST DISCUSSED BY FERNANDO CARACENA OF ERL. SUBSEQUENT ANALYSIS OF THE DALLAS ACCIDENT SUBSTANTIATED HIS FINDINGS.

DRY ADIABATIC LAPSE RATE

- A MEASURED LAPSE RATE LESS THAN A DRY ADIABATIC LAPSE RATE (-3 DEG C/1000 FT) OVER A DEEP LAYER INDICATES AN UNSTABLE, CONVECTIVE ATMOSPHERE IN WHICH THUNDERSTORMS AND THUS MICROBURSTS CAN BE SPAWNED.

- THE OTHER REQUIRED INGREDIENT IS SUFFICIENT ATMOSPHERIC MOISTURE TO PRODUCE PRECIPITATION.

- CURRENT AIRCRAFT INSTRUMENTATION IS SUFFICIENT TO MEASURE LAPSE RATE, BUT CANNOT MEASURE MOISTURE DIRECTLY.

WET VERSUS DRY MICROBURSTS

- THE NATIONAL WEATHER SERVICE, SOUTHERN REGION, HAS FOUND THAT MICROBURSTS OCCURRING IN TEXAS THROUGH MISSISSIPPI OCCUR WHEN THERE IS A LAYER OF NEARBY DRY ADIABATIC LAPSE RATE EXTENDING UPWARD AT LEAST 6000 FEET FROM THE SURFACE.

- IN THE DENVER AREA, THIS LAYER IS USUALLY 8000 FEET OR MORE.

FERNANDO CARACENA, PERSONAL CORRESPONDENCE

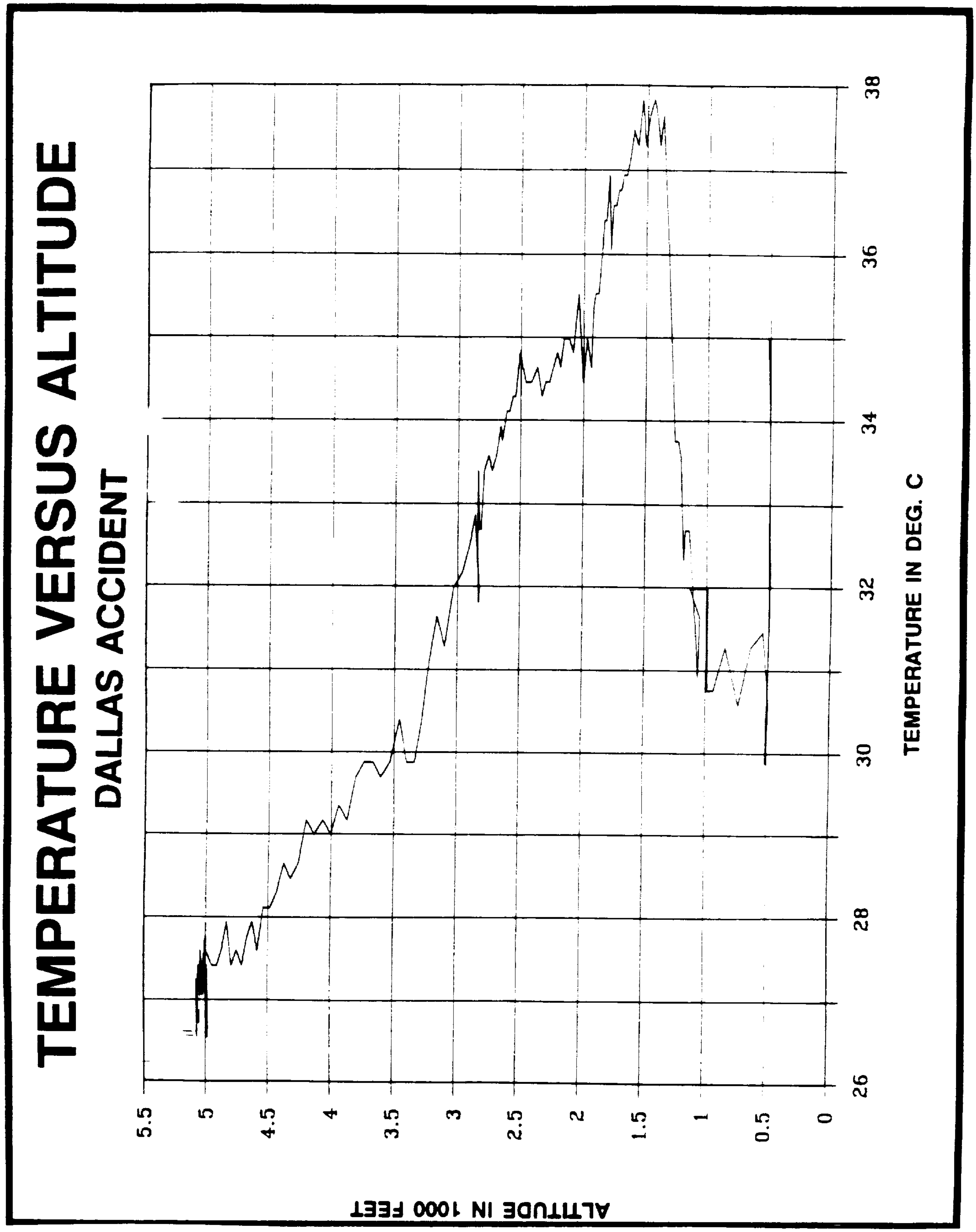
C 6

CONVECTIVE ACTIVITY

- THE IDEA THAT A DRY ADIABATIC LAPSE RATE (OR LESS) CAN PRODUCE THUNDERSTORMS AND TURBULENCE IS NOT A NEW ONE.

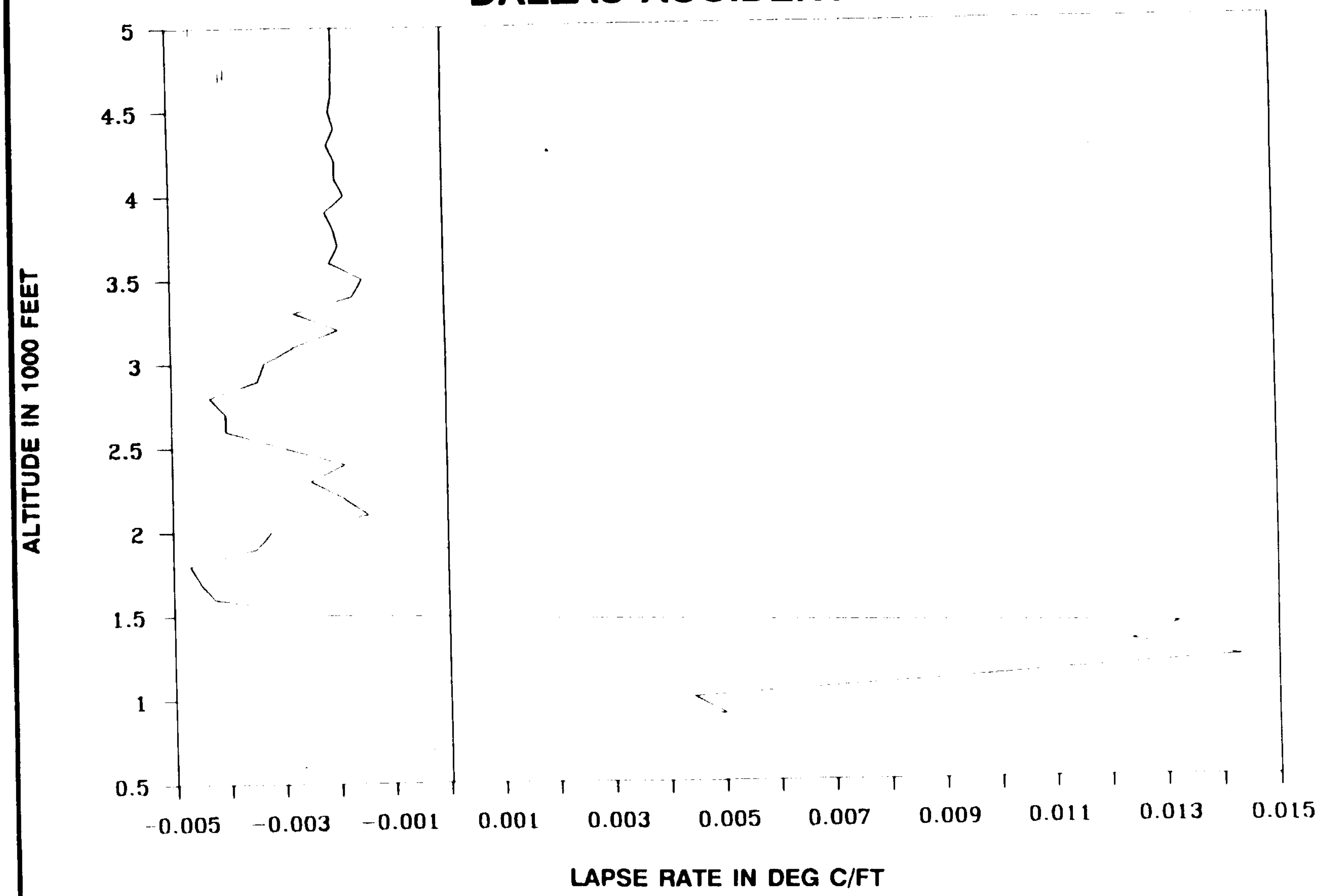
- "CONVECTIVE PHENOMENA ARE DETERMINED BY THE TEMPERATURE-HEIGHT CURVE, THE THICKNESS OF THE UNSTABLE LAYER, AND THE ALTITUDE OF THE CONDENSATION LEVEL", A PILOT'S METEOROLOGY, C.G. HALPINE, 1953.

