19930010407

Session I. NASA Flight Tests

N93-19596

Flight Test of an Infrared Wind Shear Detector

Dr. Burnell McKissick, NASA Langley Research Center

FLIGHT TEST OF AN INFRARED WINDSHEAR DETECTOR

by

BURNELL T. McKISSICK
NASA, Langley Research Center
Hampton, VA 23665

Fourth Combined Manufacturers' and Technologists' Airborne Wind Shear Review Meeting
Fort Magruder Inn
Williamsburg, Virginia

COMMENTS ON "TOPICS DISCUSSED" SLIDE

The "TOPICS DISCUSSED" slide presents an outline of the presentation. The 5 microburst core penetrations are presented because they represent the only penetrations through the core of a microburst during the Orlando and Denver deployments and therefore the greatest opportunity of detecting a hazardous wind shear.

TOPICS DISCUSSED

- Introduction
- 5 Microburst Core Penetrations
- AWAS III Overall Performance
- Issues of Concern

COMMENTS ON "BACKGROUND" SLIDE

The central problem that is addressed in infrared wind shear detection is the relationship between air temperature change and wind shear. Efforts to draw a link between the two physical phenomena date back to 1954 to work done by Fawbush and Miller. Sinclair, Kuhn and others measured air temperatures around storms during the late 1970's. Sinclair has continued to develop passive infrared technology to measure air temperatures and infer wind shear hazards. Modelling of microbursts by Proctor produced an empirical relationship between temperature change and maximum horizontal wind outflow speed. Finally, Adamson developed a passive infrared wind shear detector which is a part of the NASA/FAA wind shear program and the subject of this presentation.

BACKGROUND

"Can detection of ambient air temperature changes lead to the detection of hazardous wind shears"

–Fawbush and Miller(1954):
Peak Gust $=7+3.06T-0.007T^2-0.00284T^3$

–Foster(1958): $W_0=-(-gz\delta T_0/T_m)^{1/2}$

–Sinclair and others(late 1970's to present): infrared radiometer flown on NASA Learjet (1982)

–Proctor(mid 1980's to present): microburst modelling; $u_{max}=-2.5\Delta T$

–Adamson(mid 1980's to present): development of a passive infrared sensor for wind shear detection

–IR sensor is an intergal part of the NASA/FAA wind shear detection and warning research program

NASA SPONSORSHIP OF TPS INFRARED SYSTEM DEVELOPMENT

Phase I SBIR (1987)

- Determined that a passive infrared sensor is feasible for windshear detection
- Passive infrared has considerable commercial potential

Phase II SBIR(1989–1991)

- Flight test of AWAS I on NASA 515 in 1989–1990
- Development of AWAS III
- AWAS III flown on FAA sponsored UND Cessna Citation through microbursts at Orlando

Flight test of AWAS III on NASA 515 at Orlando and Denver in 1991

COMMENTS ON "MICROBURST TEMPERATURE MEASUREMENTS, GLOBAL AND LOCAL" SLIDE

AWAS III computes a delta temperature (DT) which is a measurement of a far field temperature (T_{far}) minus a near field (T_{near}): DT = T_{far} - T_{near}. T_{near} is close to the aircraft while T_{far} is nominally 4 kilometers ahead of the aircraft. If the DT measured by AWAS III is used in Proctor's relationship, for example:

