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Development of the Advance Warning Airborne System (AWAS)

Pat Adamson, Turbulence Prediction Systems

FOURTH COMBINED MANUFACTURERS'
&
TECHNOLOGISTS'
AIRBORNE WINDSHEAR REVIEW MEETING

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DEVELOPMENT OF THE ADVANCE WARNING AIRBORNE SYSTEM (AWAS)

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ABSTRACT

DEVELOPMENT OF THE ADVANCE WARNING AIRBORNE SYSTEM (AWAS)

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The thermal characteristics of microbursts are utilized by the AWAS IR and OAT features to provide predictive warning of hazardous microbursts ahead of the aircraft during landing or take off. The AWAS was evaluated satisfactorily in 1990 on a Cessna Citation that was intentionally flown into a number of wind shear events. The events were detected, and both the IR and OAT thermal features were shown to be effective. In 1991, AWAS units were flown on three American Airlines MD-80s and three Northwest Airlines DC-9s to study and to decrease the nuisance alert response of the system. The AWAS was also flown on the NASA B737 during the summer of 1991. The results of these flights were inconclusive and disappointing. The results were not as promising as before because NASA conducted research flights which were outside of the normal operating envelope for which the AWAS is designed to operate. In an attempt to compensate for these differences in airspeed and mounting location, the automatic features of the system were sometimes overridden by NASA personnel during the flight. Each of these critical factors is discussed in detail. The effect of rain on the OAT signals is presented as a function of the air speed. Use of a 4 pole 1/20 Hertz filter is demonstrated for both the IR and thermal data. Participation in the NASA 1992 program was discussed. FAA direction in the continuing Certification program requires the addition of a reactive feature to the AWAS predictive system. This combined system will not require flight guidance on newer aircraft. The features of AWAS-IV, with the NASA algorithm included, were presented. Expected completion of the FAA Certification plan was also described.

AWASIII

UND/TPS PROGRAM

CESSNA CITATION

Over the past five years, Turbulence Prediction Systems (TPS), in Boulder, Colorado has combined the concepts of the thermal properties of microbursts with the behavior of infrared (IR) in the atmosphere, and OAT (Outside Air Temperature) response on the aircraft flying into such events. From these studies, TPS has established an Advance Warning Airborne System (AWAS) that has proceeded through its third version, AWAS-III, and is in process of FAA certification.

INITIAL INSTALLATION 6/90

SW 2.0

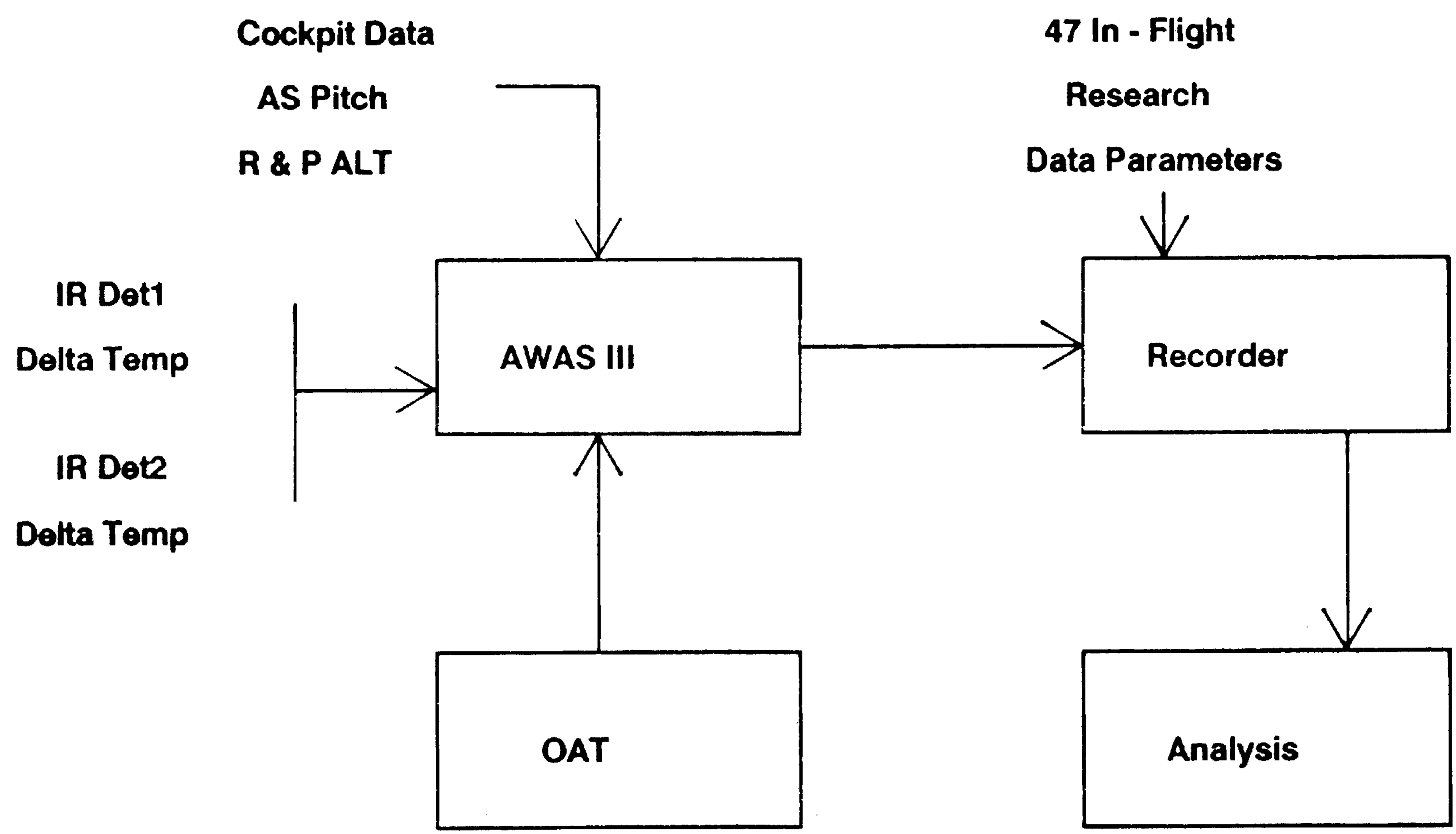
66 FLTS ~100 HRS

During the summer of 1990, AWAS-III was flown on the Cessna Citation research aircraft operated by the University of North Dakota (UND) in conjunction with the FAA study of the MIT Terminal Doppler Weather Radar (TDWR) in the detection of microbursts. This provided unique opportunity for AWAS-III to predict and enter a number of wet microbursts in Orlando, Florida, and several dry microbursts in Denver, Colorado.

AWAS-III, with software version 2.0, was installed in the Citation in June of 1990. It was located in the luggage compartment in front of the pilot, and the IR from ahead of the aircraft was reflected into AWAS-III via a 2" gold coated mirror mounted outside, just below the windshield, where it did not interfere with the pilot's view. Sixty-six flights were flown in attempts to make wind shear contacts.