- SINCE CONVECTIVE ACTIVITY IS OFTEN ASSOCIATED WITH TURBULENCE, LAPSE RATE MEASUREMENTS MAY ALSO BE USEFUL IN WARNING OF IMPENDING ROUGH AIR.

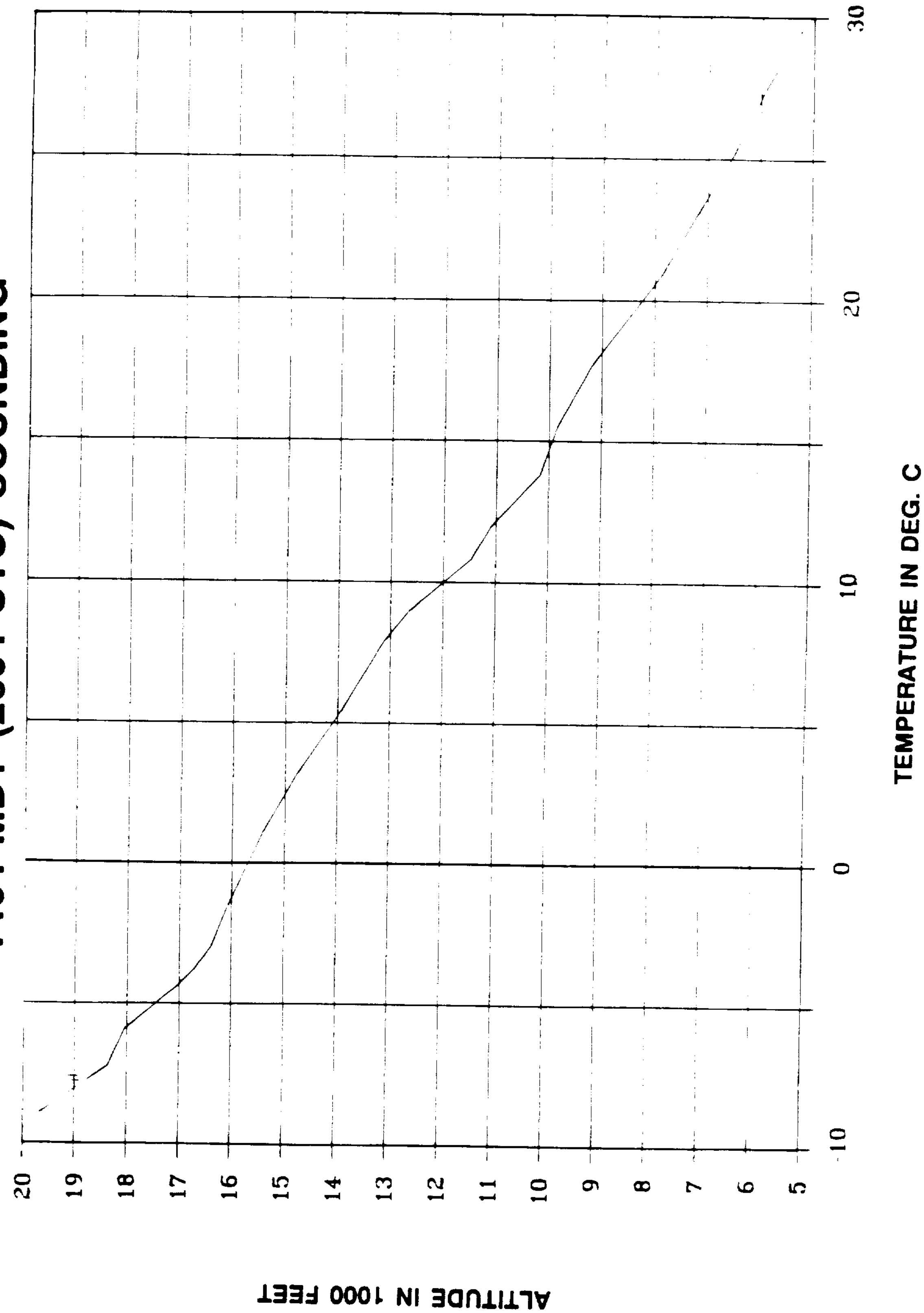

TEMPERATURE VERSUS ALTITUDE
DALLAS ACCIDENT
TEMPERATURE IN DEG. C
ALTITUDE IN 1000 FEET
26
28
30
32
34
36
38
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5

LAPSE RATE

DALLAS ACCIDENT



DENVER 11 JULY 1988
1404 MDT (2004 UTC) SOUNDING



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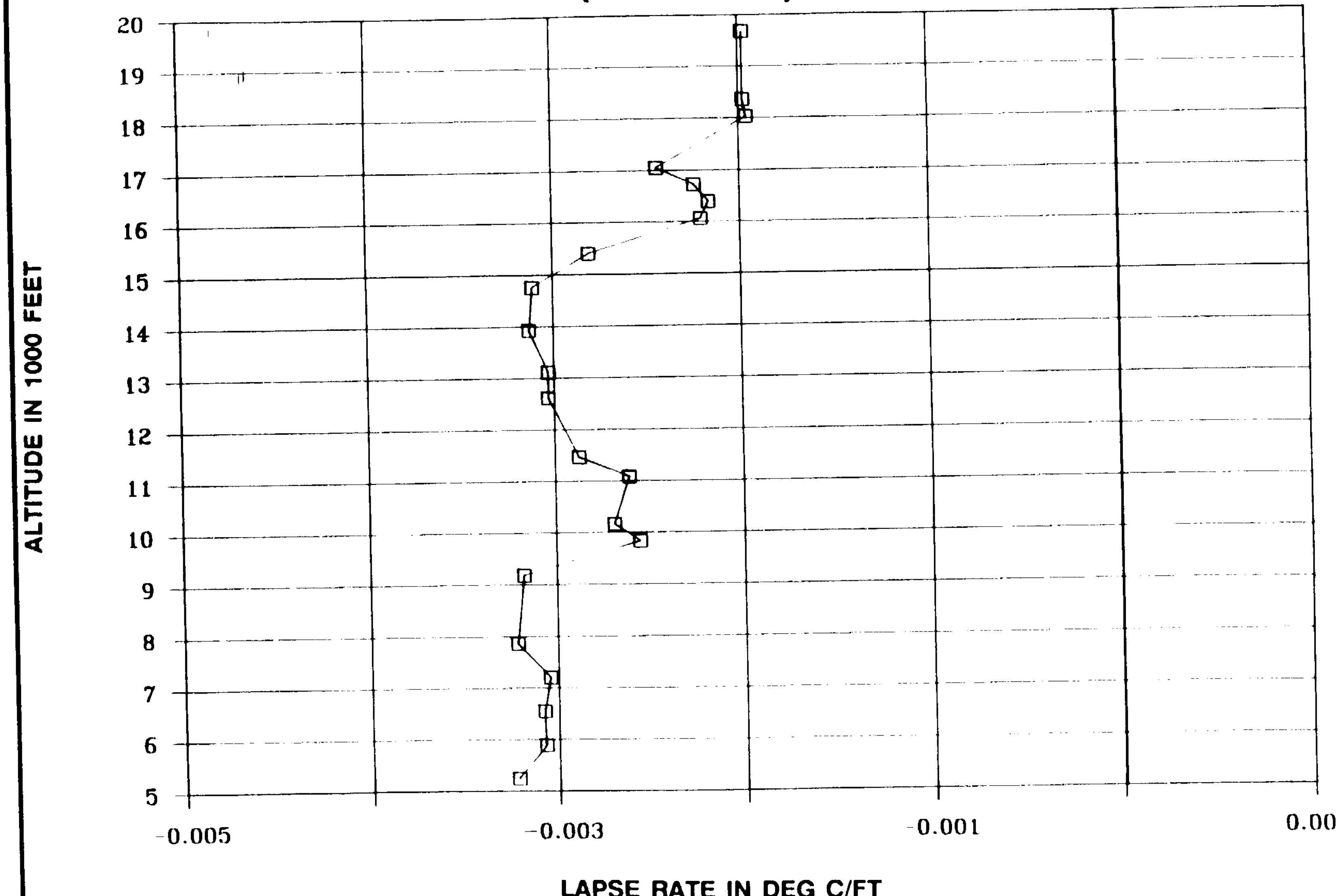
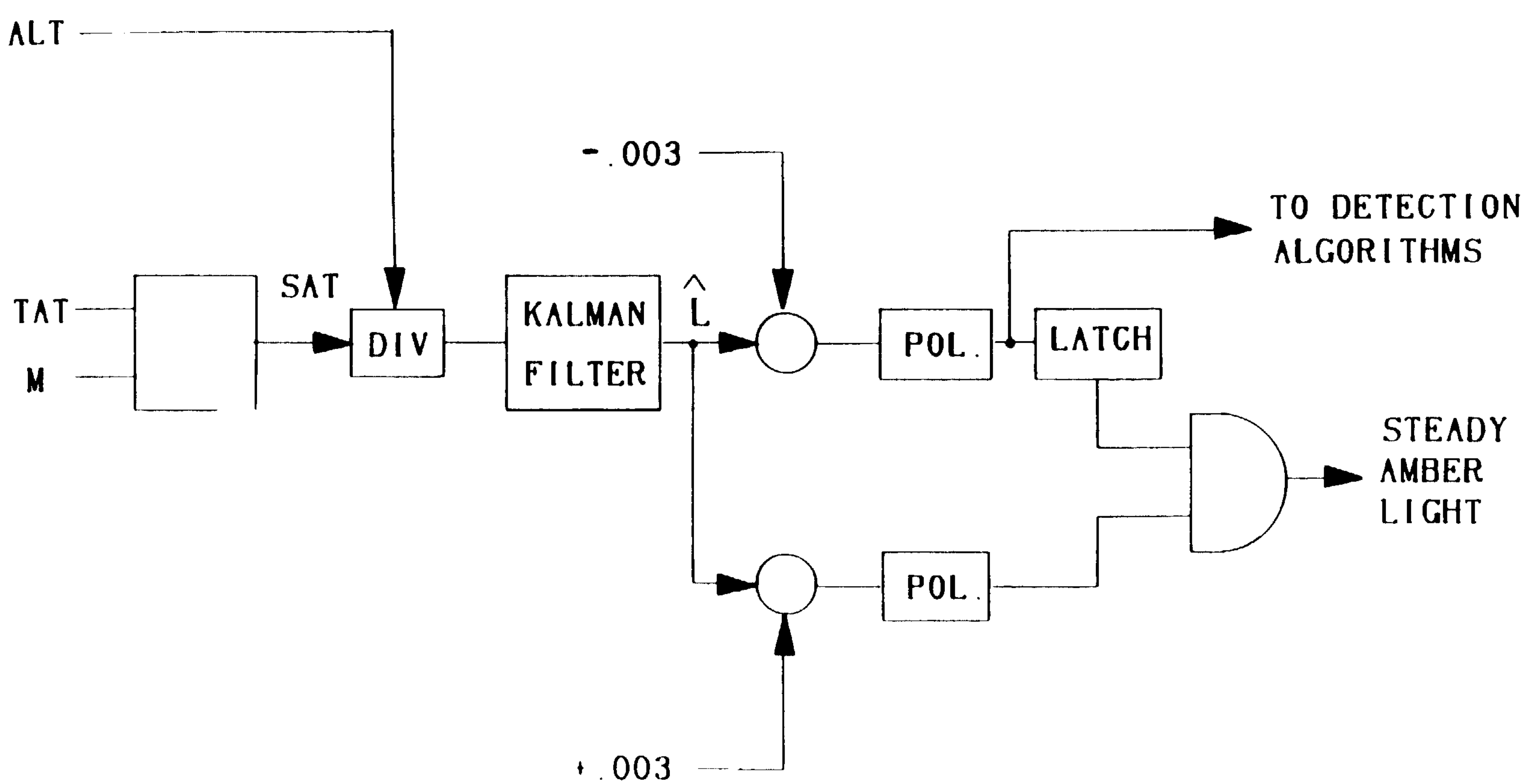