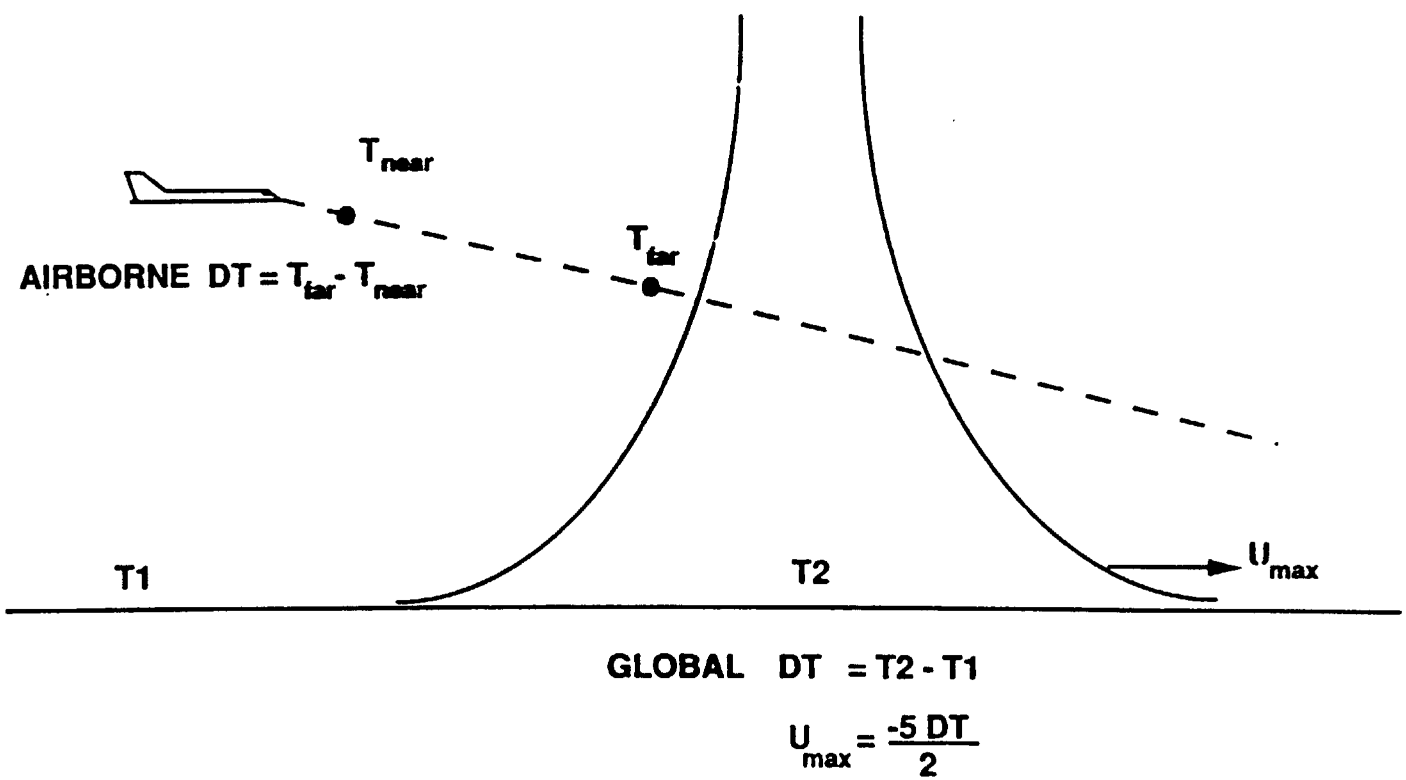
$$U_{max} = -5DT/2,$$

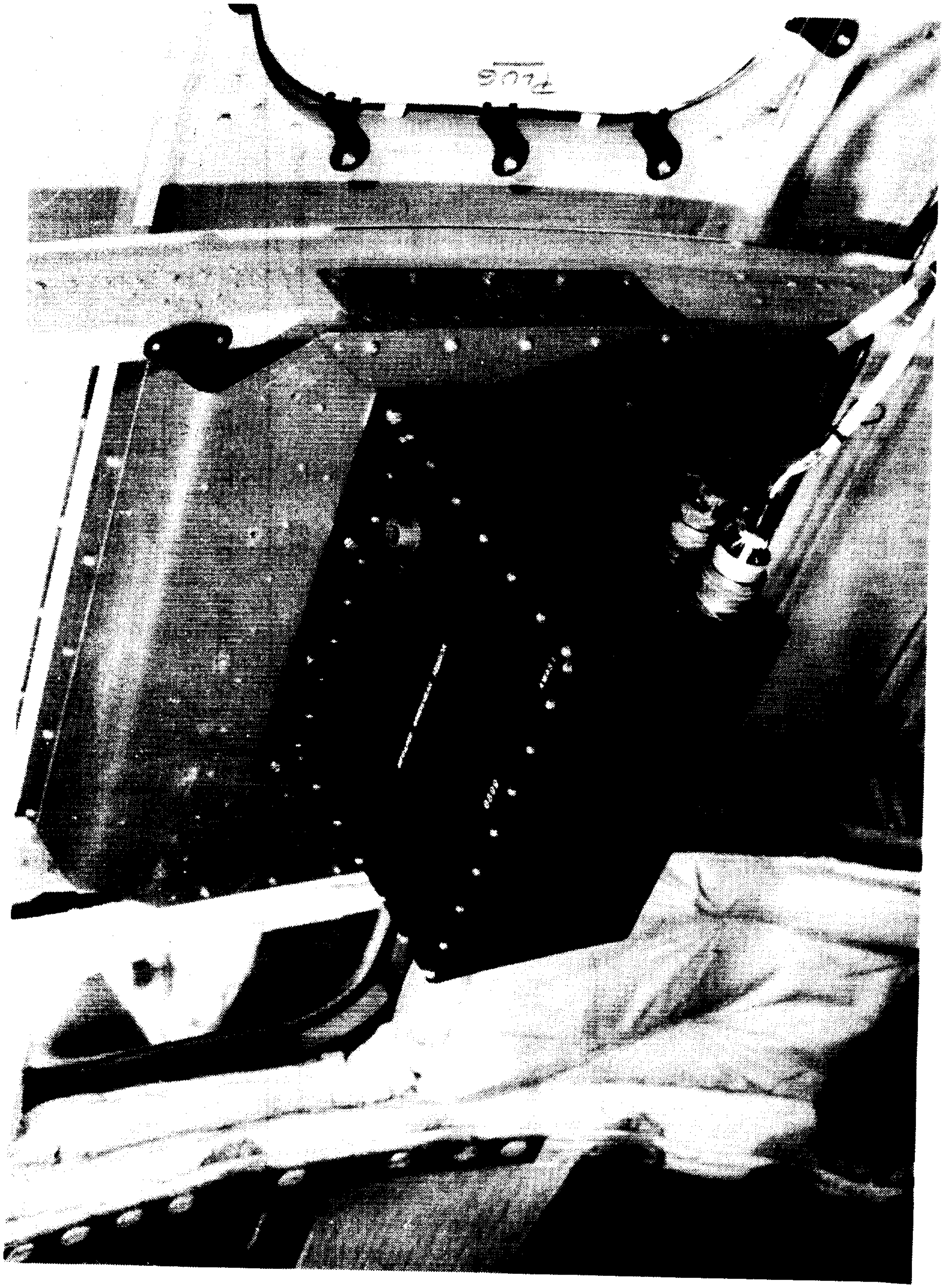
U_{max} becomes an estimate of maximum radial outflow. DT is a point (local) measurement of T_{far} - T_{near}. The ΔT in Proctor's equation is a temperature difference between minimum temperature in the core of a microburst and air temperature outside the microburst at the surface, a global difference. There is no assurance that

$$DT = \Delta T$$

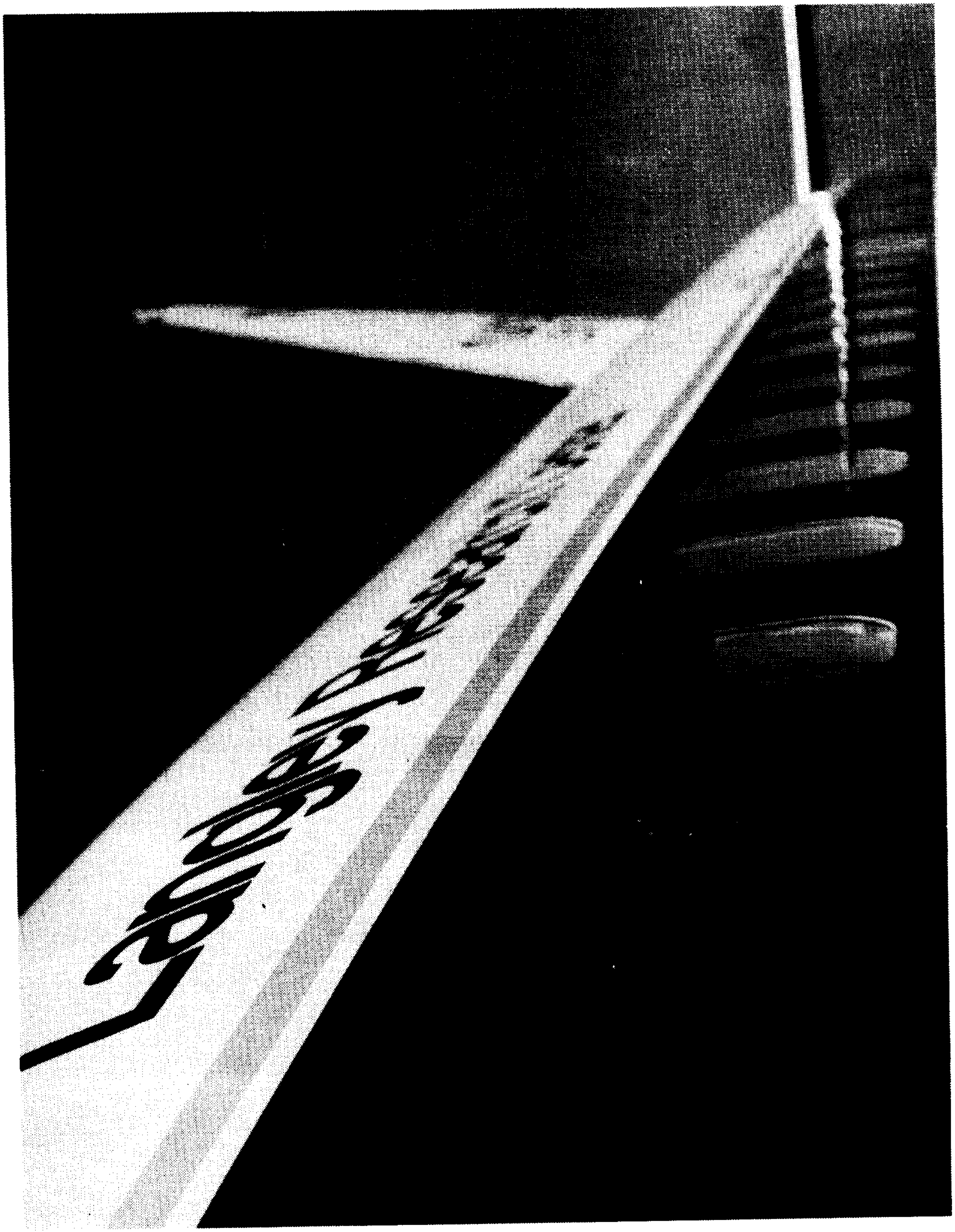
or that Proctor's relationship will hold for every microburst. The next two slides are pictures of AWAS III as it is installed on NASA Langley's Boeing 737. The first of the two slides is an exterior view of AWAS III while the second slide shows how AWAS looks from the inside of the airplane.

MICROBURST TEMPERATURE MEASUREMENTS, GLOBAL AND LOCAL





ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



COMMENTS ON "OUTPUT OF AWAS III" SLIDE

AWAS III provides more parameters than are listed on this slide. The ones listed were used during the research presented in this talk.

OUTPUT OF AWAS III

Near Field Temperature—Approx. 100 meters ahead of the aircraft

Far field temperature—Nominally 4 kilometers ahead of the aircraft

Delta Temperature—Spectral measurement of far field minus near field temperatures

Thermal Hazard Index—A local hazard index based on outside air temperature

IR Hazard Index—A predictive hazard index based on Delta Temperature

COMMENTS ON "5 MICROBURST CORE PENETRATIONS AT ORLANDO" SLIDE

Some pertinent information on the 5 core penetrations is presented on this slide. For example, the penetration labeled as event 143 occurred on June 20, 1991. The in situ F-factor had a peak value of .167 and the thermal hazard index had a peak value of .14. Both indices gave a wind shear alert. The thermal hazard index is an in situ index based on air temperature measured from aircraft sensors.

5 MICROBURST CORE PENETRATIONS AT ORLANDO

Event #	Date	Peak Values		Type of Alert	
		In situ	Thermal		
81	6/15/91	.116	.12	Insitu	
134	6/19/91	.069	.13		Thermal
142	6/20/91	.098	.13		Thermal
143	6/20/91	.167	.14	Insitu	Thermal
144	6/20/91	.077	.13		Thermal

COMMENTS ON "METHOD OF ANALYSIS" SLIDE

The basis of the analysis of the 5 events is the correlation between pairs of important variables: OAT (outside air temperature), LLWSR (thermal hazard index), LLWS2 (predictive hazard index based on infrared measurements), D2 (infrared measured T_{far} - T_{near}, basis of LLWS2), Pitch (aircraft Euler angle) and FE3 (in situ F-factor based on inertial and air data measurements). Estimating correlation coefficients and performing detailed comparisons of time series can determine if AWAS III generated predictive wind shear indices. The analysis of event 143 using these techniques will be presented in this talk.