Turbulence Prediction Systems

Block Diagram



The received IR power is separated into appropriate wavelengths by a spectrometer. The IR power in these wavelengths is then registered by two IR detectors. AWAS processes the difference between far and near IR indicated temperatures to generate a "Predictive Hazard Index" that relates to the microburst's hazard. Airspeed, pitch, radio and pressure altitudes are also used. The OAT data is also used to create a "Thermal Hazard Index" relating to microbursts. For research purposes, 47 AWAS in flight and aircraft data parameters are recorded. These parameters were used for the post-flight analyses.

07/07/90 PENETRATION

F(TDWR) = 0.155

F(CITATION) = 0.17 @ 180 kts

F(AWAS) = 0.15

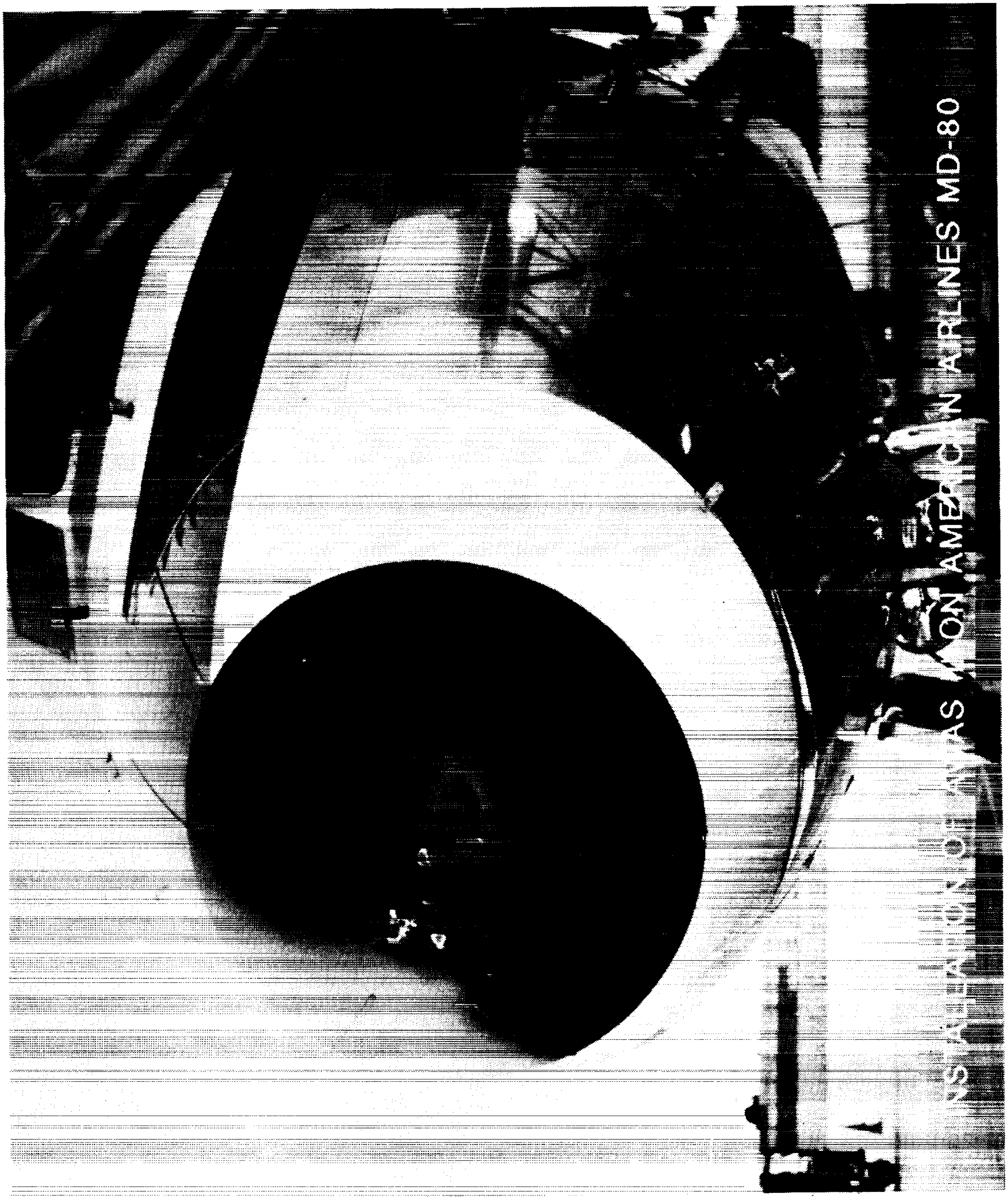
REFERENCE 3rd COMBINED...NASA JAN 1991

One of the most important microburst penetrations was on July 7th, 1990. The aircraft airspeed during approach was 180 knots, and the aircraft entered the center of the microburst. The IR created a warning at 55, and 35 seconds before that which would have been provided using a hazard index calculated from the winds recorded by the inertial system, i.e., inertial warning. The Thermal Hazard Index provided a warning 15 seconds before the inertial warning. The TDWR measured the event a few seconds before the aircraft entered the microburst. The hazard value calculated by the TDWR was 0.155, inertial hazard index was 0.17, and the AWAS IR hazard index was 0.15. This data was presented at the 3rd Combined NASA meeting in January 1991.