LAPSE RATE MEASUREMENT

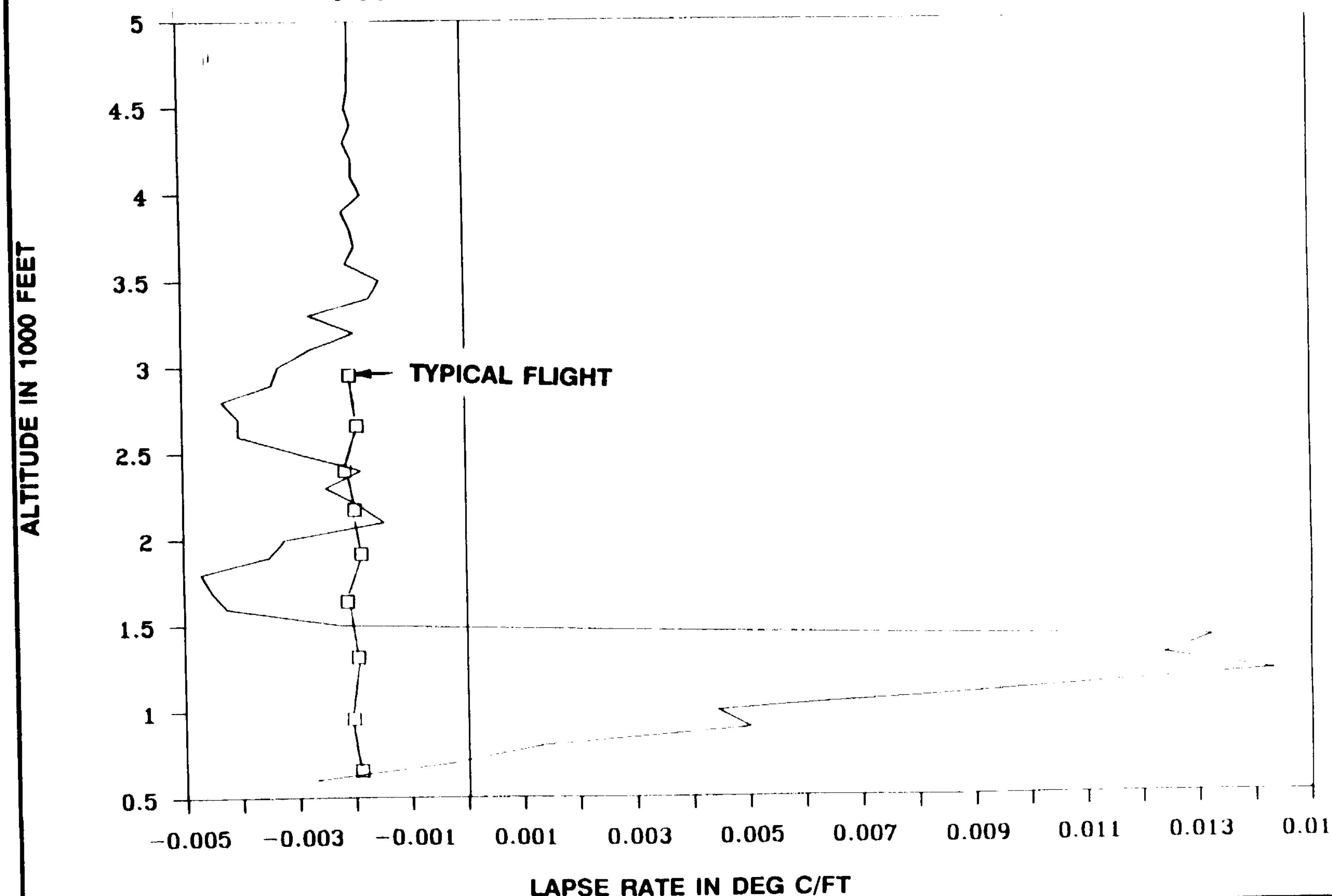
SIMPLIFIED BLOCK DIAGRAM

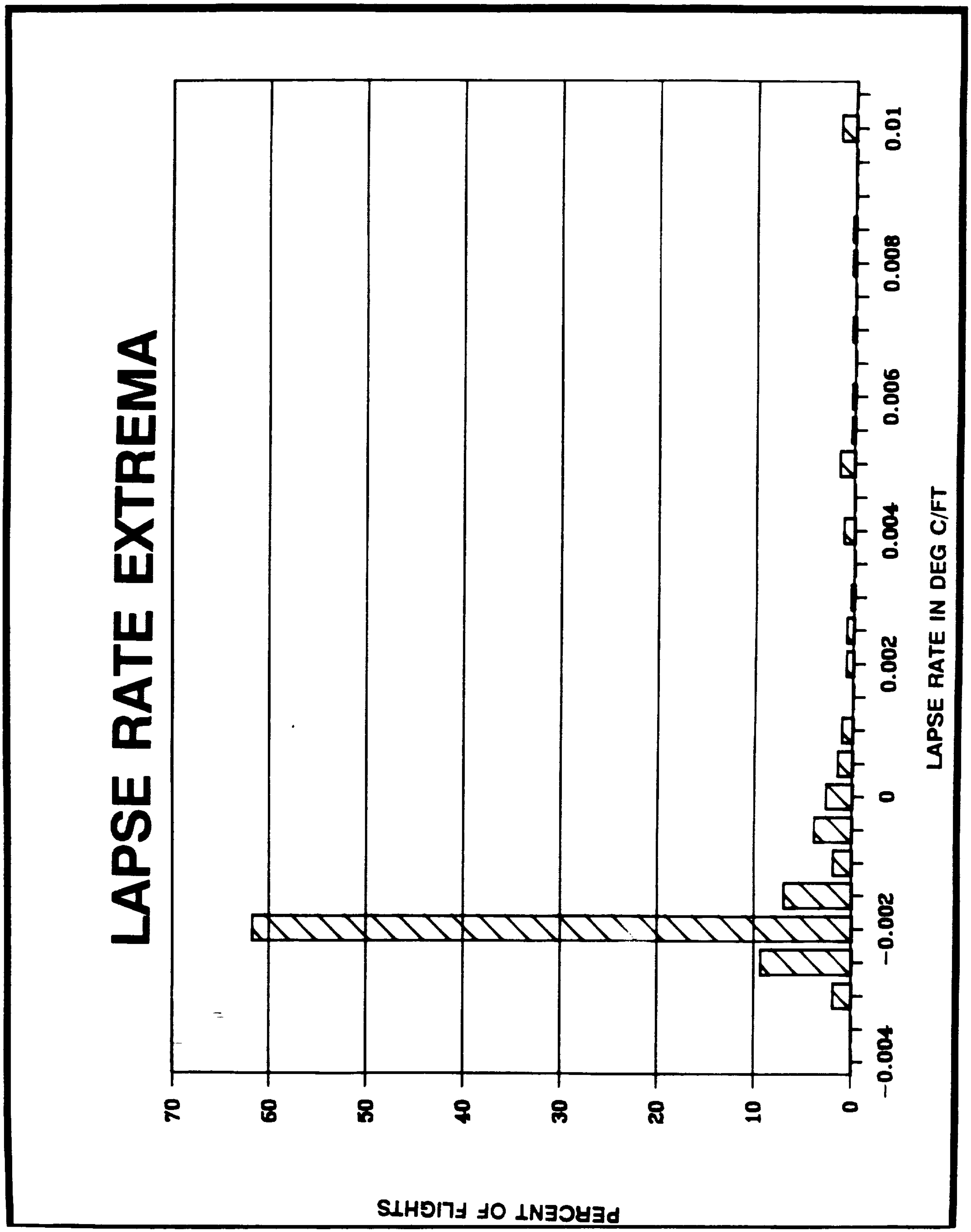


PATENT 4,947,165

LAPSE RATE COMPARISON

TYPICAL FLIGHT VS. DALLAS ACCIDENT




LAPSE RATE EXTREMA
PERCENT OF FLIGHTS
0
10
20
30
40
50
60
70
LAPSE RATE IN DEG C/FT
−0.004
−0.002
0
0.002
0.004
0.006
0.008
0.01

CONCLUSIONS

- LAPSE RATE MEASUREMENTS CAN BE SUCCESSFULLY UTILIZED TO DETECT THE OCCURRENCE OF CONVECTIVE ACTIVITY AND THUNDERSTORM ENVIRONMENTS.

- LAPSE RATE BY ITSELF CANNOT BE USED TO DETECT MICROBURSTS RELIABLY. AT BEST, IT INDICATES THE PROBABILITY OF A MICROBURST OCCURRENCE.

- LAPSE RATE CAN BE USED TO MAKE REACTIVE SYSTEMS MORE "INTELLIGENT", HENCE PROVIDING ADDED ASSURANCE THAT A DANGEROUS SHEAR HAS OCCURRED.

- LAPSE RATE MAY BE A GOOD INDICATOR OF LOW LEVEL TURBULENCE.

CURRENT STATUS

- THE LAPSE RATE ALGORITHM HAS BEEN FAA CERTIFIED AND IS CURRENTLY OPERATIONAL IN THE HONEYWELL WINDSHEAR COMPUTER.

- GIVEN THAT A DRY ADIABATIC LAPSE RATE IS DETECTED FOLLOWED BY A VERY POSITIVE LAPSE RATE, A STEADY AMBER LIGHT IS ILLUMINATED AS A CAUTION TO THE FLIGHT CREW, INDICATING A POTENTIALLY UNSTABLE AIRMASS CONDITION.

- THE DETECTION OF A DRY ADIABATIC LAPSE RATE IS ALSO USED TO ALTER THE THRESHOLDS OF THE BASIC WINDSHEAR DETECTION ALGORITHMS.

FUTURE DEVELOPMENT

- LAPSE RATE MEASUREMENTS ARE CURRENTLY BEING INVESTIGATED AS A MAJOR COMPONENT OF A WINDSHEAR EXPERT SYSTEM.

- KELVIN DROEGEMEIER OF THE UNIVERSITY OF OKLAHOMA IS SIMULATING MICROBURSTS WITH VARYING ATMOSPHERIC CONDITIONS, INCLUDING LAPSE RATE, FOR HONEYWELL.

- USING THESE DATA, HONEYWELL IS PROGRAMMING AN EXPERIMENTAL EXPERT SYSTEM THAT NOT ONLY USES ATMOSPHERIC PARAMETERS, BUT ALSO OVERSEES THE INPUTS OF BOTH REACTIVE AND LOOK-AHEAD SENSORS.

Optimal Guidance during a Windshear Encounter

An aircraft caught in windshear experiences a dangerous loss of lift. An application of optimal control theory has identified the best strategy for surviving such conditions, a strategy now implemented in the Honeywell Windshear Computer.

Terry Zweifel
(Sperry Commercial Flight Systems Division)
AZ75-N30D2: 602-869-2979