METHOD OF ANALYSIS

Correlation of OAT, LLWSR, LLWS2, D2, Pitch and FE3

Assumption
–Temp. Fields are Constant During an Event

Goal of Analysis is to Determine if AWAS III
Generates Predictive windshear hazard indices

COMMENTS ON "RESULTS FROM 5 CORE PENETRATIONS" AND "COMPUTED LOOK DIST:FLT TST 91" SLIDES

One of the first things that is noticeable from AWAS III generated data are short computed look distances. The slide named "COMPUTED LOOK DIST:FLT TST 91" shows this data for the Orlando and Denver deployments. Estimates of the correlation coefficients between D2 and temperature give evidence that D2 is measuring t_{near}. Because of this, D2 cannot provide a predictive response to wind shear. Several possible explanations exist for the short look distances. One of the first possible explanations is that the flights were through heavy rain which resulted in shortened look distances. Flights at Denver were not through rain, but the computed look distances were small for many of those events. Another possible explanation was that the installation of AWAS III on the NASA Boeing 737 resulted in short look distances. The NASA installation is different than that of American and Northwest airlines, but no one knows how or if the NASA installation affected look distances. In order to eliminate any possible installation effect, TPS redesigned NASA's installation of AWAS III so that it is more like that of American and Northwest airlines for the 1992 deployments.

In the 5 core penetrations there were 4 thermal alerts given due to large drops in measured ambient air temperature. For example, the measured temperature drop for event 143 was approximately 10°C. A temperature drop of this magnitude would correspond to a larger wind shear than experienced in event 143. All of the microburst events of the Orlando deployment involved flying through heavy rain and aircraft temperature probes are affected by rain. Rain effects cause the measured temperature drops to be larger than the true temperature drops. Large measured drops in temperature may have been a contributing factor in the four thermal alerts in the five core penetrations.