AMERICAN / TPS
CERTIFICATION PROGRAM

MD80 CONFORMED INSTALLATIONS
2/91

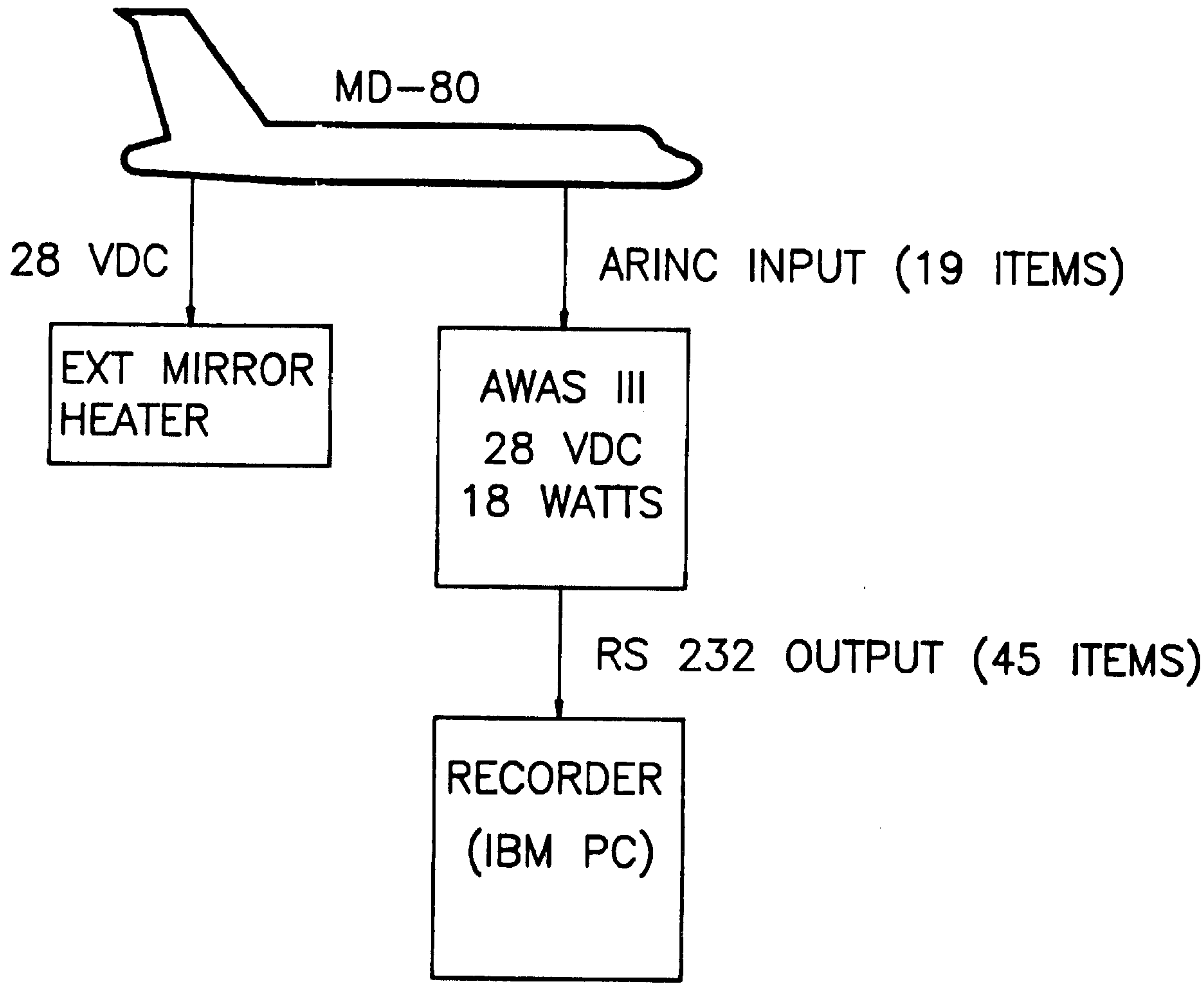
Another important aspect of the certification program was to determine the level of nuisance alerts which might occur in revenue service. American Air Lines cooperated with TPS in this phase of the program. An AWAS-III with a recorder was installed, starting in February of 1991, on 3 MD-80 aircraft. Many thousand flights have been conducted with these units on board.



ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

AWAS was installed in the front wheel-well of the MD-80. The mirror, which is seen lower right in the picture, has the red alignment laser beam centered on it. The laser is used in the installation to guarantee that AWAS looks out the flight line of the aircraft.

AMERICAN AIRLINES/TPS AWAS INSTALLATION DIAGRAM



10APR92

630277 REV X

The AWAS uses 28 VDC and the mirror is also heated with 28 VDC. The AWAS receives the necessary aircraft data via ARINC. This aircraft data and the AWAS generated data is transmitted to the recorder. A lap-top computer was used as the recorder.

AA PROGRAM

SW VER	DATE	FLTS	FLT HRS
2.1.1.2	4/91 - 10/91	1336	2134
2.1.1.4	10/91 - PRESENT	1216	2047

From an analysis of the early data the software version was changed in October, 1991. Over a thousand flights have been recorded since these minor software changes were installed.

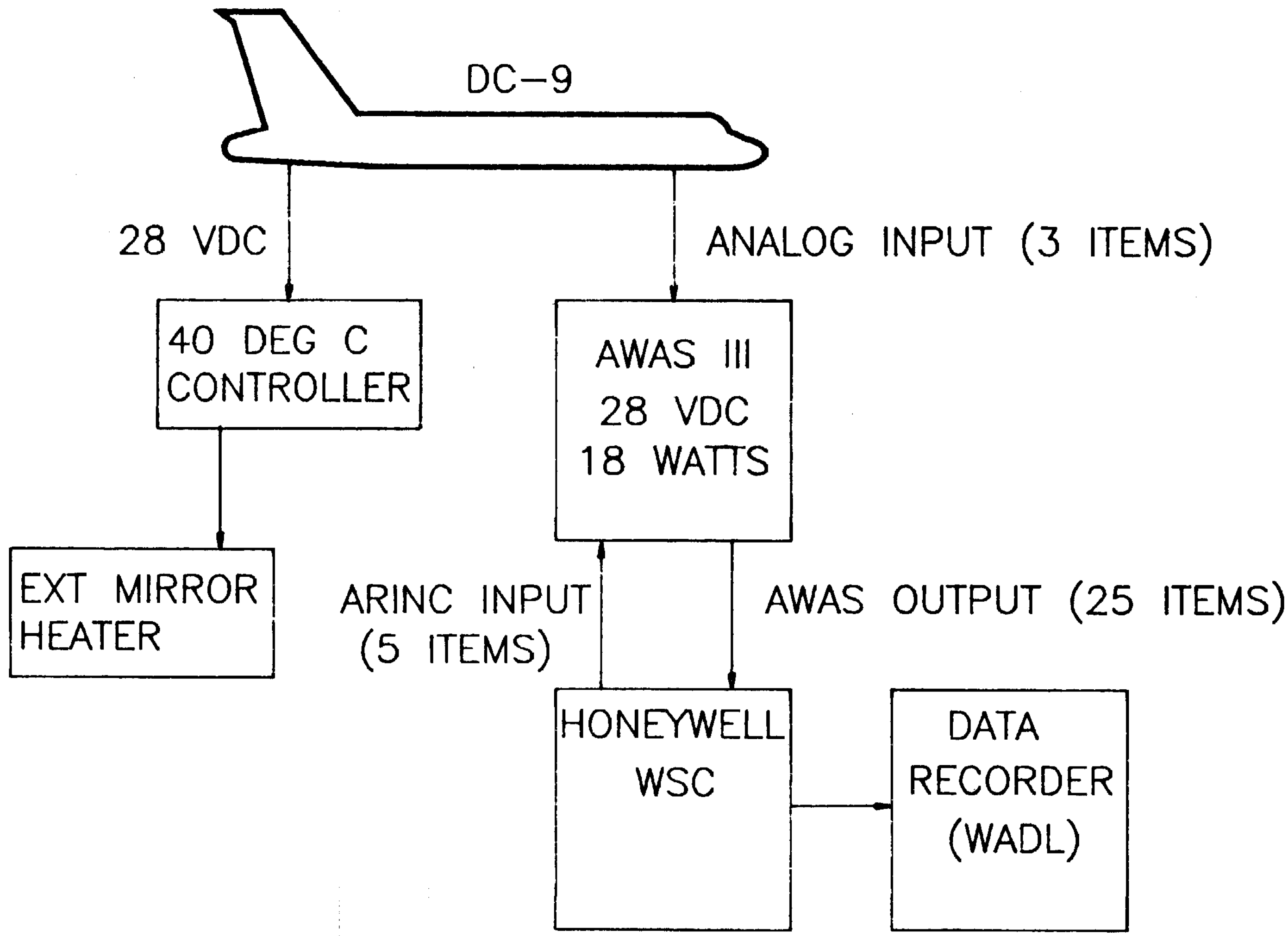
NORTHWEST / TPS EVALUATION PROGRAM

DC9 INITIAL INSTALL 6-12/91

A second commercial airlines program involved the installation of AWAS-III with a Honeywell Windshear Computer on three DC9 aircraft. Northwest Air Lines installed these units from June to December of 1991.