At six o'clock on the evening of August 2, 1985, Delta Air Lines Flight 191 was on final approach for a landing at Dallas-Fort Worth International Airport. A thunderstorm was forming near the north edge of the field, directly on the approach path to the active runway. Two other aircraft landed safely, but by the time Flight 191 reached the storm cell, it had built up to a dangerous intensity. Within the cell, the aircraft entered a region of severe windshear and began losing altitude. In spite of the crew's strenuous efforts to maintain control, the aircraft fell below the prescribed glide slope and struck the ground more than a mile short of the runway. The crash killed 134 people on board the aircraft as well as the driver of an automobile on a highway just outside the airport.

The loss of Flight 191 is the most recent of 28 aircraft accidents since 1964 caused by the meteorological effect called windshear. The accidents have resulted in 623 deaths and 237 injuries. In the past decade, about half of all commercial-aircraft accidents have been related to windshear. All of them have happened during takeoff or landing maneuvers.

To prevent such accidents in the future, the best policy is doubtless to avoid flying into regions of windshear. To this end, various sensor systems, such as Doppler radars, have been developed to detect windshear conditions near airports, so that pilots can be warned to delay takeoffs and landings until the danger passes. But ground-based detectors can never be perfectly accurate and reliable. Inevitably, an aircraft will occasionally stray into a windshear region. The question then becomes how best to get out of the predicament.

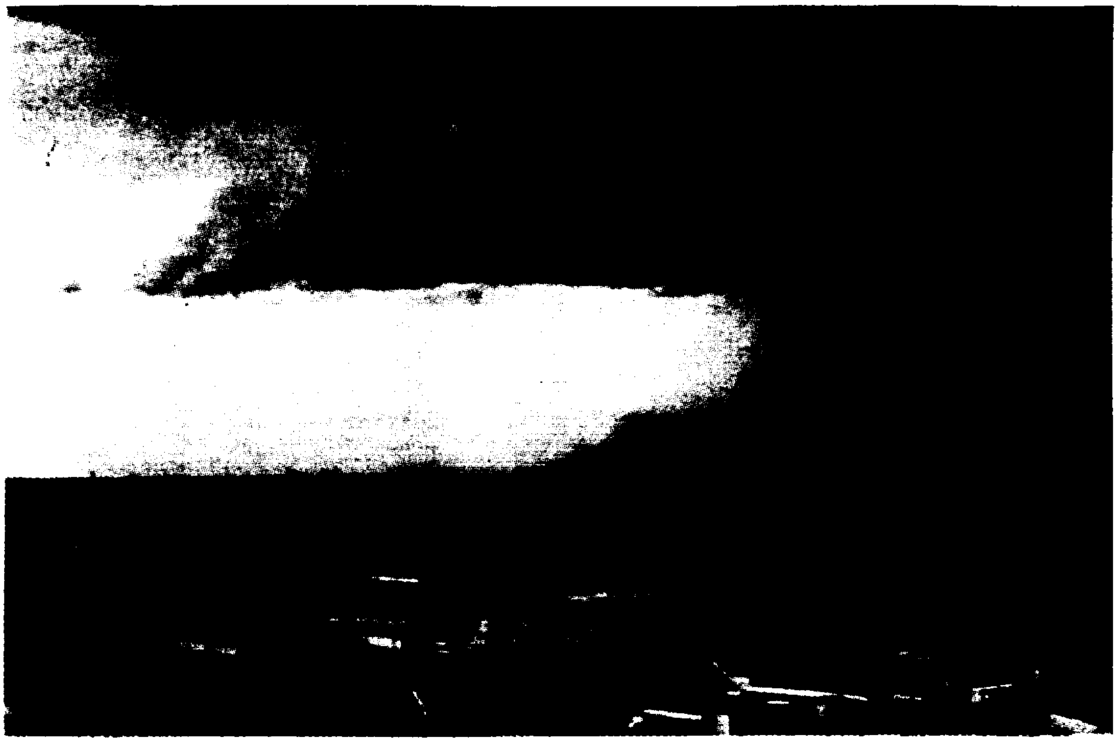
My colleagues and I at the Sperry Commercial Flight Systems Division have approached this question as a problem in optimal control. In other words, we have asked what control strategy should be adopted to maximize the chances of successfully flying through the windshear. We have discovered that the optimum strategy is in fact a simple one, which we have implemented in the Honeywell Windshear Computer. This instrument is now capable of detecting the presence of windshear and then either directing the pilot or commanding the aircraft's autopilot to follow the optimum escape path.