RESULTS FROM 5 CORE PENETRATIONS

Computed Look Distance Shorter than Expected

Infrared Detectors Measure Near Field Temperature

No Predictive Response Due to the Infrared Detectors

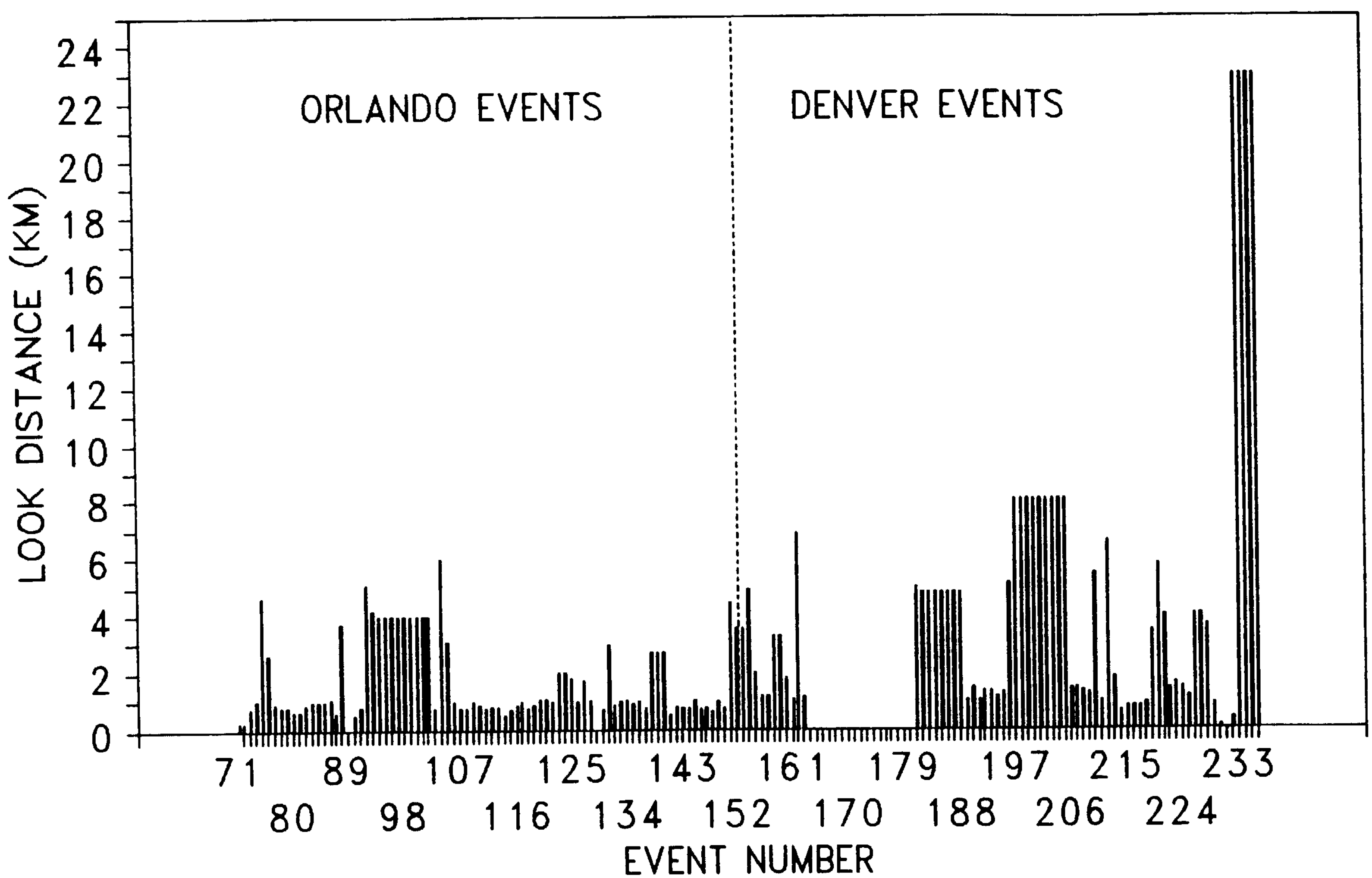
Rain affected Measurement of OAT

4 Thermal Alerts

2 Insitu Alerts

COMPUTED LOOK DIST:FLT TST 91

NOTE: ZERO INDICATES NO DATA AVAILABLE

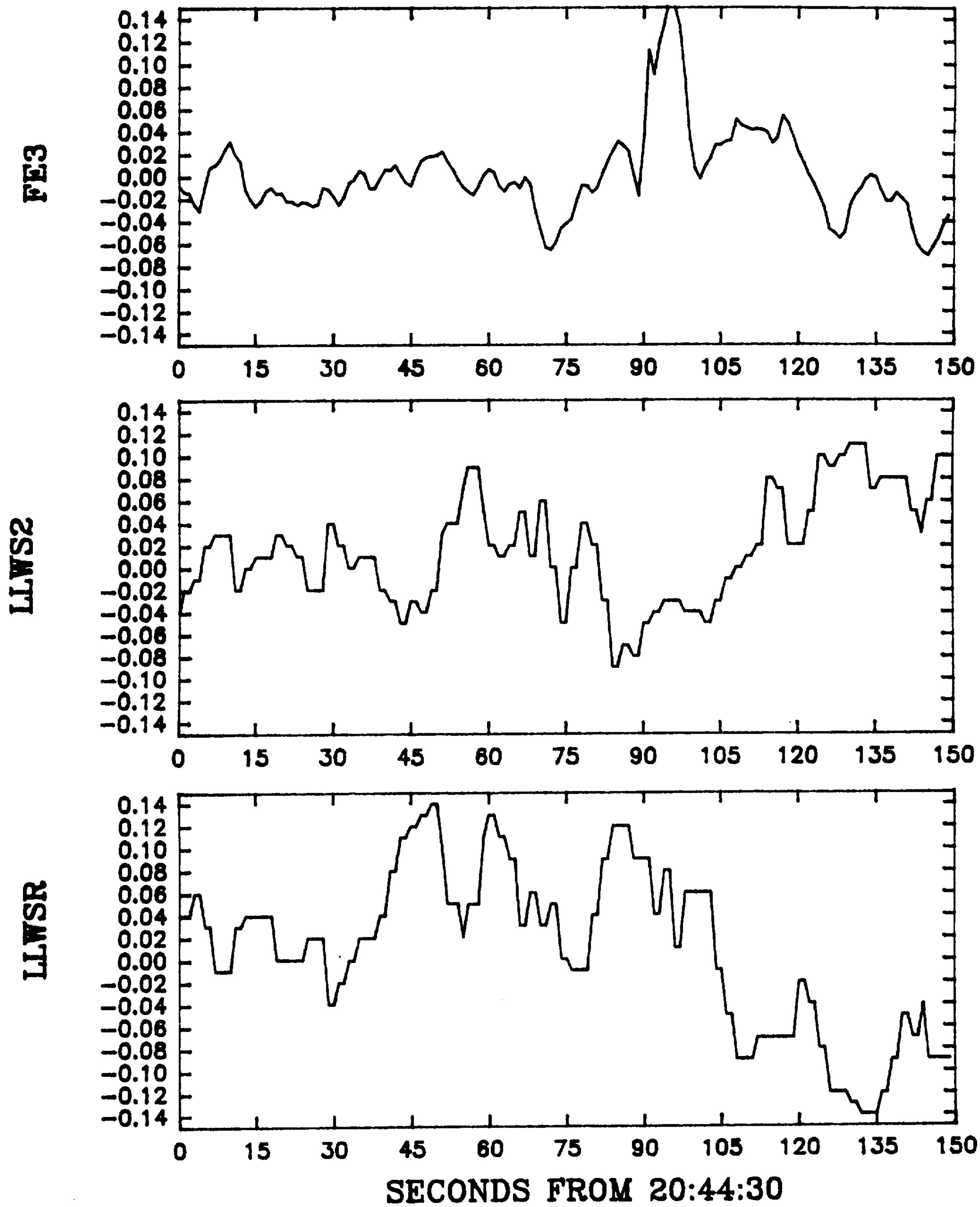


PRECEDING PAGE BLANK NOT FILMED

COMMENTS ON "FE3...FOR A MICROBURST PENETRATION" SLIDE

This is the first of a series of slides that present a detailed analysis of event 143. In this slide, time histories of the hazard indices FE3, LLWS2 and LLWSR are shown. At approximately 95 seconds after the beginning of the event FE3 alerts for a wind shear. There are peaks in LLWS2, but these peaks are not a predictive response to wind shear. This will be shown in the subsequent analysis. LLWSR generates an alert at about 50 seconds after the beginning of event 143 or about 45 seconds before the alert caused by FE3. This may be due to the rain effect on the temperature measurement since heavy rain was encountered before penetrating the microburst.

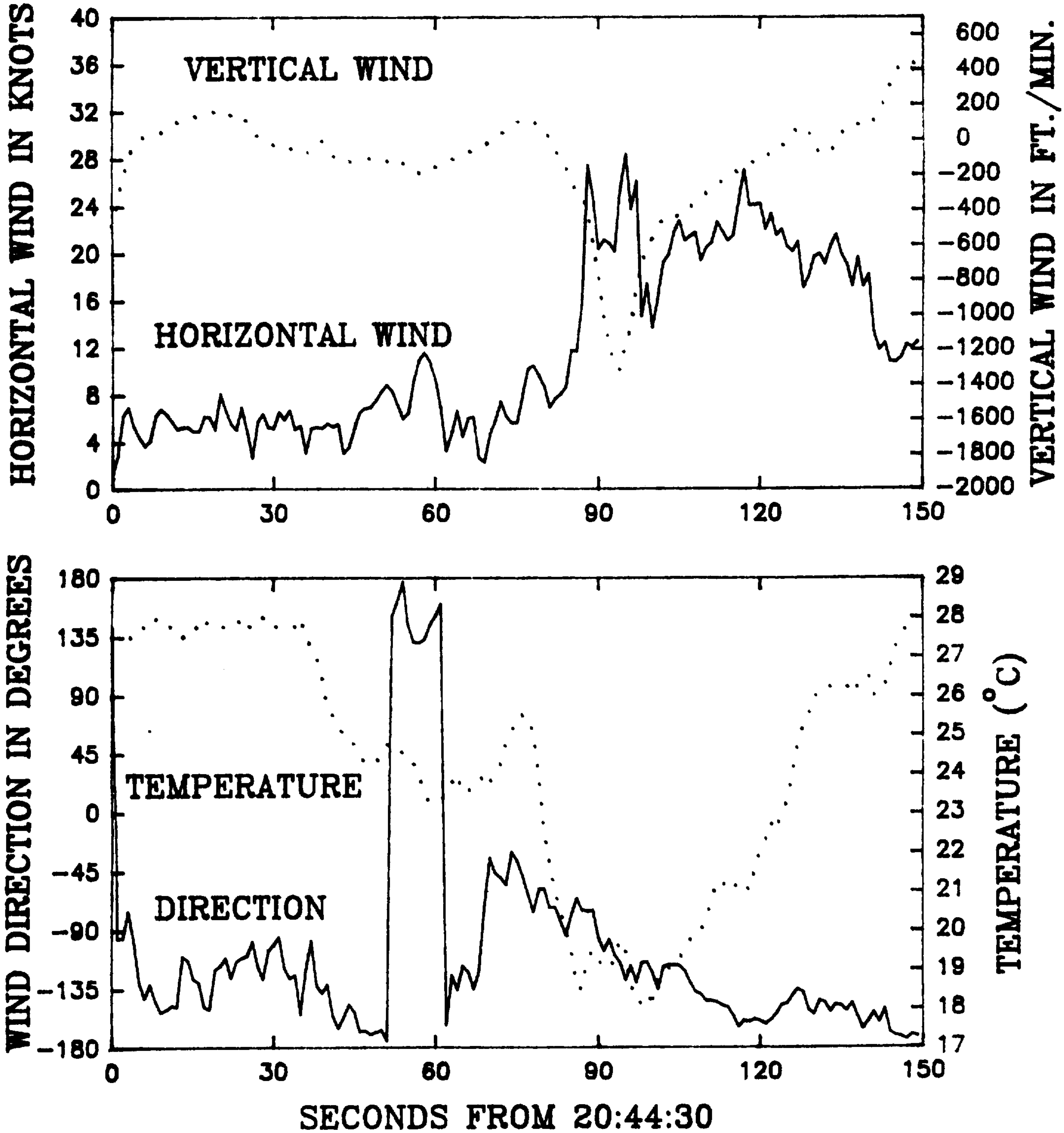
FE3 , LLWS2 ,TLLWS2 AND LLWSR for #143
FLIGHT 612 ON 6/20/91 AT ORLANDO
FOR A MICROBURST PENETRATION



COMMENTS ON "WIND SPEED..." SLIDE

At approximately 90 seconds after the start of event 143 a substantial down draft is encountered. Temperature begins to drop around 35 seconds after the start of the event. As stated before, the drop in measured temperature may be due to the rain effect on the aircraft temperature probe.

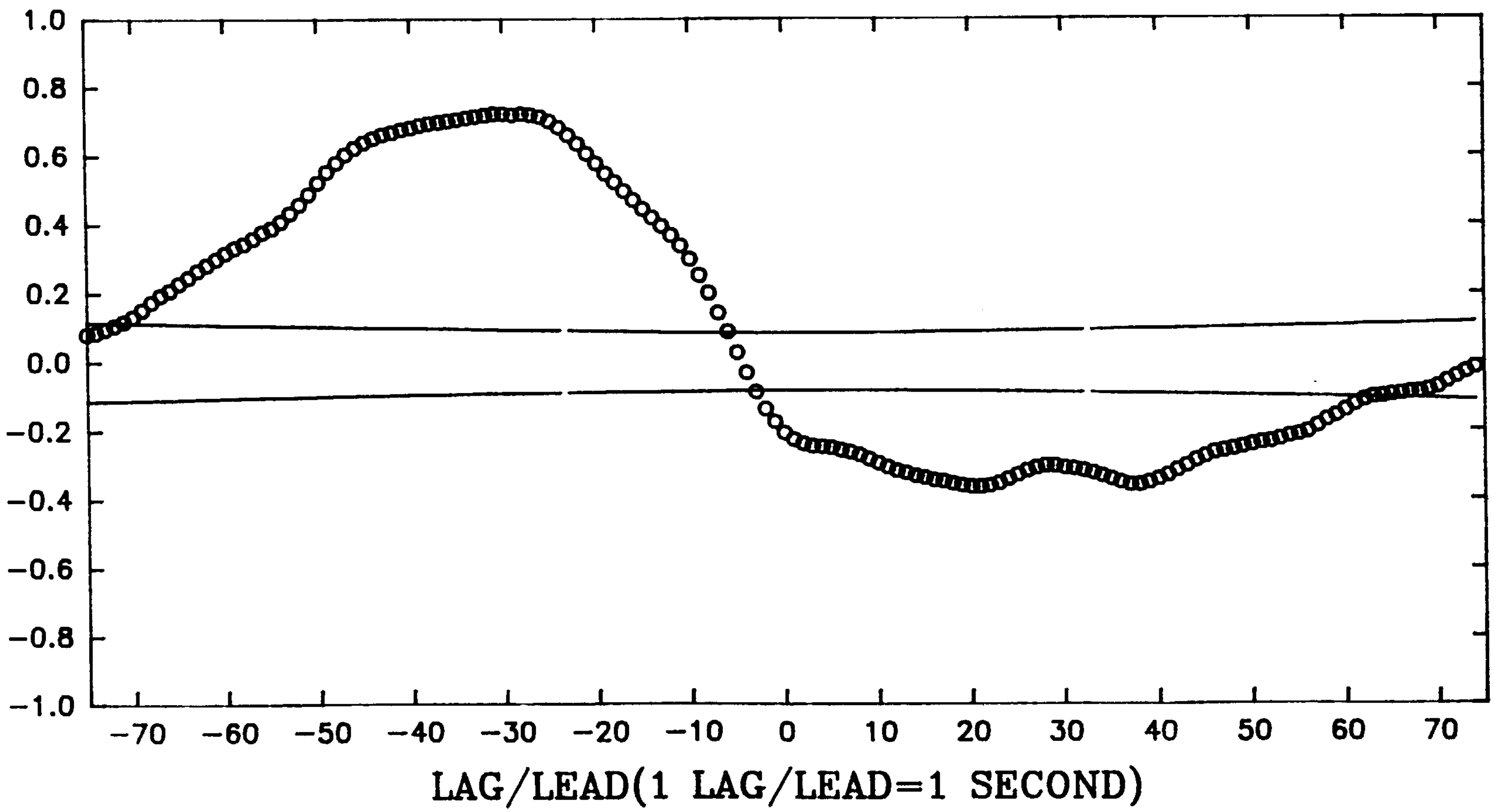
WIND SPEED, DIRECTION AND TEMP. for #143 FLIGHT 612 ON 6/20/91 AT ORLANDO FOR A MICROBURST PENETRATION



COMMENTS ON "...CROSS CORRELATION OF LLWSR AND TEMPERATURE" SLIDE

Normally the correlation at zero lag is much stronger than what is shown in this slide. LLWSR is a function of temperature and usually has a correlation coefficient of about .6.