This installation was also in the front wheel well, on the port side, but at a somewhat higher level.

NORTHWEST AIRLINES/TPS AWAS INSTALLATION DIAGRAM



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630279 REV X

In this program, both an AWAS and a Honeywell WindShear Computer (WSC) were installed. The AWAS received three inputs from analog connections with the aircraft instruments, and five from ARINC through the WSC. These 8 input items plus 17 AWAS generated items were passed through the WSC to the recorder.

NWA PROGRAM

SW VER	DATE	FLTS	FLT HRS
3.0	6/91 - 2/92	1710	2052
3.1	2/92 - 3/92	590	708
3.2	3/92 - PRESENT	135	191

The AWAS-III software was updated twice in this program. The major changes were to prevent AWAS nuisance response to non-hazardous weather conditions.

SOFTWARE EFFECTS

ALERTS	AA 2114	NWA 3.1	NWA 3.2
LLWS	20% / FLT	12% / FLT	1 ALERT IN EVALUATION
CAT	30% / HR	0% / HR	0% / HR
FLTS	1216	590	135
HRS	2047	708	191
FLT LENGTH	1.7 hrs	1.2 hrs	1.4 hrs

NWA3.2 represents the latest software upgrade. These changes were to reduce nuisance from inversions, and to incorporate improved pitch correction equations.

LESSONS LEARNED

MTBF / MTBR

AWAS / WINDOW / MIRROR

ENVIRONMENTAL ENVELOPE

The operation of the AWAS has been exceptionally free of failure over more than 2 years. The IR window and the gold coated, heated mirror have been inspected regularly. While the mirrors have not required any replacement, the windows have been cleaned every 4 to 6 weeks--to eliminate these cleanings, a protective coating has been applied to one window on American Air Lines, and to all 3 windows on Northwest Air Lines. The coating, while still under study, appears to solve the problem of window degradation. Because both of the airlines testing these AWAS units have flights through a wide variety of weather conditions, it is believed that these tests are effective for establishing response to a large environmental envelope.

IR WEATHER EFFECTS

OPERATIONAL ISSUES-DEICING

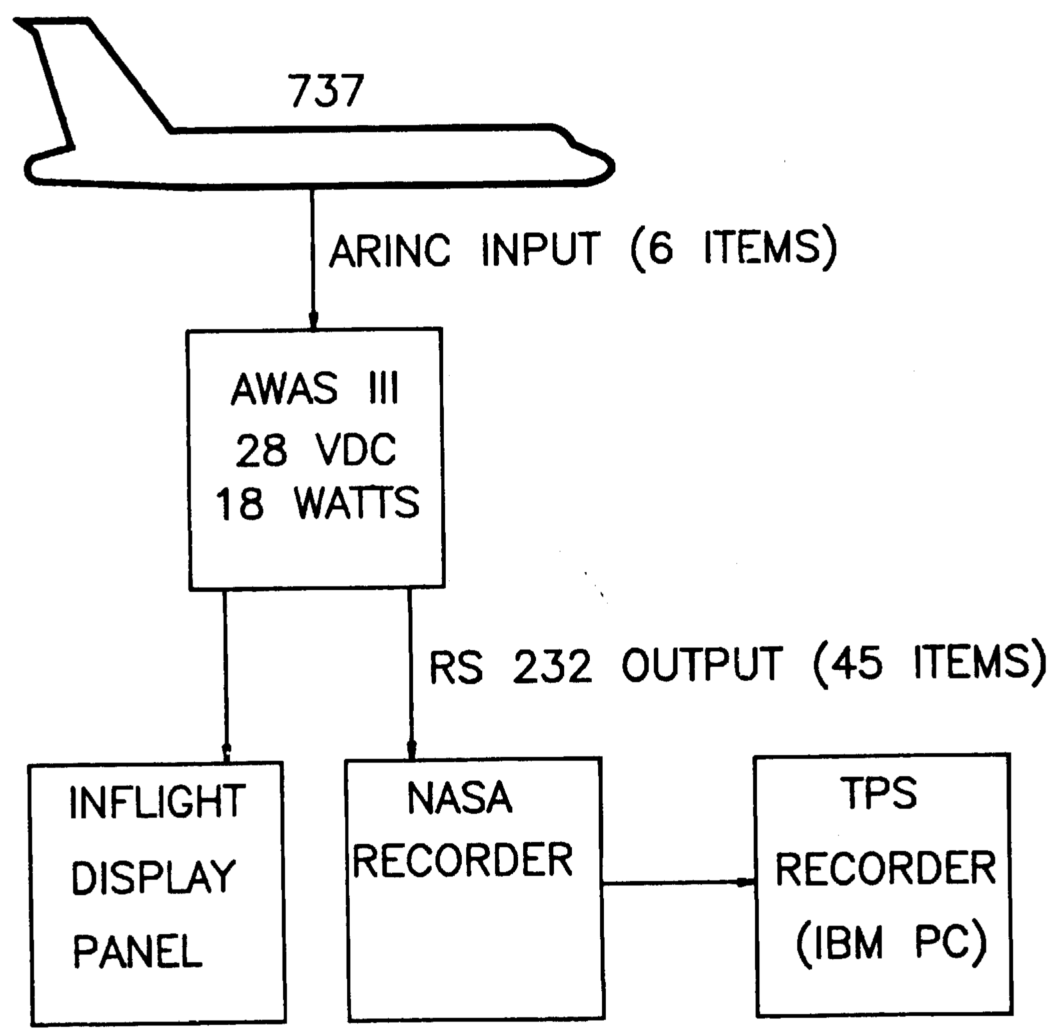
While passive IR power may be diminished somewhat in rain, this has not appeared to be a problem during any commercial test flight. Heating the mirror within a pre-set range of temperatures is important for the proper function of the AWAS, and to prevent icing.

NASA / TPS SUMMER PROGRAM 91

SW 2.1.2.0 = 2.1.1.2 AA

In the summer of 1991, NASA included AWAS-III in its tests of radar in penetrations of microbursts. The AWAS unit operated in these flights used a software configuration comparable to the early version used in the American Air Lines flights.

NASA/TPS AWAS INSTALLATION DIAGRAM



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WHY DID THE AWAS NOT PERFORM

AS EXPECTED IN 1991 VERSUS THE

GOOD PERFORMANCE IN 1990?

Normal Flight Mode:

The AWAS is programmed to operate in a normal flight pattern and not in a research mode. Consequently, the AWAS changes from one mode to another automatically as the aircraft takes off, cruises and then enters the landing phase of flight. During these phases the AWAS collects and stores data necessary for different phases of the flight. If the AWAS is rebooted (restarted), or if the modes are changed by means other than that automatically prescribed by the internal software of the AWAS, valuable data necessary for the proper functioning of the AWAS may be lost, or not be collectable again in time to provide an adequate warning. In normal flight, if the system is rebooted, the failure light is illuminated until the AWAS is again operating properly.