The Windshear Hazard

The term *windshear* refers to any situation where wind velocity varies sharply from point to point. Windshears can be caused by a number of atmospheric phenomena, such as weather frontal systems, but the most lethal form of windshear is called a microburst. Events of this kind, which are always associated with thunderstorms, were discovered by T. Theodore Fujita of the University of Chicago. A microburst is a column of rapidly descending air, which fans out radially as it nears the ground, like the stream from a faucet splashing into a basin *(see upper illustration on page 112)*. A typical microburst is less than three miles across and lasts 15 minutes or less.

An aircraft attempting to traverse a microburst during takeoff or landing usually encounters a headwind first, followed by a downdraft and finally a tailwind. Contrary to what one might guess, it is not the downdraft that represents the greatest hazard to aviation but rather the tailwind. When the horizontal component of wind velocity shifts from a headwind to a strong tailwind, the effect is to reduce the craft's air speed; that in turn reduces lift. Loss of lift, of course, causes the aircraft to descend.

The corrective for the loss of lift is to increase the aircraft's angle of attack, or in other words to pitch the nose upward relative to the airstream. If the angle of attack exceeds a limiting value, however, the aircraft will enter an aerodynamic stall. The limiting value is called the "stick-shaker" angle, because a mechanical vibrator attached to the pilot's control column is activated at this point to warn of an impending stall. On a typical commercial jet transport the difference between normal angle of attack and stick-shaker angle is only about six degrees. Thus the range of control available for counteracting the effects of windshear is quite limited.



THUNDERSTORM CELL spawns a microburst—a descending column of cold air—near Stapleton International Airport in Denver. The microburst is the dark area in the right half of the photograph. As it flares out in a radial pattern on reaching the ground, it creates severe windshear, or in other words a strong gradient in wind velocity. Windshear conditions encountered during takeoff and landing are the most serious weather hazards to modern commercial aviation. Much effort has been put into detecting and avoiding windshear; the Commercial Flight Systems Division has developed an instrument that implements the optimum strategy for escaping a windshear. The photograph was made July 8, 1984, by T. Theodore Fujita of the University of Chicago and Wendy Schreiber of the National Center for Atmospheric Research.

Apart from the limited range of control, the natural dynamics of an aircraft create further difficulties in coping with windshear. Speed and altitude in an aircraft are closely coupled: If a windshear causes a loss of air speed, the aircraft naturally tends to pitch down (that is, decrease its angle of attack) and regain the speed at the sacrifice of some altitude. A loss of altitude, on the other hand, has the opposite effect: the aircraft tends to gain air speed as it descends, which increases lift and causes the aircraft to climb. The result of this continual exchange of potential and kinetic energy is a roller-coaster motion called a phugoid oscillation. It is an oscillation with a long period (typically 30 seconds), and in most aircraft it is poorly damped or even divergent *(see lower illustration on page 113).*

In normal flight the phugoid oscillation is suppressed by continually adjusting the angle of attack in order to maintain a zero rate of change in altitude or air speed. The adjustments can be made by the pilot through the control column or by an automatic flight-control system. In a windshear encounter, however, there may not be sufficient control latitude to arrest the phugoid motion, since the angle of attack may be near the stick-shaker limit. If the phugoid oscillation is not controlled, the altitude excursions can grow large enough to cause ground impact.

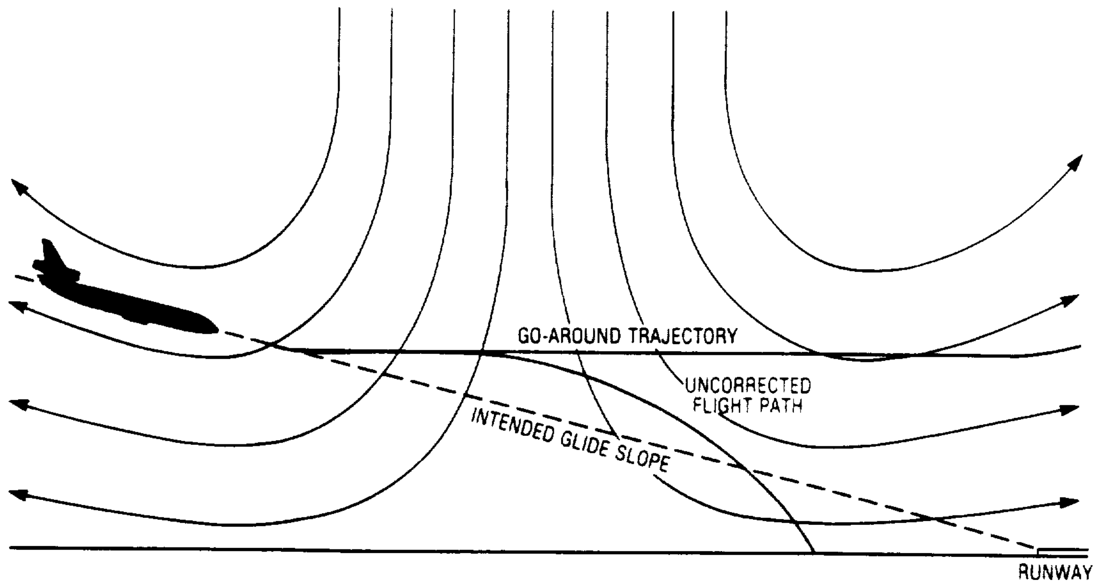
Given these aerodynamic constraints, the object of a windshear guidance law is to make optimum use of the available range of control and thereby to maximize the probability of survival. To achieve this goal, we employed the methods of optimal control theory.

The Best Flight Path

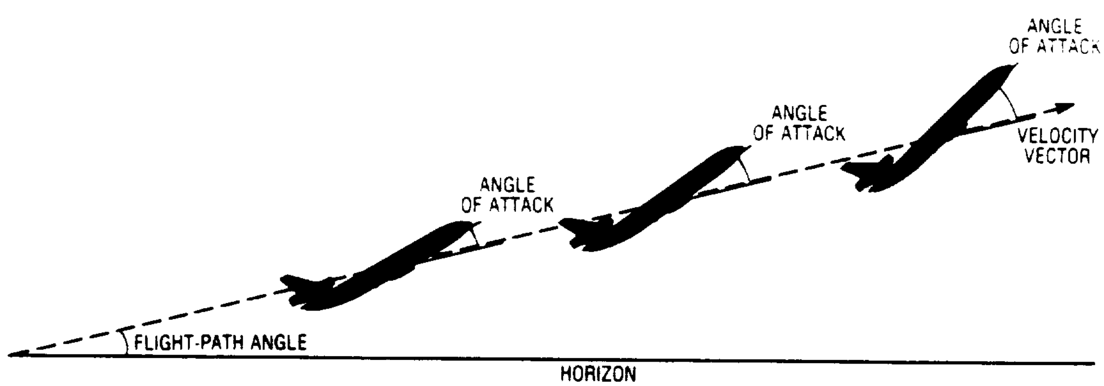
The first and most fundamental rule for negotiating windshear conditions during the approach to landing is that no attempt is made to land the aircraft. Instead, the pilot initiates a go-around maneuver, increasing engine thrust to the maximum and adjusting angle of attack so as to establish a nonnegative rate of climb.

To determine the optimal guidance law for executing such a go-around maneuver, we simulated an aircraft's flight in windshear conditions. The simulation program, which ran on a personal computer, was adapted from one written by J. René Barrios. The original version had been used in the development of the Honeywell Performance Management System to determine the Mach number that yields minimum fuel consumption [see "Optimizing Aircraft Performance," by Sam Lidén, on page 101]. In our studies of the windshear problem we modified the program to make the control variable angle of attack rather than Mach number. At each instant during a simulation the state of the aircraft was defined by its altitude, air speed and distance travelled and by the wind velocity.