CROSS CORRELATION COEFFICIENT FOR #143
WITH +/- ONE STANDARD ERROR
CROSS CORRELATION OF LLSWR AND TEMPERATURE

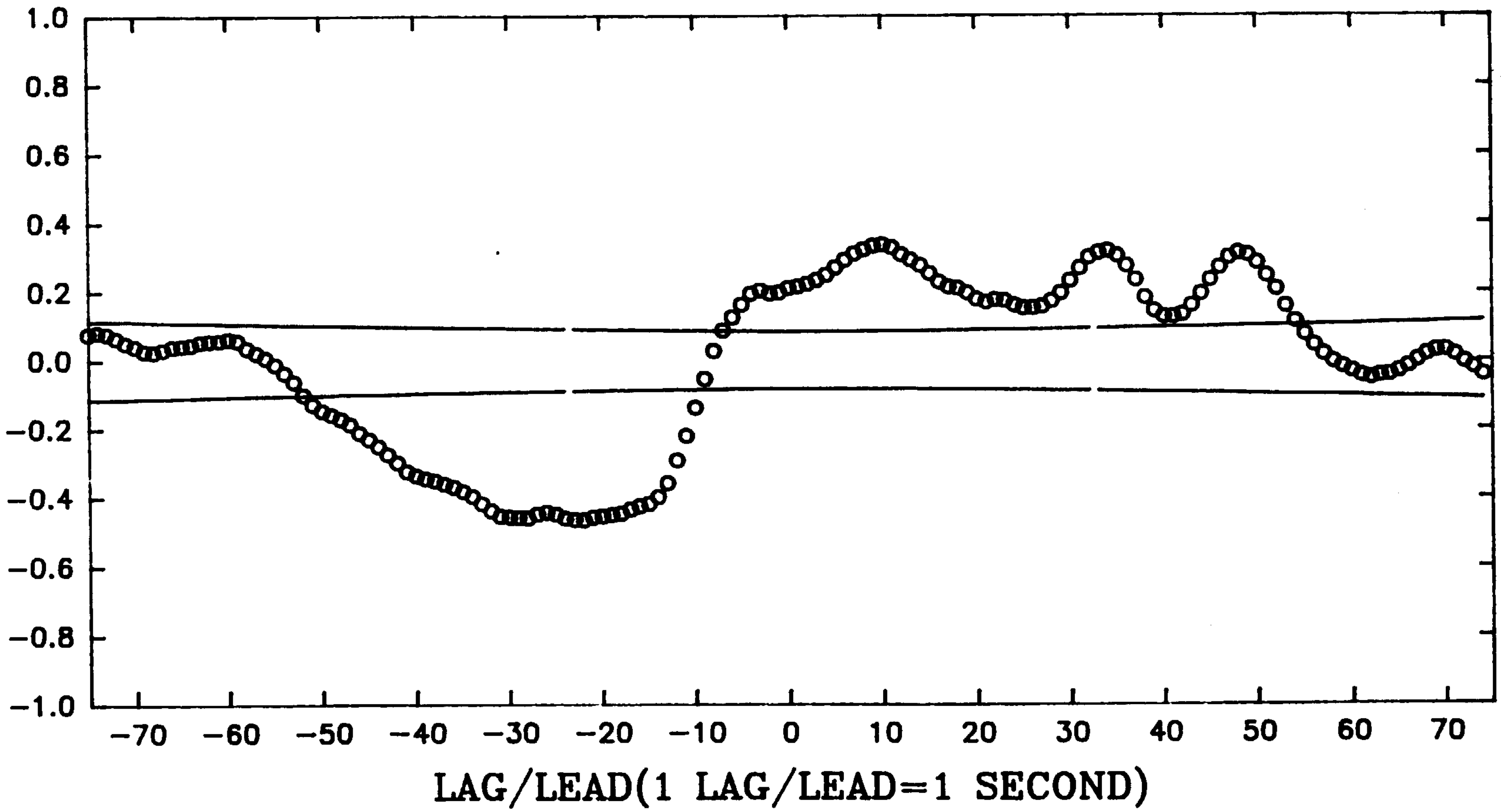


COMMENTS ON "...CROSS CORRELATION OF LLWSR AND FE3" SLIDE

The three peaks in the cross correlation coefficient correspond to the three peaks in LLWSR correlating with the one peak in FE3. Peaks in LLWSR occurred at 10, 34 and 48 seconds before the peak in FE3. LLWSR is based upon measured temperature which may be affected by rain. Therefore, the peaks in LLWSR may be due to rain effects.