AWAS FLIGHT MODES:

NORMAL FLIGHT MODE

RESEARCH FLIGHT MODE

Research Flight Mode:

It was discovered that NASA, in an effort to assure accurate data for research purposes, overrode the automatic mode functions of the AWAS. Unfortunately, if this switching occurred shortly before an encounter with a microburst, all of the data banks would be zeroed, with the result that some of the information, e.g., lapse rate, required for the AWAS to operate properly would be lost. To date, NASA has been unable to provide TPS with the time of occurrence when the five manual overrides occurred. If this information becomes available, it may be possible to determine what effect, if any, these overrides would have had on the performance of the AWAS.

In conclusion, the 1991 test flights of the AWAS by NASA were not as successful as anticipated because the AWAS was flown in an inappropriate flight envelope.

The factors, either individually or combined, that contributed to this poor performance were:

1. The ability of NASA to override on command the AWAS automatic mode selection routine;
2. The undesirable location and method of mounting the mirror and the infrared window assembly;
3. Airspeed in excess of that which is encountered in normal landings and take offs.

The first of these, mode selection, has been discussed, and the problems with the periscope location and design, and airspeed factors, will now be discussed.

LOOK DISTANCE PERISCOPES

UND

AA

NWA

NASA

The effect on the performance of the AWAS due to the location and method of mounting of the mirror and window assembly became very apparent during the NASA 1991 summer flights. While there had been no impairment of the infrared line of sight in the earlier installations on the UND Citation II, American Airlines MD-80's, or Northwest Airlines DC9's, it became apparent when TPS analyzed the flight data received from NASA that the look distance of the AWAS was often seriously impaired.

The exact cause of this impairment has not yet been determined. In some cases it appears that it may be due to rain collecting in the periscope. Yet, in other cases where rain existed, the look distance did not appear to be affected. It was determined in the very earliest flights that extensive damage was occurring to the mirror. The damage over the summer was sufficient to require that the mirror be replaced twice. No significant damage has occurred on any of the other installations. This includes over 10,000 hours of flight in revenue service.

The effect of reduced look distance will, of course, reduce the ability of the AWAS to sense the microburst within an adequate time, and/or to measure the intensity of the event accurately.

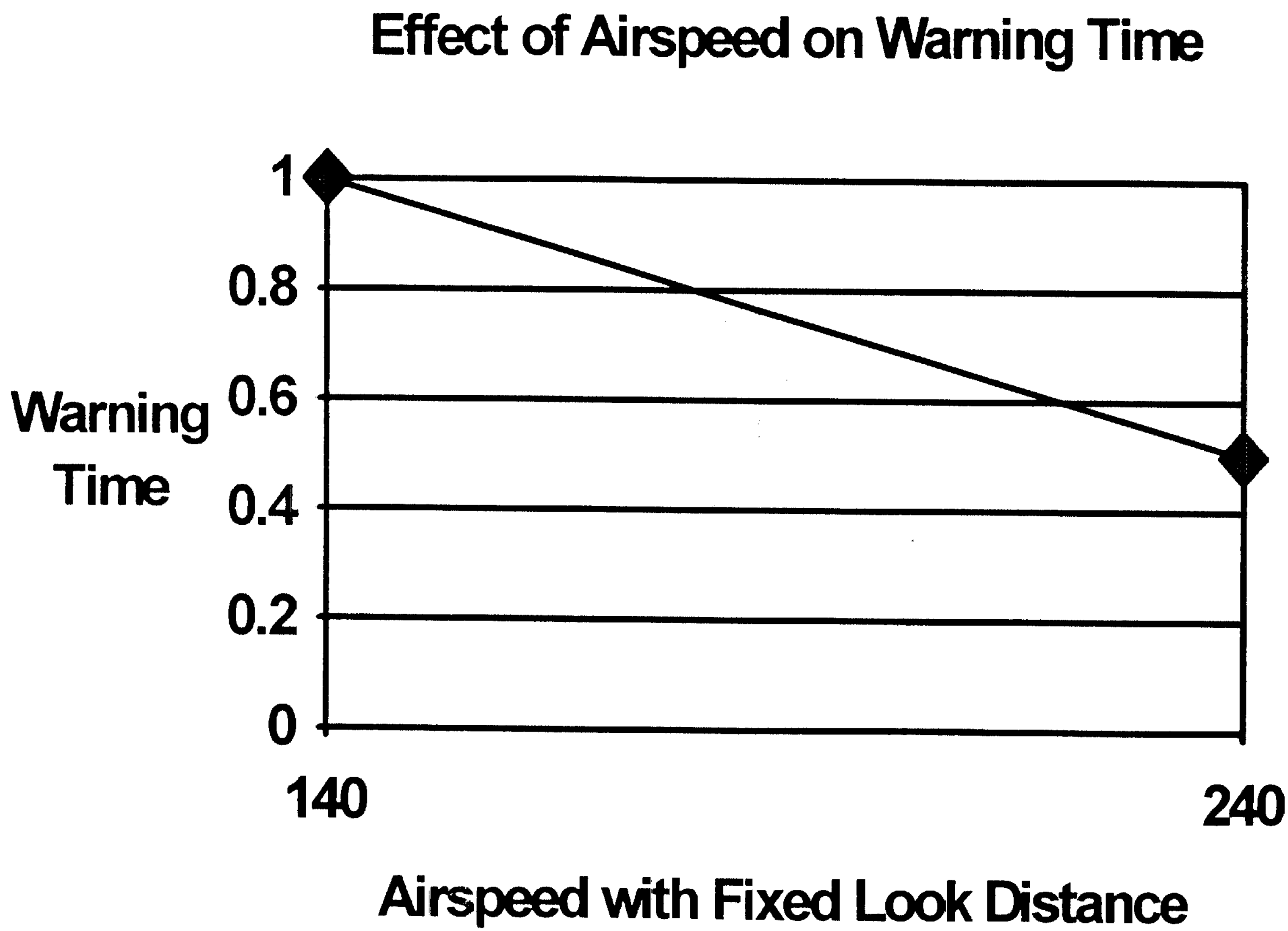
Consequently, the impairment of the look distance during these summer 1991 flights certainly contributed to the apparent poor performance of the AWAS.