An interesting aspect of the problem was choosing criteria by which to



MICROBURST is a small-scale but intense meteorological phenomenon, seen only in conjunction with thunderstorms. The downdraft in a microburst can have a velocity of 40 knots or more, and the horizontal winds near the surface are even more violent, sometimes exceeding 200 knots. The high wind velocities, however, are not the principal hazard to aviation; the main threat comes instead from the rapid change in wind speed and direction experienced by an aircraft traversing the microburst at low altitude. In the diagram an aircraft encounters severe windshear on final approach to landing. Initially, a headwind augments the craft's air speed and lift, so that it rises above the intended glide slope. But a steadily increasing tailwind then reduces both air speed and lift, so that the aircraft sinks and strikes the ground short of the runway. The recommended action in these circumstances is not to attempt a landing but rather to initiate a go-around maneuver. Optimal control theory has identified the best strategy for executing a go-around in windshear.

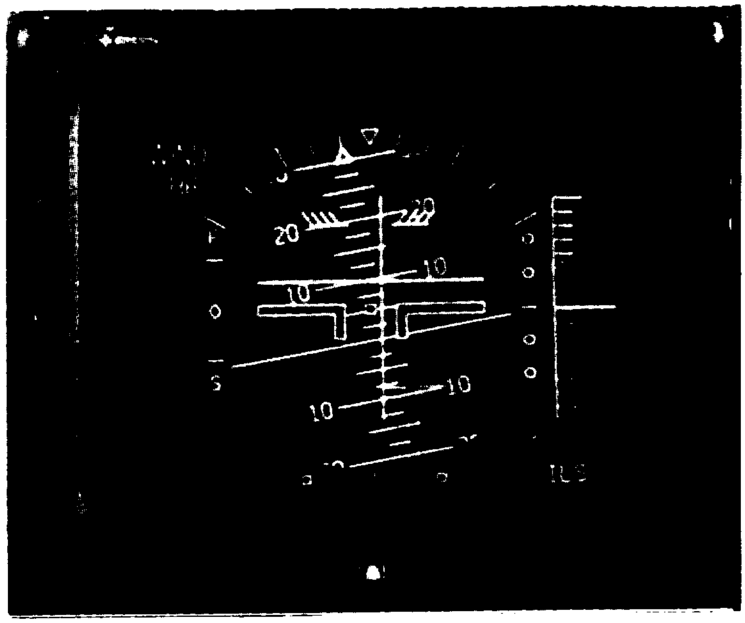


ANGLE OF ATTACK is the primary means of controlling an airplane's path during a windshear encounter. The angle of attack is the angle formed between an aircraft's axis and its direction of motion relative to the air mass. Increasing the angle of attack generates greater lift, but there is a limiting angle that cannot be exceeded or the aircraft will enter an aerodynamic stall. The limiting angle of attack is called the stick-shaker angle because a vibrator attached to the control yoke is activated at this point to warn the pilot of an impending stall. The difference between normal angle of attack and the stick-shaker angle is only about six degrees, which is all the latitude available for controlling flight in a windshear episode. The aim of the optimal control law is to make the most effective use of this limited range.

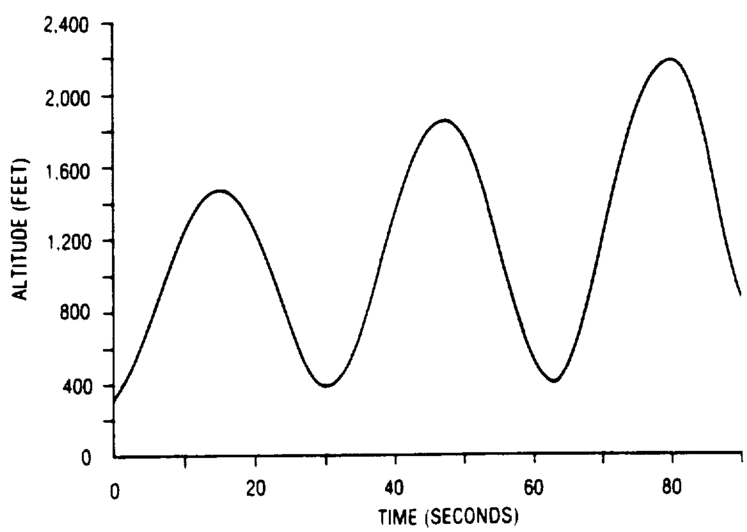
judge candidate control laws. In the early stages of the investigation we considered a number of possible criteria. For example, one approach takes as an ideal the flight path that would be followed during a go-around in the absence of windshear; then the optimal control law is the one that minimizes deviations from this path. Other criteria favor control laws that minimize the curvature of the flight path or the rate of change in altitude or that maximize ground clearance. We constructed grading schemes that incorporated various combinations of these factors. After a multitude of simulation runs, however, the correct criterion proved to be a simple one, although not necessarily an obvious one. To understand the motivation for this choice, it must first be observed that some windshears are so severe that an aircraft cannot traverse them no matter what control law it employs. We found that the optimal control law is the one that under such extreme conditions keeps the airplane airborne for the longest possible time.

What control law provides the maximum time aloft? The answer to this question also emerged from our simulations. It turns out that the best policy is to maintain level flight, or in other words to fly at a constant inertial altitude. There are two reasons this strategy works well. First, it maximizes the time available before the angle of attack must be increased to the stick-shaker limit in order to maintain altitude. Second, flying a constant altitude tends to damp the phugoid oscillation.

Other candidate control laws invariably call for climbing in the presence of windshear. The weakness of this strategy is that it diminishes air speed, and, as noted above, at a lower air speed angle of attack must be increased to maintain lift; thus the angle-of-attack margin available for control is quickly dissipated. Once the stick-shaker angle is reached, the aircraft is essentially uncontrollable. If the angle of attack is increased further, the aircraft will stall; conversely, if the angle of attack is decreased, the aircraft will rapidly descend. Even



COCKPIT FLIGHT DIRECTOR advises the pilot when windshear conditions have been detected and provides guidance on the best strategy for recovery. The warning "WIND SHR" in the upper left corner of the display flashes red to indicate the presence of a serious windshear. The large crosshair in the center of the display consists of vertical and horizontal command bars, which instruct the pilot on what action to take. At the left edge of the display is a scale bounded by the letters "F" (for "fast") and "S" (for "slow"). During takeoff and landing this scale indicates the aircraft's angle of attack, with the "S" mark representing the stick-shaker angle; thus the instrument shows the pilot how much control is available before the aircraft reaches the stick-shaker limit.



PHUGOID OSCILLATION complicates the task of flight control in windshear. The oscillation results from a natural coupling between air speed and altitude: If some perturbation causes an aircraft to lose speed, it will also lose lift and so will begin to sink. The descent, however, increases air speed and lift, inducing a climb. In most aircraft the phugoid oscillation has a long period (30 seconds or more) and is poorly damped or even divergent. In normal flight it is easily controlled by manual or automatic adjustments to the angle of attack, but in a windshear the angle of attack may have to be held at the stick-shaker limit. In that circumstance the fluctuations in altitude can grow until the aircraft strikes the ground. The graph records a simulation of an uncontrolled oscillation.

holding the controls perfectly steady at the stick-shaker angle is not an attractive option. With no range of control motion to damp the phugoid oscillation, the aircraft begins a series of altitude excursions that inevitably result in ground impact.

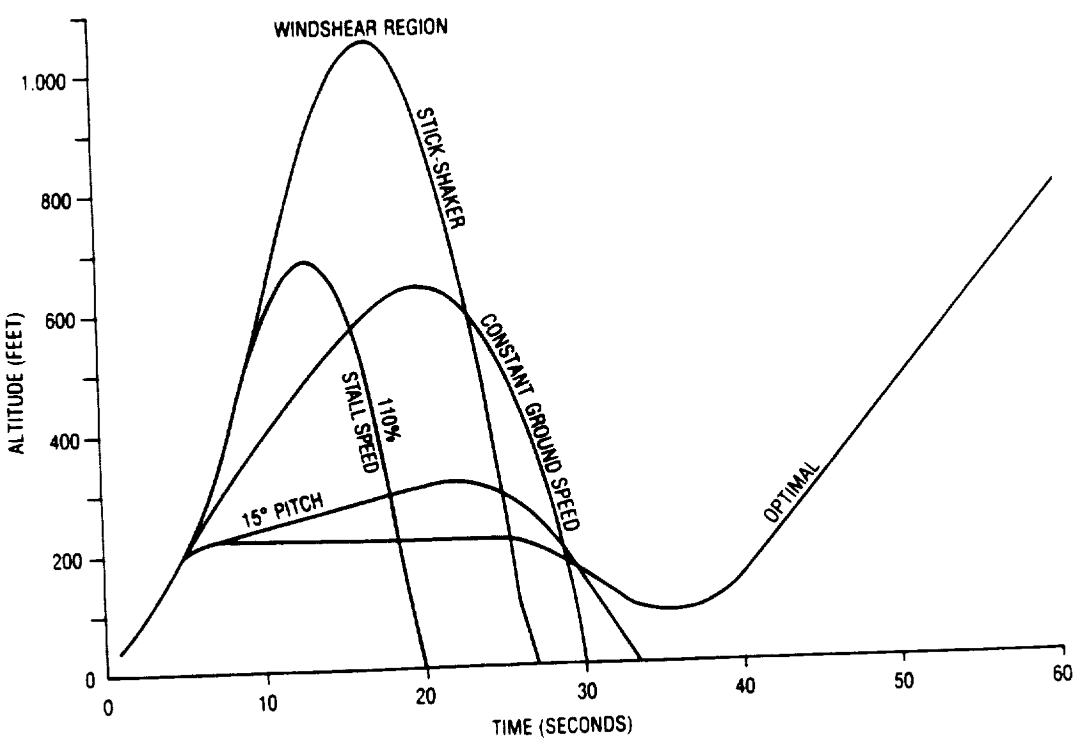
The clear imperative emerging from our simulations was to maximize the time available before a pilot must resort to stick-shaker angle of attack in order to keep the airplane aloft. Actually, the theoretical maximum time is attained not in level flight but when the aircraft is allowed to descend slightly. Incorporating this strategy into a general control law does not seem prudent, however. After all, a windshear might be encountered at very low altitude, or features of the surrounding terrain, such as hills and tall buildings, might make descent hazardous.