CROSS CORRELATION COEFFICIENT FOR #143
WITH +/- ONE STANDARD ERROR

CROSS CORRELATION OF LLSWR AND FE3

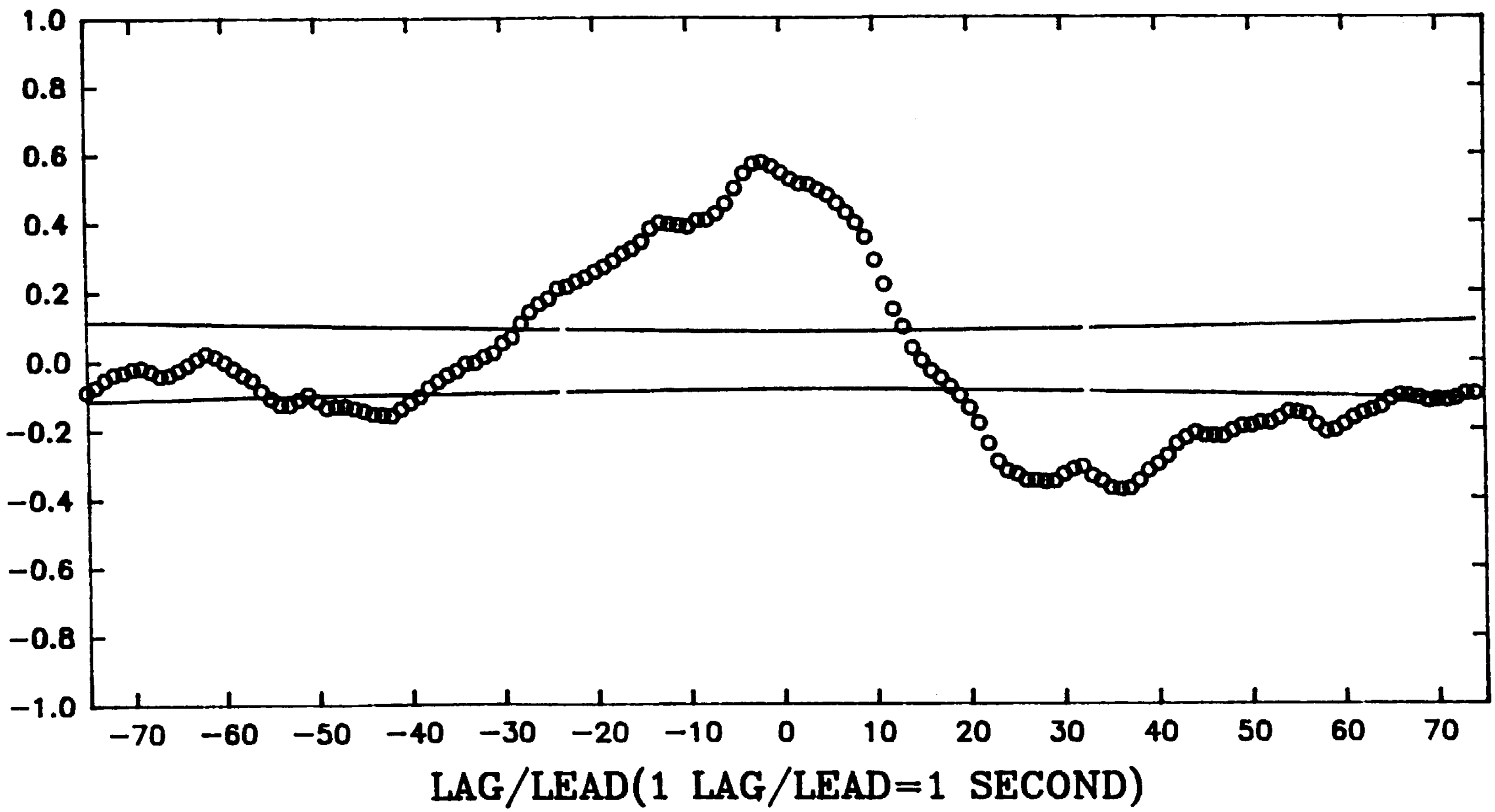


COMMENTS ON "...CROSS CORRELATION OF D2 AND PITCH" SLIDE

D2 and pitch have a correlation coefficient of approximately .6 near zero lag. This indicates a strong pitch effect in the D2 measurement. Also, this positive correlation is evidence that D2 is following a near field temperature. The reasoning goes as such: as the aircraft pitches up (increased pitch) a colder temperature is sensed (temperature decreases) since the sensor is not pitch stabilized. But, since D2 = $t_{far} - t_{near}$, pitch is correlating with $-t_{near}$ which gives a positive correlation coefficient. This is evidence that D2 was primarily measuring near field temperature.

CROSS CORRELATION COEFFICIENT FOR #143
WITH +/- ONE STANDARD ERROR

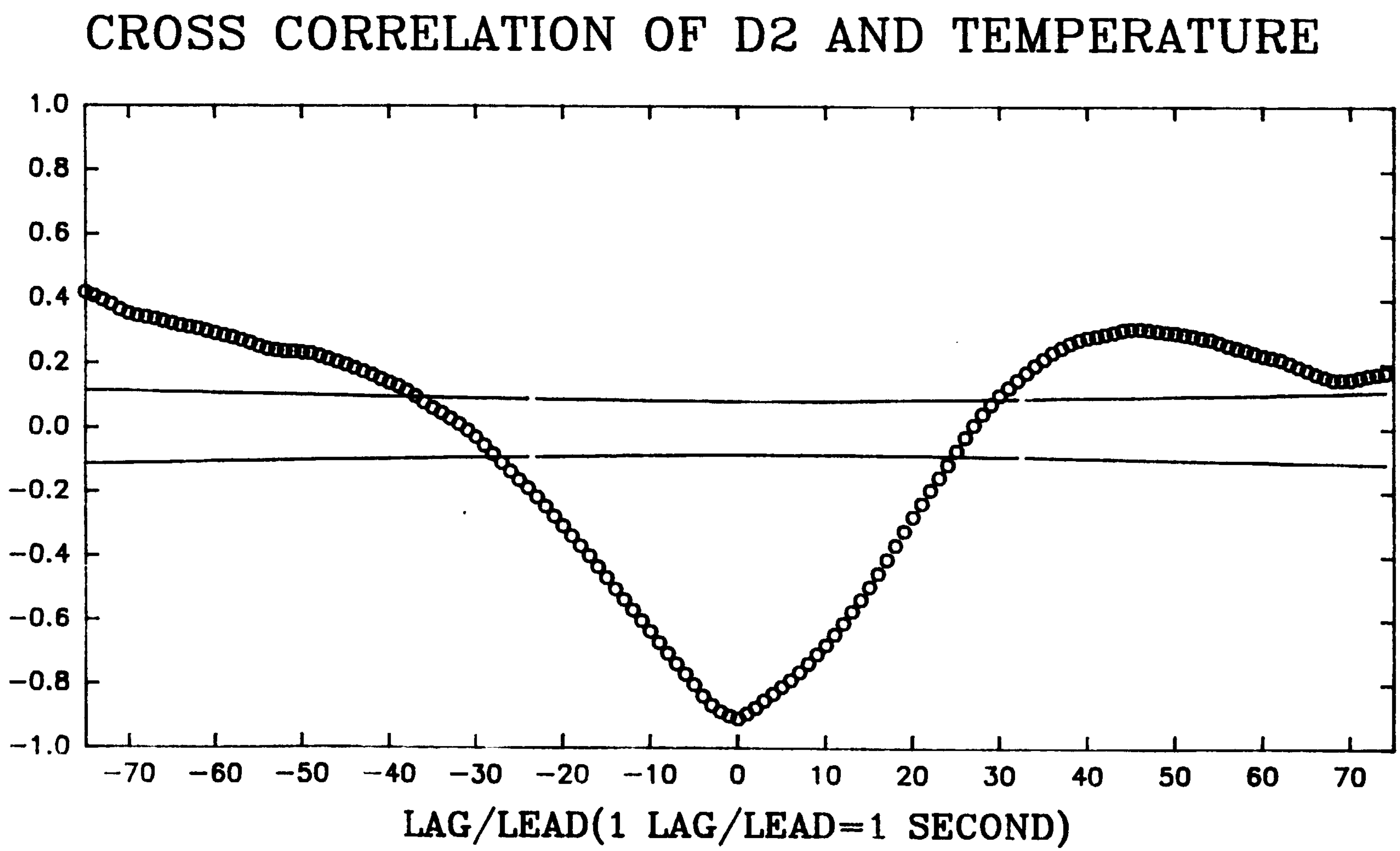
CROSS CORRELATION OF D2 AND PITCH



COMMENTS ON "...CROSS CORRELATION OF D2 AND TEMPERATURE" SLIDE

In this slide D2 shows very strong correlation with temperature at the aircraft. There also seems to be much weaker correlation of D2 with a far field temperature 45 seconds ahead of the aircraft. This is additional evidence that D2 was primarily measuring near field temperature.