AIRSPEED

EFFECT ON WARNING TIME

EFFECT ON F FACTOR

EFFECT ON OAT SENSOR

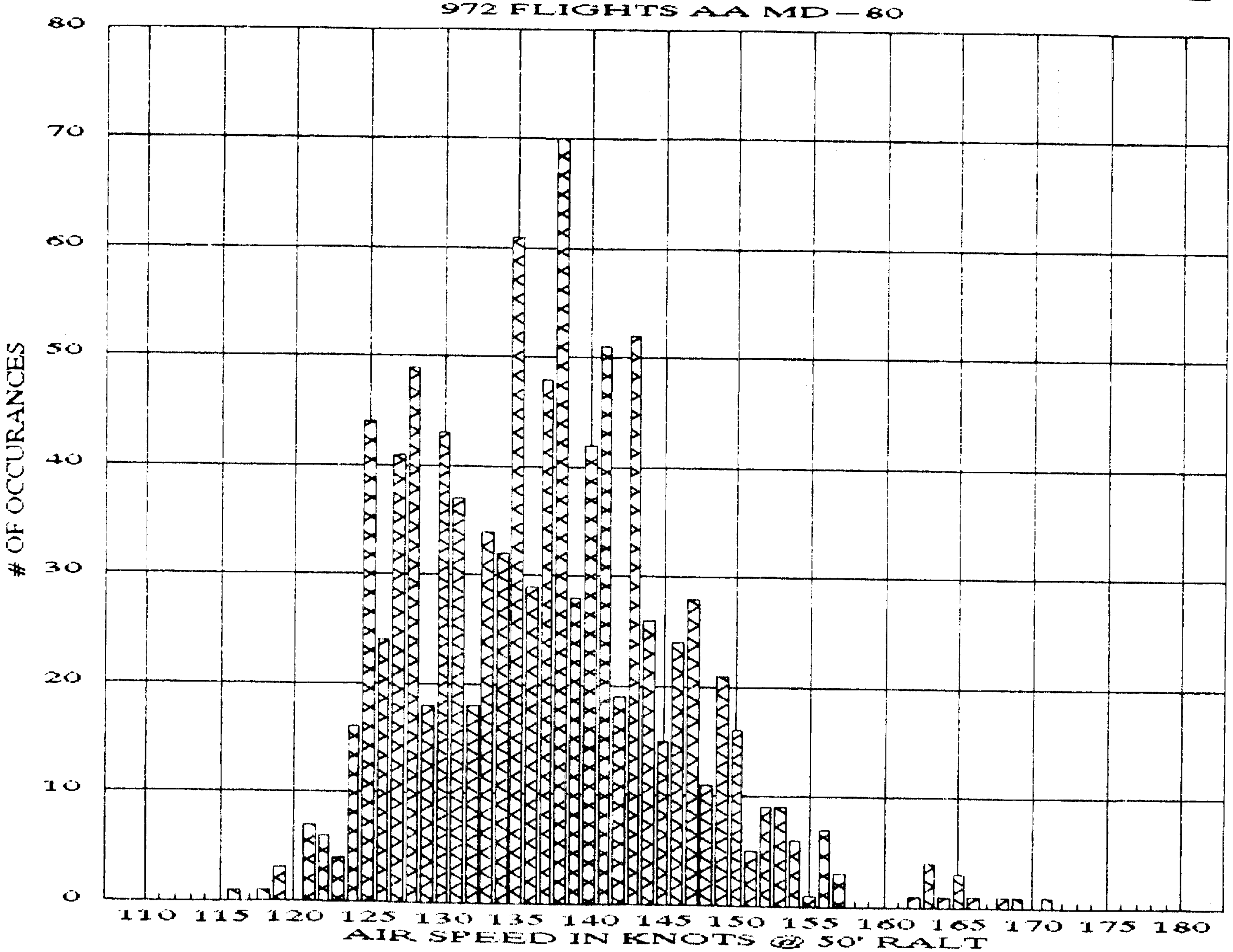

Effect of Airspeed on Warning Time
Warning Time
1
0.8
0.6
0.4
0.2
0
140
240
Airspeed with Fixed Look Distance

The aircraft airspeed has, as is indicated in the previous graph, a significant effect on the amount of warning time provided. This relationship is quite apparent when it is noted that the AWAS will sense the event from a given distance, but that distance will be traversed by the aircraft in less time due to the greater airspeed. Because of safety reasons, the NASA B 737 flew at airspeeds from 230 to 260 knots rather than the 130 to 160 knots flown in normal revenue service by jet aircraft. The airspeed factor was not as significant when the UND Citation II encountered microbursts during the summer of 1990 because the Citation was able to approach and penetrate the events at a much slower airspeed, e.g., 160 to 190 knots.

The distribution of landing speeds from 972 flights is depicted in the following graph.

LANDING AIRSPEED DISTRIBUTION

972 FLIGHTS AA MD−80



F INDEX VS AIRSPEED

AWAS F INDEX VS AIRSPEED

The AWAS-III was designed to estimate the hazard or F factor for use with aircraft operating at a normal landing, or take off speed of approximately 140 knots. For example, the MD-80's data shown in the previous graph indicates a central value of about 140 knots with a maximum value of 171 knots. The F factor as measured at approach speeds of up to 260 knots in the NASA research flights are not comparable with the F factor computed at the lower normal airspeeds. The effect of these differences can be understood by an analysis of the following equations.

The hazard index, F, is based upon the vertical and horizontal winds. These F factors can be appreciated more completely relative to the airspeeds if we look at the nature of the equations and the measurements.

DEFINITION OF TASS F MODEL
PAGE 1

USING THE TASS DATABASE AS INPUT:

$$F_{WIND} = F_{\dot{u}} + F_{w}$$

WHERE $F_{\dot{u}} = \dfrac{\frac{du}{dt}}{G}$ WHERE $dt = 1$ second

WHERE $F_{w} = -w/AIRSPEED$

$$F_{WIND} = \left(\dfrac{\frac{du}{dt}}{G}\right) + \left(-w/AIRSPEED\right)$$

if $\frac{du}{dt} > 0$ then u = tailwind / decreasing headwind -w is a downdraft

The TASS F model represents a hazard index that is separated into two terms, one related to the acceleration of horizontal winds, and the other related to the velocity of vertical winds. The acceleration of the horizontal winds are shown as a time derivative of the horizontal wind velocity. This is divided by G, which is the acceleration of gravity. This provides a first term which is independent of the dimensions. The second term contains the vertical wind velocity divided by the airspeed. This again provides a term that is dimensionless. It is important to apply the directional senses shown, in order for the F values to be of the signs anticipated. An important aspect of the TASS database used in conjunction with these equations is the continuity of time, t. This does not mean that data is present for all possible time values. It means that the data is generated from equations that could provide meaningful wind values at all possible time values, without "exploding" anywhere between time values. Values for study are provided by the instrumentation only once each second. Thus, dt is one second.

DEFINITION OF TASS F MODEL
PAGE 2

USING THE TASS DATABASE AS INPUT:

t IS CONTINUOUS FOR THE FOLLOWING EQUATIONS

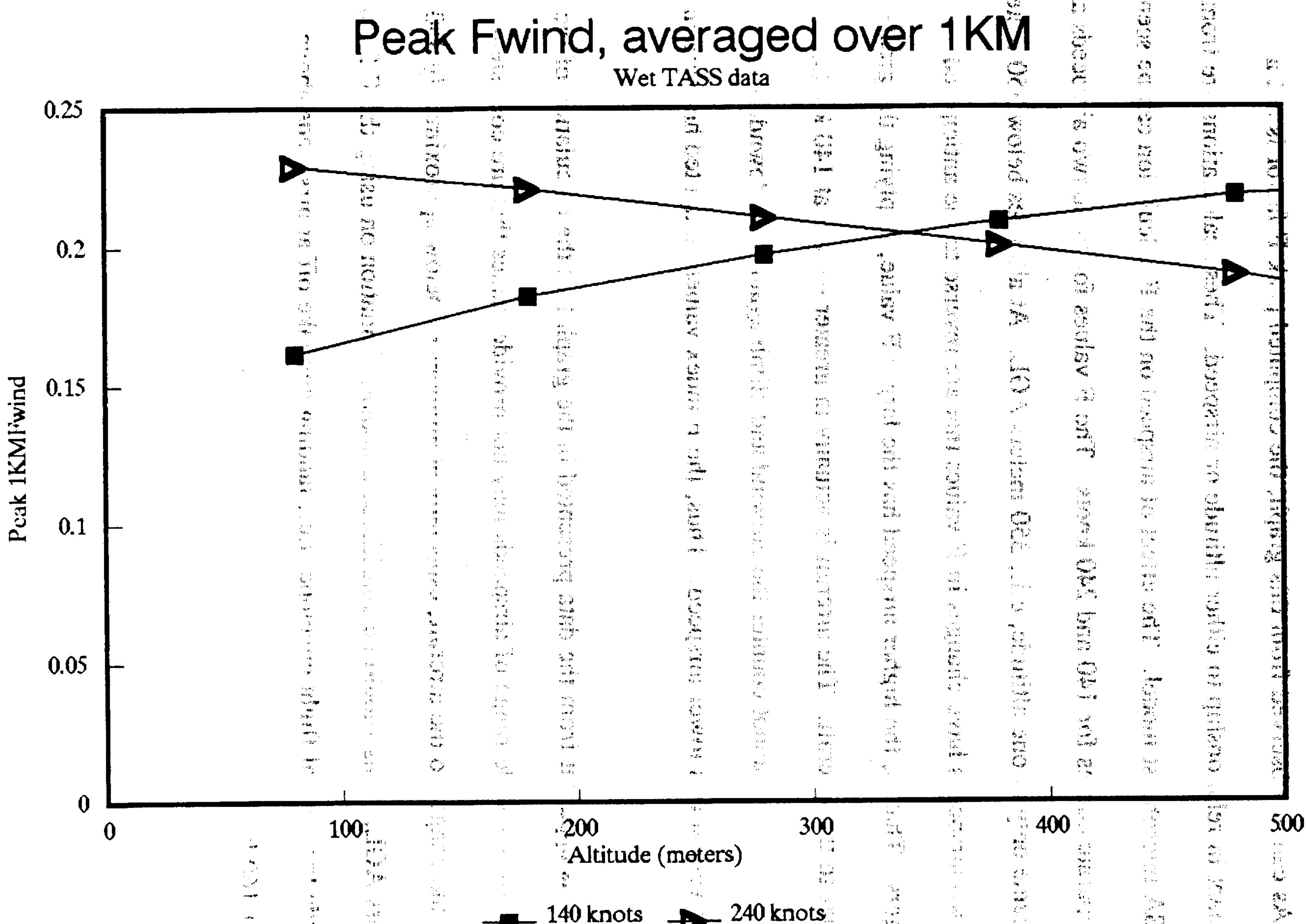
$$WHERE\ S_{INTEGER} = \frac{1000\ METERS}{AIRSPEED_{M/S}}$$

$$1KMFT_{WIND} = \frac{\sum_{1}^{S_{INTEGER}} F_{WIND}}{S_{INTEGER}}$$

TASS IS THE TERMINAL AREA SIMULATION SYSTEM WET MICROBURST STUDY
NASA WINDSHEAR MODEL (PROCTOR 1987)

called nasaiv.dat

In order to obtain an average value of F over a kilometer of flight, we first establish the number of seconds (S) required to proceed 1000 meters. Because the data comes only each second, we choose the closest integer value for S. The lower equation shows the use of this integer, S, and the F values obtained at each second from 1 to S. This provides us with the average F value over that 1 km distance.



FILENAME: FW14WA.DAT
DATE: 04-30-1992

Peak F Index versus Altitude at Different Airspeeds:

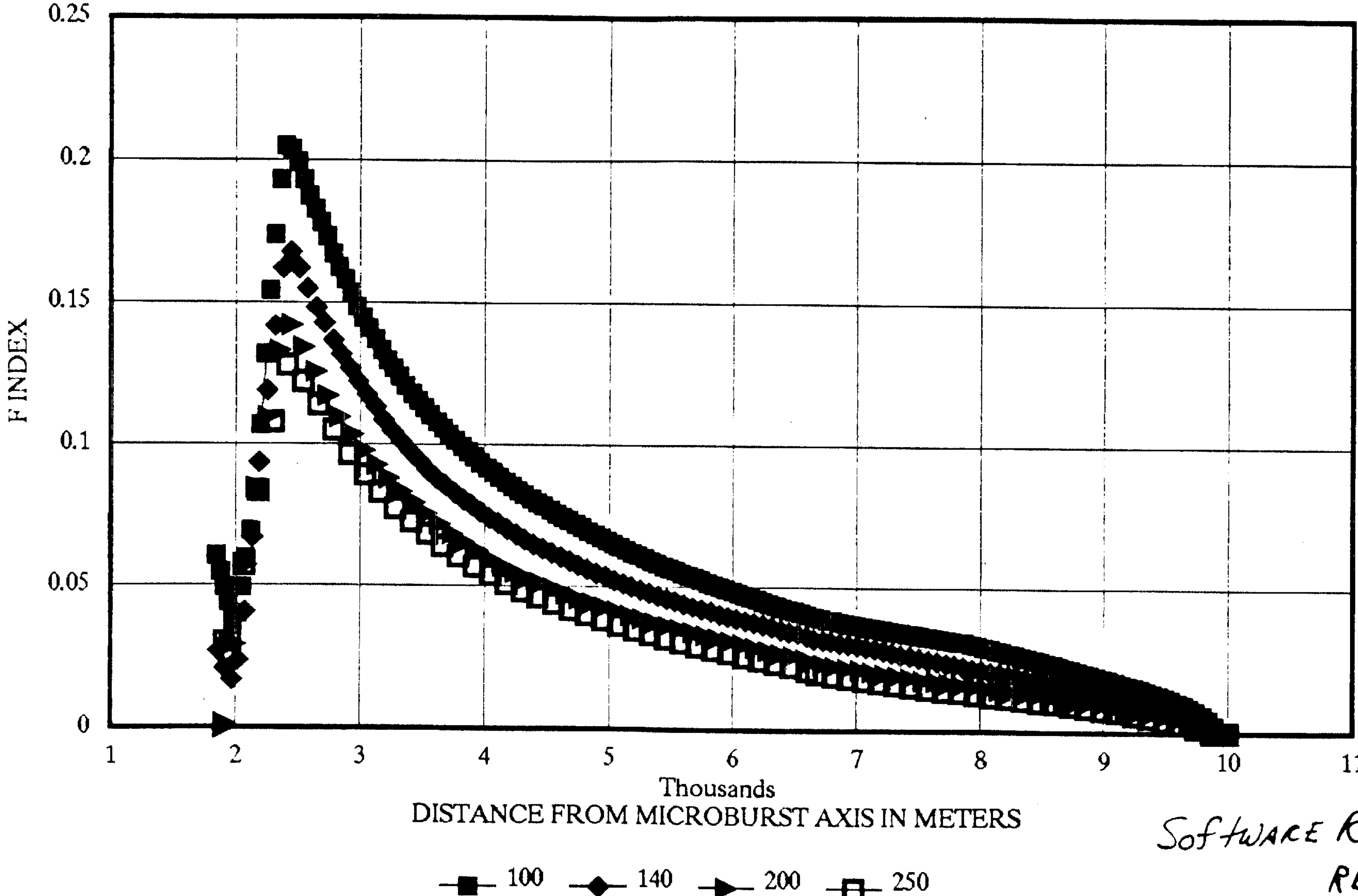
As can be observed from this graph, the computed peak F factor is not a constant in relationship to either altitude or airspeed. These calculations are from a NASA microburst model. The effect of airspeed on the F calculation can be seen as separate curves for 140 and 240 knots. The F values for these two airspeeds are the same only at one altitude, e.i., 350 meters AGL. At altitudes below 350 meters the two airspeeds have changes in F values that are reverse to the anticipated dangers. That is, the higher airspeed has the larger F value, implying the greater danger to the aircraft. The aircraft is actually in greater danger at 140 knots, however, for it cannot counter the tailwind and climb against the downdraft as effectively at this lower airspeed. Thus, the F index values computed here are in error relative to the aircraft situation.