Other investigators have also explored the question of optimal guidance in windshear. For example, Angelo Miele of Rice University has applied numerical methods to the problem. Even though the methodology differs in the various studies, the conclusion is the same: the optimum practical guidance strategy for a pilot caught in windshear is maintaining level flight.

Simulation Results

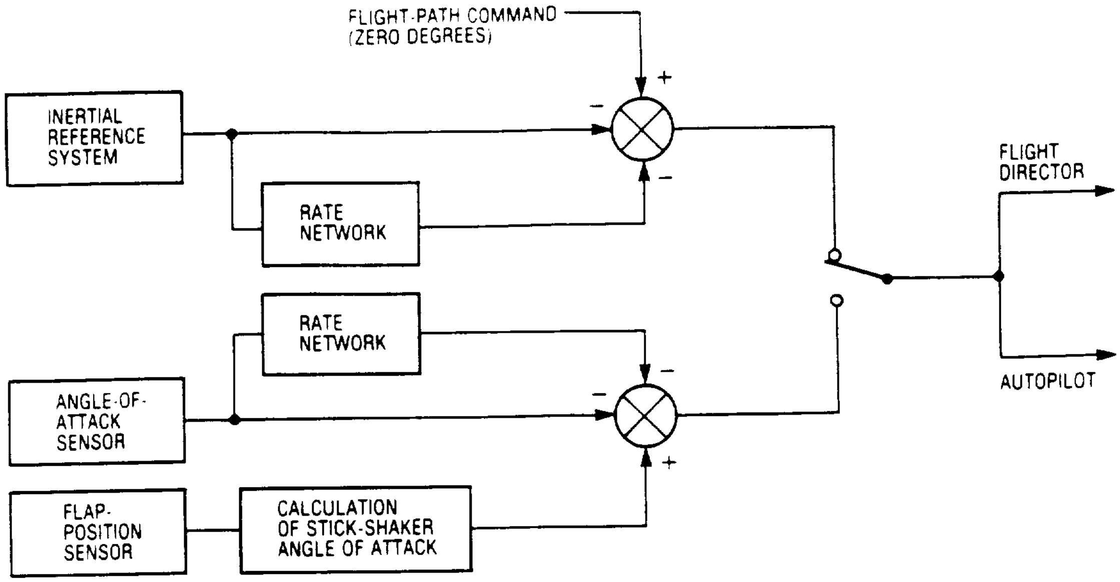
The outcome of one series of simulations is shown in the illustration below. Here a typical commercial jet aircraft encounters a windshear shortly after takeoff, when it is at a height of about 200 feet. The tailwind develops about five seconds into the simulation run and increases at a rate of five knots per second; it ends after 23 seconds, when the total change in wind velocity is 115 knots. This represents a severe windshear episode. In the crash of Flight 191, for comparison, the horizontal component of the wind shifted over a period of about 30 seconds from a 23-knot headwind to a 49-knot tailwind.

The simulation examines the effects of five control laws, each of which has been advocated at one time or another during the past decade as an appropriate response to windshear. The first strategy is to regulate angle of attack so as to maintain 110 percent of stall speed. The result is a steep climb, which cannot be sustained; after just 20 seconds the aircraft plunges back to earth. Holding the controls at stick-shaker angle of attack leads to an even more dramatic rise—the peak altitude is greater than 1,000 feet—and an



CANDIDATE CONTROL LAWS were tested by simulation on a personal computer. The simulated weather conditions included a tailwind beginning about five seconds into the run and increasing at a rate of five knots per second, then ending 23 seconds later. Four of the control laws tested had been recommended at one time or another as strategies for escaping windshear. Flying at 110 percent of stall speed, holding stick-shaker angle of attack or maintaining a constant ground speed all produce a dramatic climb followed by a catastrophic plunge. When the aircraft maintains a 15-degree pitch angle, it remains aloft slightly longer. The optimal strategy of flying a constant inertial altitude—or in other words a zero-degree flight-path angle—is the only one that allows the aircraft to survive.

Scientific Honeyweller



OPTIMAL CONTROL LAW has been implemented in the Honeywell Windshear Computer. When windshear is detected, the system continually regulates angle of attack in order to maintain level flight (a zero-degree flight-path angle) without exceeding the stick-shaker angle. The zero-degree commanded flight-path angle is compared with the actual angle, as measured by an inertial reference system; the rate of change in the angle is also included in the calculation to help damp fluctuations. The difference between commanded and actual flight-path angle is an error signal that goes to a flight-director indicator on the pilot's instrument panel or to an autopilot that directly controls angle of attack. If the angle of attack reaches the stick-shaker limit, an auxiliary control network takes over, maintaining this maximum useful angle of attack (and thus maximum lift) without allowing the aircraft to stall.

equally catastrophic descent. Maintaining zero longitudinal acceleration, or in other words constant ground speed, keeps the craft airborne a few seconds longer.

The most effective of the nonoptimal strategies tested here is flying at a constant pitch angle of 15 degrees. This is the escape plan currently recommended by the Federal Aviation Administration for aircraft not equipped with windshear detection and guidance systems. If the simulated windshear had ended a few seconds sooner, the aircraft following the 15-degree strategy would have successfully crossed the danger zone.

The optimal strategy of maintaining constant altitude is the only plan that allows the aircraft to survive the simulated windshear episode. Even in this case it is not possible to stay aloft indefinitely. At about 25 seconds into the simulation run, the angle of attack has reached the stick-shaker limit and cannot be increased further; hence the aircraft begins to sink. If the windshear had continued a few seconds more, the aircraft would have crashed.

Implementation

The optimal control law derived from our simulations and analyses has been implemented in the Honeywell Windshear Computer, an instrument developed in the early 1980's by the Sperry Aerospace & Marine Group and certified by the FAA in 1985. In its original form the windshear computer merely detected the presence of windshear, alerted the flight crew and provided an angle-of-attack reference the pilot could use in flying out of the danger zone. With the optimal control laws the computer can now offer more specific guidance to the pilot or can take over control of the aircraft, guiding it on the optimum flight path.

The computer detects windshear conditions by comparing signals from a number of inertial and air-data sensors. For example, one warning sign is a change in airspeed (as measured by a pitot probe in the airstream) that is not matched by a change in inertial velocity (as determined by integrating the output of an accelerometer). Going beyond mere detection to active control does not require any additional inputs.

In its simplest form the control mechanism requires only one input: a signal representing the flight-path angle, or in other words the aircraft's rate of climb or descent. If the aircraft is equipped with an inertial-reference system, the flight-path angle can be measured directly by a system of gyroscopes and accelerometers. Otherwise, the angle of the craft's trajectory with respect to the air mass is calculated from air-data sensors and is then corrected for the effects of vertical and longitudinal winds. Regardless of the source of the information, it serves the same function. When the computer detects a windshear condition, the controller commands an inertial flight-path angle of zero degrees and compares this value with the actual angle. The difference is an error signal that indicates deviation from the optimum flight-path angle. If the aircraft is under manual control, the error signal is supplied to the flight director, an instrument that guides the pilot to the correct control actions. Under autopilot control, the error signal is translated directly into movements of the elevator or other aerodynamic control surfaces.

The actual windshear control system is somewhat more complicated than this account might suggest *(see illustration on page 115)*. In addition to the flight-path angle, the computer also considers the rate of change in this angle; including a rate term in the feedback loop helps to damp out rapid fluctuations and makes the aircraft more "flyable."

Another part of the control system takes over when level flight can no longer be sustained. As a rule, the controller will call for steadily increasing angle of attack during a windshear episode in order to avoid loss of altitude. This trend cannot be allowed to continue once the stick-shaker angle is reached, or the aircraft will stall. A separate control loop is therefore included to monitor angle of attack. The stick-shaker angle, which depends on the position of the wing flaps, is continuously calculated and compared with the actual angle of attack. Whenever the actual angle exceeds the upper limit, the constant-altitude controller is switched off, and the airplane is held at stick-shaker angle of attack. Rate of change in the angle of attack is also included in the calculation as a damping and anticipatory factor: If the angle of attack is increasing rapidly, the rate term will prevent overshooting and a possible stall.