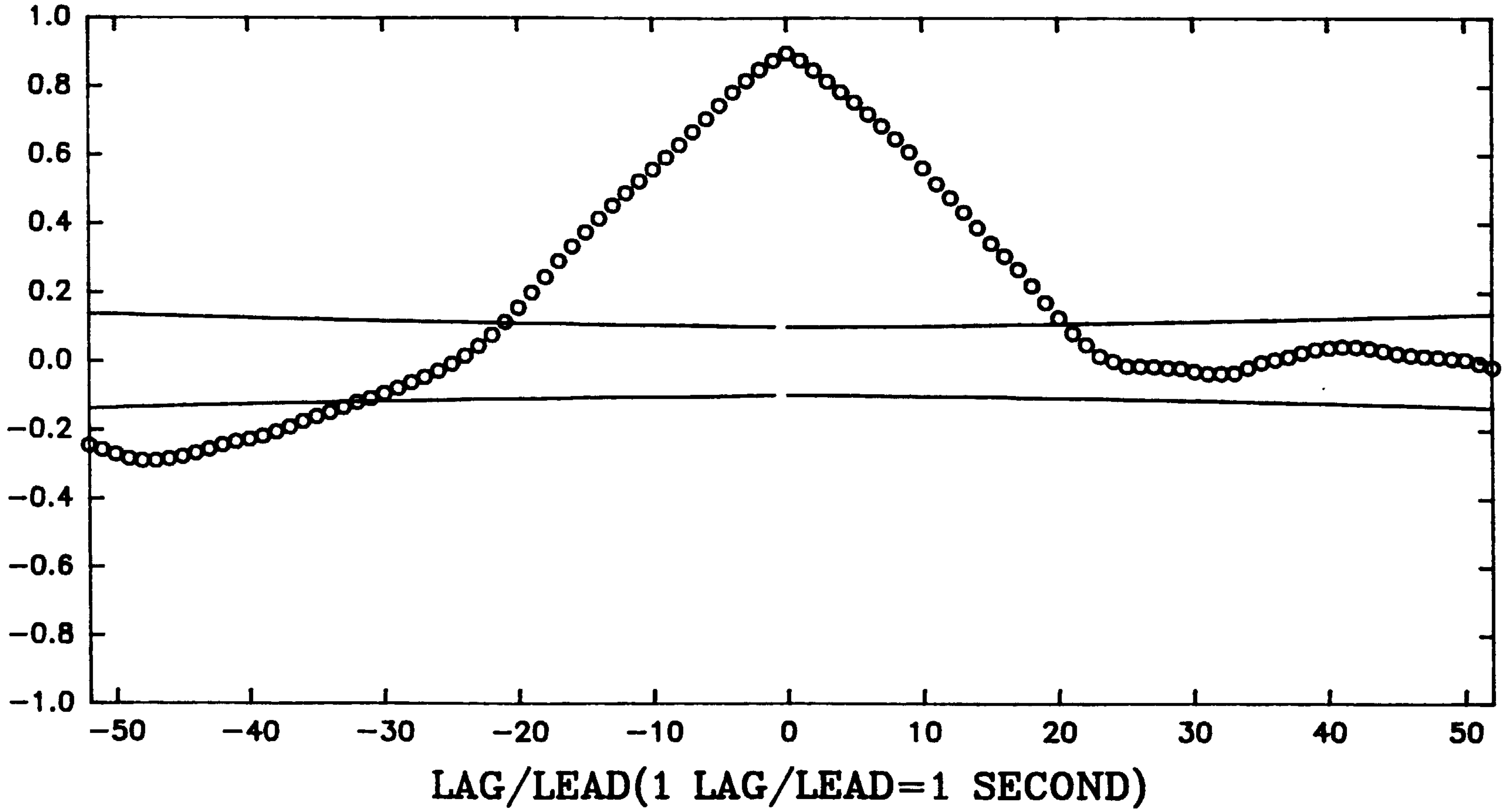
CROSS CORRELATION COEFFICIENT FOR #143
WITH +/- ONE STANDARD ERROR



COMMENTS ON "...CROSS CORRELATION OF D2 AND T(t+45)-T(t)" SLIDE

A pseudo $t_{far} - t_{near}$ is formed by computing T(t+45)-T(t), temperature 45 seconds ahead of the aircraft minus temperature at the aircraft. D2 shows a very strong correlation with T(t+45)-T(t), but not as strong as the correlation with temperature at the aircraft as shown in the previous slide. Strong correlation between D2 and T(t+45)-T(t) may mean that D2 is measuring a far field temperature 45 seconds ahead of the aircraft minus a near field temperature at the aircraft. A look at the appropriate time series will show that D2 was measuring near field temperature.

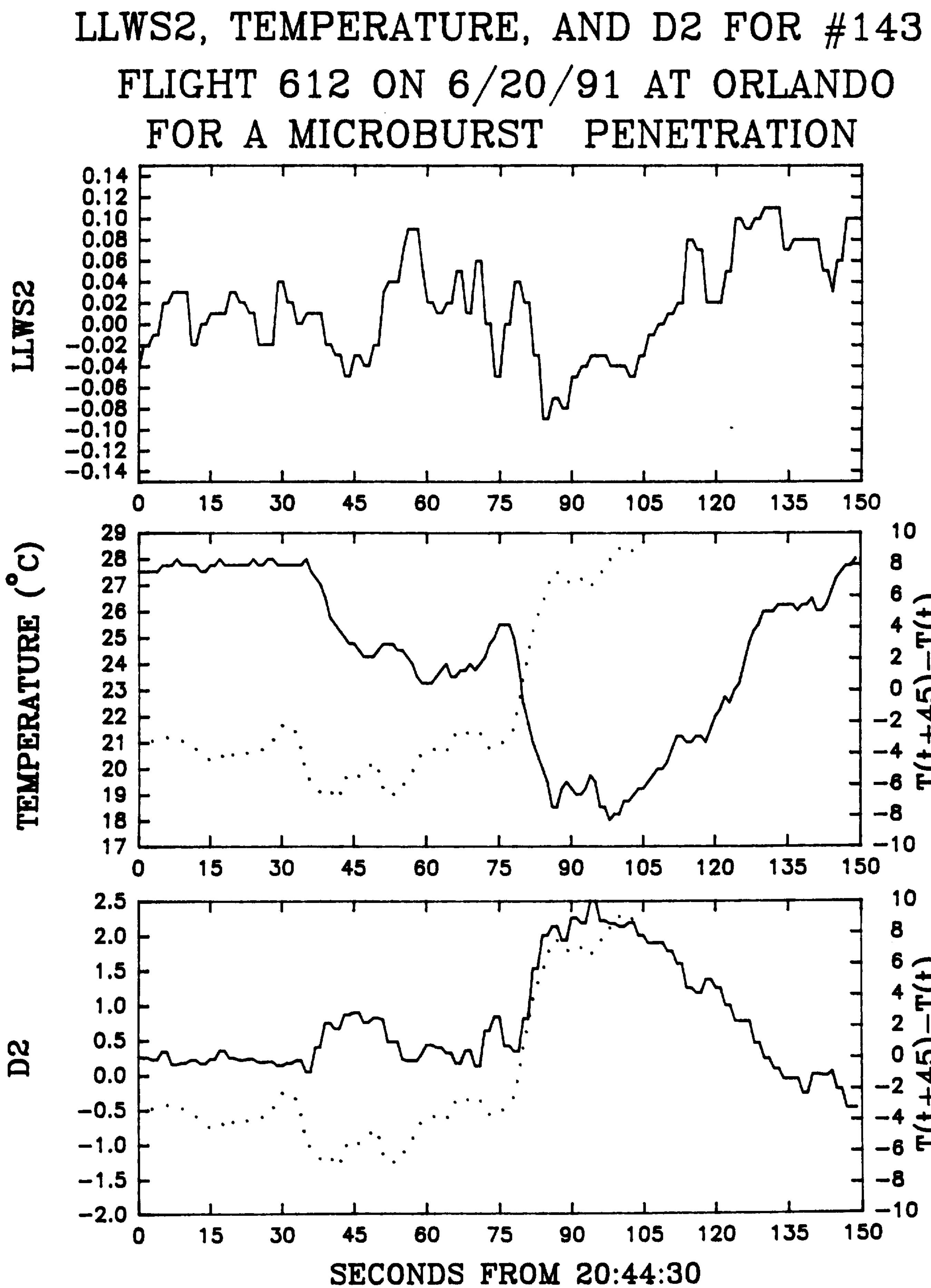
CROSS CORRELATION COEFFICIENT FOR #143
WITH +/- ONE STANDARD ERROR
CROSS CORRELATION OF D2 AND T(t+45)-T(t)



T(t) = TEMP. AT TIME t SECONDS

COMMENTS ON "LLWS2, TEMPERATURE...FOR A MICROBURST PENETRATION" SLIDE

The correlation of D2 and T(t-45)-T(t) does not represent a predictive response to temperature changes. D2 was measuring near field temperature. In the bottom graph of this slide D2 (the solid line) and T(t-45)-T(t) (the dotted line) are plotted against time. The middle graph has outside air temperature (solid line) and T(t+45)-T(t) versus time. Compairing the two graphs shows that D2 varies inversely with temperature. After approximately 35 seconds from beginning of event 143 the aircraft encounters the cold air outflow; D2 becomes a measurement of near field temperature and LLWS2 is responding to near field temperature changes. In the first 35 seconds of event 143 the temperature and D2 are essentially constant and the variation in LLWS2 is system noise. The positive correlation between D2 and T(t+45)-T(t) is due to their behavior after 75 seconds from the start of event 143. During this period both variables are increasing with time and D2 (between 75 and 90 seconds) correlates positively with temperature beyond 120 seconds. Since the aircraft is in the cold air outflow, this correlation does not represent a predictive response to temperature but is termed a nonsense correlation.


LLWS2, TEMPERATURE, AND D2 FOR #143
FLIGHT 612 ON 6/20/91 AT ORLANDO
FOR A MICROBURST PENETRATION
LLWS2
TEMPERATURE (°C)
T(t+45)−T(t)
D2
SECONDS FROM 20:44:30

COMMENTS ON "FREQUENCY...FOR ALL EVENTS" SLIDE

The in situ algorithm (FE3) alerted twice or 1.14% of the time. AWAS III alerted 32 times or 18.18% of the events contained AWAS alerts. There was one event (number 143) that had a common alert. The alert rates are statistically different based on a χ^2 test.

FREQUENCY TABLE FOR ORLANDO AND DENVER DEPLOYMENTS FOR ALL EVENTS

AWAS III \ FE3	ALERTS	NO ALERTS	
ALERTS	1 .005682	31 .176136	.1818
NO ALERTS	1 .005682	143 .8125	
	.011364		

COMMENTS ON "AWAS III THERMAL ALERTS" SLIDE

All of AWAS' alerts were thermal alerts. A large number of alerts occurred during rain cell penetrations which may have been caused by rain effects as previously stated and radar clutter runs which were low passes over runways followed by go-arounds.