The control section of the windshear computer includes several further refinements. For example, filters and variable gain schedules improve flyability. The implementation of the control laws is now complete, and the system is operational in the Honeywell Windshear Computer. Indeed, it has passed the ultimate test: it has provided guidance to successfully escape a real microburst encounter.

Acknowledgement

The author wishes to acknowledge the considerable contributions of J. Rene Barrios to the investigation of the optimal control law.

Bibliography

A. Miele, T. Wang and W. W. Melvin, "Optimal Take-Off Trajectories in the Presence of Windshear," *Journal of Optimization Theory and Applications*, Vol. 49, No. 1, April 1986, pp. 1-45.

Arthur Bryson and Yu-chi Ho, *Applied Optimal Control*, Washington, D.C.: Hemisphere Publishing, 1975.

T. Theodore Fujita, *DFW Microburst on August 2, 1985*, Chicago, Ill.: The University of Chicago, 1987.

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Temperature Lapse Rate as an Adjunct to Wind Shear Detection Questions and Answers

Q: CARL YOUNG (Eastern Airlines) - How do you tie lapse rate technology with your zero gamma reactive system?

A: TERRY ZWEIFIL (Honeywell Sperry) - A quick word on what zero gamma means. That is really what we do when the shear is detected. We fly what is called an optimal flight path which we've shown through various studies, us and others, that flying a zero gamma relative to the earth gives you the optimal flight path. That is, it will keep you in the air longer than any other strategy. The lapse rate itself has really nothing to do with the guidance part of it other than sensitizing the system so that it gives you the wind shear quicker. The way the system works, when it detects a wind shear, says "wind shear, wind shear, wind shear", if you're in take off you automatically get the optimal guidance. If you are in approach, you do a missed approach technique, either slamming the throttle full forward or hitting the go around switches, either one will give you the automatic guidance. But the lapse rate itself really doesn't have anything to do at that.

Q: CARL YOUNG (Eastern Airlines) - If we're going to use an accelerometer based system to trigger a wind shear reactive system, how would you weight that versus lapse rate technology? Are you tending more to have lapse rate technology be predictive?

A: TERRY ZWEIFIL (Honeywell Sperry) - No, the lapse rate right now is not intelligent enough to handle the wind shear detection case. The only thing we can use it as is the probablistic measure of wind shear, really microburst threats. It, in itself, will never replace the current reactive systems that you see today.

Q: PAUL ROBINSON (Lockheed) - From your presentation I got the impression that it was of the greatest importance to detect dangerous wind shears from microburst only. What precautions are taken to insure that dangerous shear from other sources, not microburst, are not overlooked by the dependents on lapse rate?

A: TERRY ZWEIFIL (Honeywell Sperry) - We never turn the system off with lapse rate measurements. It's simply an adjunct to what we're doing now. We'll change the thresholds slightly, not greatly. Without going into a great, elaborate thing to show you how actually we detect shears it's kind of hard to explain. The lapse rate is primarily used to sensitize for microbursts and the reason is that most of the wind shear accidents we have seen are in fact microburst caused. But we will still detect frontal shears, even terrain induced shears could set the system off.

Q: BOB OTTO (Lockheed) - What is the reduction in alert time when first generation reactive systems are coupled with temperature lapse rate measurement? That is, if the reactive system affords *t* seconds warning, then what increase to *t* does lapse rate measurements afford?

A: TERRY ZWEIFIL (Honeywell Sperry) - That's going to depend a lot, of course, on what particular shear model you use and what the lapse rate looks like. Let me give you an example, from Dallas you will get about 3 - 4 seconds quicker warning that you would have from a purely reactive system alone. It's of that magnitude. I think Don Bateman was saying that they also use lapse rate. I don't think it's quite the same mechanization but I think he had numbers very much along that line.

Q: FRED PROCTOR (MESO) - Low level stable layers can sometimes be present prior and during microburst events. Could your system function properly in such cases?

A: TERRY ZWEIFIL (Honeywell Sperry) - It depends. If you look at, as an example, the 11 July sounding, and you can see that in fact there was a stable layer. It did drop back below the unstable measurement of -0.003. In this case the system, by having read the previous lapse rate values up in here, has already armed. Then it just sits there and waits to see if the temperature ever swings out the other way, implying that you've flown into the cold down flow. So, even though this phenomenon occurs, it does not disarm the system. It says I saw it once, therefore I'm going to maintain this. Actually, that's not quite true, if we see it long enough, over about 1000 feet that it has dropped below -0.0025, then it will reset and say there really wasn't a serious problem here. Surely I could conceive of some situation when in fact we wouldn't do exactly what we wanted to do. But in the cases that we have looked at, even with these stable layers, it still performs it's intended function.

Q: WAYNE SAND (NCAR) - Can you tell us more about your chip to measure dew point? How accurate is it? How much does it cost? How does it interface with existing air data computers?

A: TERRY ZWEIFIL (Honeywell Sperry) - How accurate is it -- based on our people up in SRC, I understand that it is something of the order of + or - 5% in measuring relative humidity. Basically the reason we, Honeywell, designed this was that we built a lot of systems to monitor computer rooms and keep them at certain relative humidities and certain temperatures. That's what the chip is built for. It's not in production so I really can't tell you how much it costs. Hopefully, not much. Does it interface with existing air data computers -- not yet, though we have looked into it and I am a little concerned about some of the engineering that goes into that. We certainly have the room to put it inside our computer. Our wind shear computer, by the way, has a complete air data computer of its very own, we don't use anybody else's. How we do that -- haven't got that far. It doesn't seem to me to be an insurmountable problem. It would be a beautiful thing to have. That's one part we're missing.

Q: TON NIEUWPOORT (Fokker Aircraft) - Using a Kalman filter means that the noise characteristics have to be known. How are these noise characteristics determined?

A: TERRY ZWEIFIL (Honeywell Sperry) - He's exactly right and that puzzled me for some time, still does for that matter. Basically the way I did it, a brief explanation. To compute the time constant for a Kalman filter, basically you have to know the variation of the thing that you are measuring and also your measuring equipment. In this case we're really not so much concerned about what is the variance of the temperature probe, we assume that is accurate enough. What we're really trying to do is separate out the lapse rate, that's the signal, from the noise, which is the garbage you get from little eddy's going around in the atmosphere. Basically what I did was back into it almost like a circular reasoning type of thing. I figured out what the number had to be to give the quickest results, to get the filter as fast acting as possible, yet still giving us enough filtering so we don't just get total noise. I could give you the number but it wouldn't I don't think mean a heck of a lot.

Q: PETER SINCLAIR (Colorado State University) - How does your temperature lapse rate sensing device determine what part of the measured temperature change is due to the horizontal and vertical temperature components?

A: TERRY ZWEIFIL (Honeywell Sperry) - The answer to that one is real simple. It doesn't. It assumes that the temperature signature that it measures is simply an indication of a microburst. It does not care whether it's from a vertical or a horizontal sense.

ROLAND BOWLES (NASA Langley) - Isn't that a fairly significant shortfall? When we do soundings we release balloons to get temperature altitude profiles. The idea is that if it goes miles down range it's beginning to get cluttered up. Here an airplane on approach can travel several miles with relatively small altitude change. So are we really getting a lapse rate measurement off that airplane?

TERRY ZWEIFIL (Honeywell Sperry) - Yes, you are. You're not getting a perfectly vertical measurement of lapse rate but then when you really look at the data we have from all these accidents, none of those were done right there at the site.

ROLAND BOWLES (NASA Langley) - Understood, but maybe a significant discriminator is the along-track rate of change of temperature, a thermal plume that's sitting out there and we encroach upon it and there's rapid variation along-track. Maybe that's the give away.

TERRY ZWEIFIL (Honeywell Sperry) - That's Conceivable. Typically on approach you've got about a 3 degree gamma so most of your component is along-track. We do make that tacit assumption that this is not a real small scale type of event. We assume that the atmosphere in fact looks like this uniformly within the region of interest, whatever that might be and, you're right, that is a tacit assumption that we do make.

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16. Abstract

The Third Combined Manufacturers' and Technologists' Conference was hosted jointly by NASA Langley Research Center (LaRC) and the Federal Aviation Administration (FAA) in Hampton, Virginia, on October 16-18, 1990. The meeting was co-chaired by Dr. Roland L. Bowles of LaRC and Herbert Schlickenmaier of the FAA. The purpose of the meeting was to transfer significant ongoing results of the NASA/FAA joint Airborne Wind Shear Program to the technical industry and to pose problems of current concern to the combined group. It also provided a forum for manufacturers to review forward-look technology concepts and for technologists to gain an understanding of the problems encountered by the manufacturers during the development of airborne equipment and the FAA certification requirements. The present document has been compiled to record the essence of the technology updates and discussions which followed each.

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