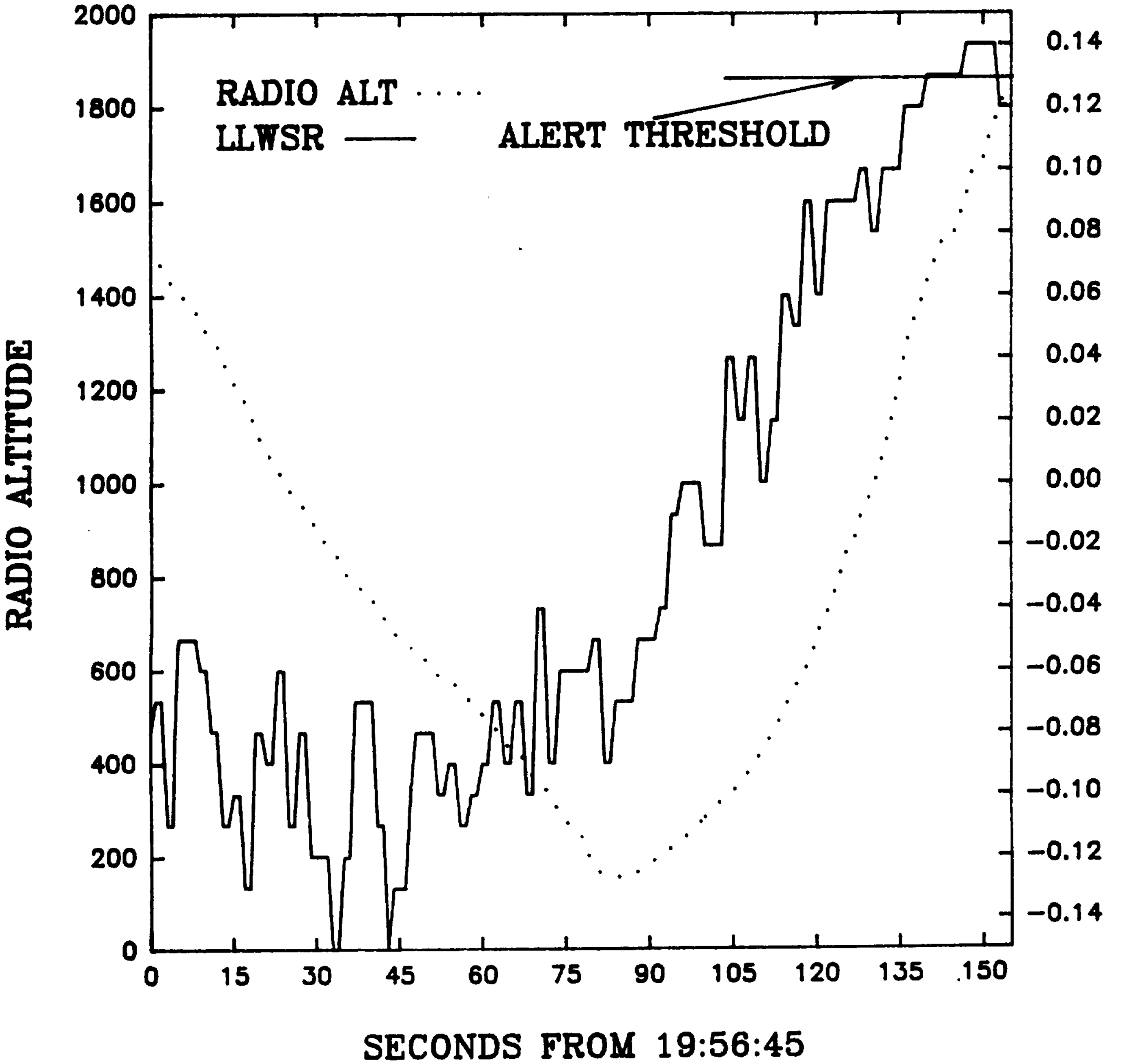
AWAS III THERMAL ALERTS

Event Type	Number of Events
Microburst	9
Rain Cell	11
Gust Front	1
Go-around	10
Other	1
Total	32

COMMENTS ON "...FOR A GO-AROUND" SLIDE

This slide shows the typical behavior of AWAS III during a go-around. The thermal hazard index is not compensated for the change in temperature that occurs when the aircraft is climbing during a go-around.

RADIO ALTITUDE AND LLWSR FOR #190 FLIGHT 618 ON 7/11/91 AT DENVER FOR A GO-AROUND



COMMENTS ON "AWAS III CONCERNS" SLIDE

A number of issues relating to AWAS III performance need to be addressed. Some have already been mentioned during this presentation. NASA's installation of AWAS III was different than that of other installations. The TPS/NASA designed installation used a periscope and AWAS III was in a pressurized passenger compartment of the aircraft. The other installations did not use a periscope and were not in a pressurized part of the aircraft. No one is sure if AWAS III's performance was affected by possible installation effects. All of our penetrations were done with air speeds much higher than approach and landing speeds. AWAS III's hazard indices are based on normal approach and landing speeds of around 140 knots. AWAS III's performance during the go-arounds points to the need for thermal hazard alerts are probably caused by rain affecting temperature probe measurements. The hazard indices from AWAS III appear to contain a lot of noise. Filtering of the indices would reduce the noise level and possibly change the threshold for alerting.

AWAS III CONCERNS

NASA Installation of AWAS III
-Unheated mirror
-Mirror replaced twice
-Window (KRS-5) had to be cleaned
-Rain in periscope may lower
 look distance

Airspeed of 230 kts. during penetrations

Lapse rate compensation

Effect of rain on OAT measurements

Filtering of data

Threshold for alerting

COMMENTS ON "AWAS III CHANGES FOR 1992 DEPLOYMENTS" SLIDE

Numerous changes are being made to AWAS and to the NASA 737 installation. One of the biggest changes is a TPS redesigned periscope mount. NASA's installation would be more like those of other AWAS III installations. The KRS-5 window is being moved from the bottom of the periscope to the top of the periscope. This will put the window in the same relationship to the reflector as all other installations. Also the NASA installation will have a heated reflector. TPS is developing hazard indices based on microburst penetration speeds in excess of 200 knots. Also, AWAS III will have a new method of compensating for pitch affects (lapse rate effects caused by aircraft pitching) and compensation for lapse rate effects on OAT measurements. And finally, filtering is introduced into the computations of the hazard indices.

AWAS III CHANGES FOR 1992 DEPLOYMENTS

TPS Redesigned Periscope

TPS Developing Hazard Indices for Flight Test Airspeeds

New Lapse Rate Computation

Enhanced Lapse Rate Compensation for OAT

Indices Based on Filtered Data

COMMENTS ON "CONCLUSIONS" SLIDE

The AWAS III system functioned according to specifications. Flight profile modes changed when they should have and there were no system errors. There is a need for compensating for rain effects on the thermal hazard index and possible installation effects are uncertain. Various operational and installation uncertainties do not allow NASA to make conclusive statements regarding AWAS III's performance of the wind shear predictive function.

CONCLUSIONS

AWAS III System Operated Without Failures

Numerous Thermal Alerts From Rain Contamination of OAT Measurements

Installation Effects On AWAS III's Performance Are Unknown

Results Are Not Fully Conclusive For 1991

Flight Test of an Infrared Wind Shear Detector
Questions and Answers

Bob McMillan (Georgia Tech) - I have more of a comment than a question. I would like to tell you why I think the look distance was shorter in Orlando than in Denver. I think it was probably water vapor. There are just thousands of water vapor lines scattered through the infrared. I am sure that the humidity was higher in Orlando. So it was not liquid water so much as maybe water vapor.

Burnell McKissick (NASA Langley) - There were lots of events that contained short look distances for Denver too.

Pat Adamson (Turbulence Prediction Systems) - We had similar data in Orlando in 1990 and we had considerably longer look distances. Two things that I think are important, one is that these look distances are radically different than the installation on a research aircraft that we flew in 1990, a Cessna Citation, and they are radically different from both the Northwest and the American Airlines installations. The second one that I think I should mention, is when we talk about OAT effects, the wet bulb/dry bulb effect on an OAT probe is radically increased as a function of airspeed. So when we talk about overshoots from OAT at 230 or 240 knots it is considerably different than the overshoot at 140 knots. They are quite different in that sense. As far as look distance is concerned, these were very different. We had a meeting a few weeks ago to look at these issues and the first thing we noticed was that we did not have any look distance in this installation. That is one of the things that we will be looking at this year.

Q: Russell Targ (Lockheed) - In the very beginning and again at the end you said the jury is still out as to whether the temperature sensing scheme will actually measure microburst. What is your criterion going to be for you to determine whether or not this technology does what you want it to do? What are you looking to see?

A: Burnell McKissick (NASA Langley) - We are looking to see alerts at the appropriate time which match up with alerts generated by our In Situ system. So we are sort of bottom lining the whole thing with an alert at the right time, and the right event. Will it indicate a wind shear where there is actually a wind shear. The issue of relating the temperature measurements to the wind shear is one that people are still working on, and it is very interesting, but we are sort of at the bottom line of the whole thing.

Q: Russell Targ (Lockheed) - You show a mixture of missed alerts and false alarms and I am wondering how much of that is acceptable in your quantitative judgment?

A: Burnell McKissick (NASA Langley) - Well, certainly we would like to see less. No one wants to see false alarms. I would like to see less alerts from my stand point, and just a clearer picture of the whole thing. I am not going to say it won't work, there is indication that there is a possibility for it. But there is also room for improvement as there are in the other sensors too.

Session II. Hazard Characterization

C-3