It is apparent from the data presented in the graph that the calculation of the F factor over a wide range of airspeeds may not provide values that are consistent with the danger to the aircraft, especially at altitudes of below approximately 350 meters AGL. This should be considered a notable limitation on using the F factor outside the normal flight envelope, i.e., landing and take off at airspeeds above about 160 knots.

Thus, the importance of this graph is to show that the magnitude of the F peak value will be a significant function of the altitude of approach and the airspeed.

WET MICROBURST LANDING AT VARIOUS AIRSPEEDS

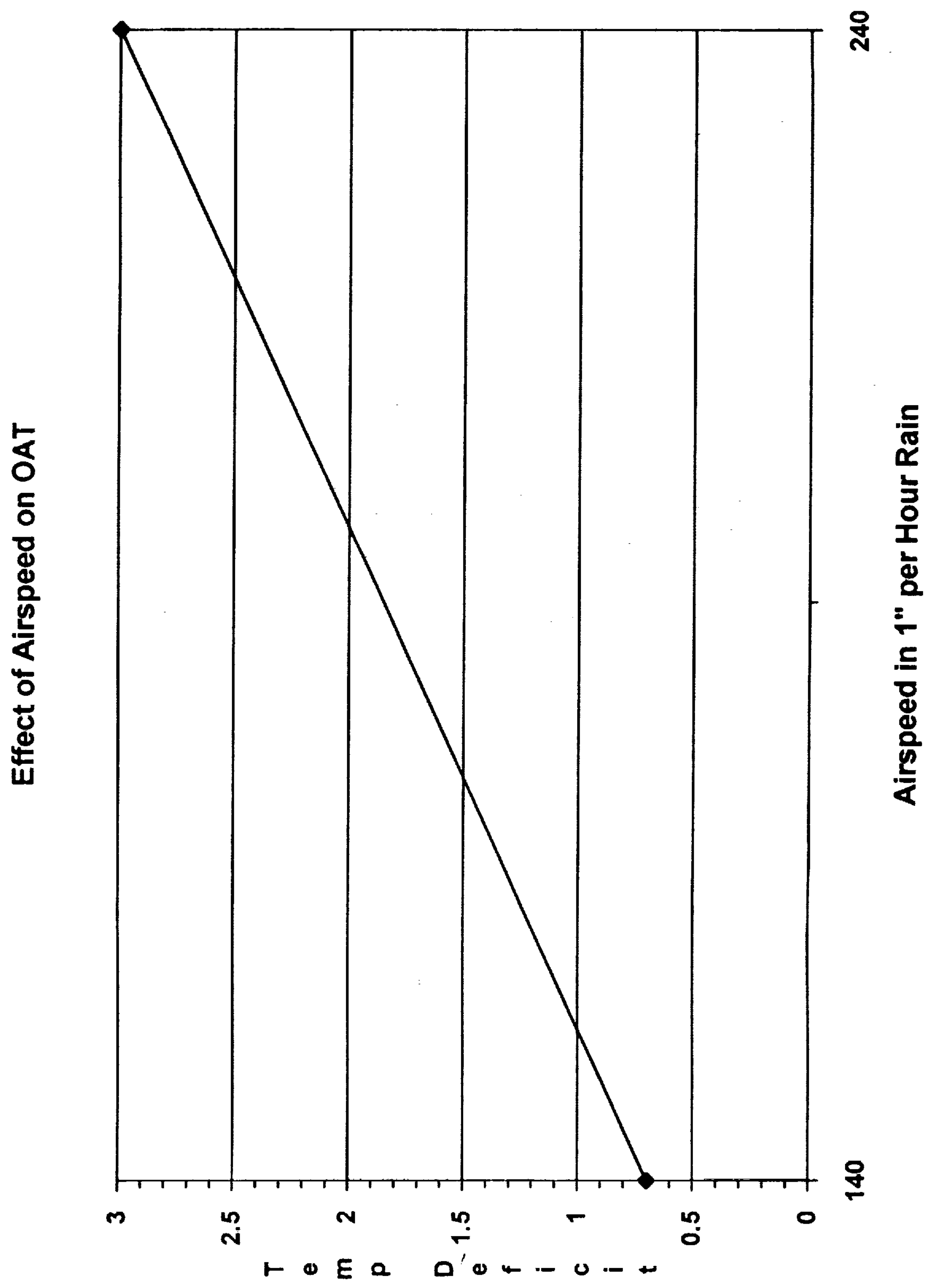
STARTING ALT 1500 FT



Software Rev 2.1.2.0
REV 2.1.1.2

GRAPH DATE: 03-20-92 - DJC
FILE: ALLLAND.WK3

When using the AWAS-III algorithm which takes advantage of thermal measurements, we obtain a rather different situation. Here, the lower the airspeed, the greater the peak value of the AWAS F index. This seems quite reasonable, for the lower the airspeed, the greater the danger to the aircraft. When the aircraft is flying fast enough, the danger is sufficiently low that a warning is not required. Also, we see that the lower the airspeed, the earlier the warning will be given. This also seems quite appropriate. Thus, we see that there is a very fundamental difference between the NASA F index, and the AWAS F index in character. These differences make it very difficult to directly compare the NASA and the TPS warning systems on a truly meaningful basis.


Effect of Airspeed on OAT
Temp Deficit
3
2.5
2
1.5
1
0.5
0
140
240
Airspeed in 1" per Hour Rain

The additional concern related to the airspeed is that of the response of the OAT transducer when operating in the presence of rain. The airspeed effect on the output of the OAT is related to the presence of rain which can evaporate and provide cooling for the gauge. The amount of cooling is a direct function of the airspeed. There is very often rain associated with the microbursts, thus there can be quite different response to these events with different airspeeds. It is possible at these considerably higher than normal landing and take off speeds to obtain temperature indications that can cause nuisance alarms when there are no microbursts present. Here we see that between 2 and 3 degrees Celsius temperature change can occur due to the difference in airspeed from 140 to 240 knots when flying into one inch per hour of rain. As a result, the higher airspeed can cause a warning to be given even when there is no actual change in air temperature. This is of considerable concern, for it keeps the OAT indicated temperature from being an accurate sensor of windshear when the airspeed is significantly greater than 140 knots. The problem of evaporate cooling has not presented a serious problem on other flights at normal landing speeds.

MICROBURST PENETRATION B143

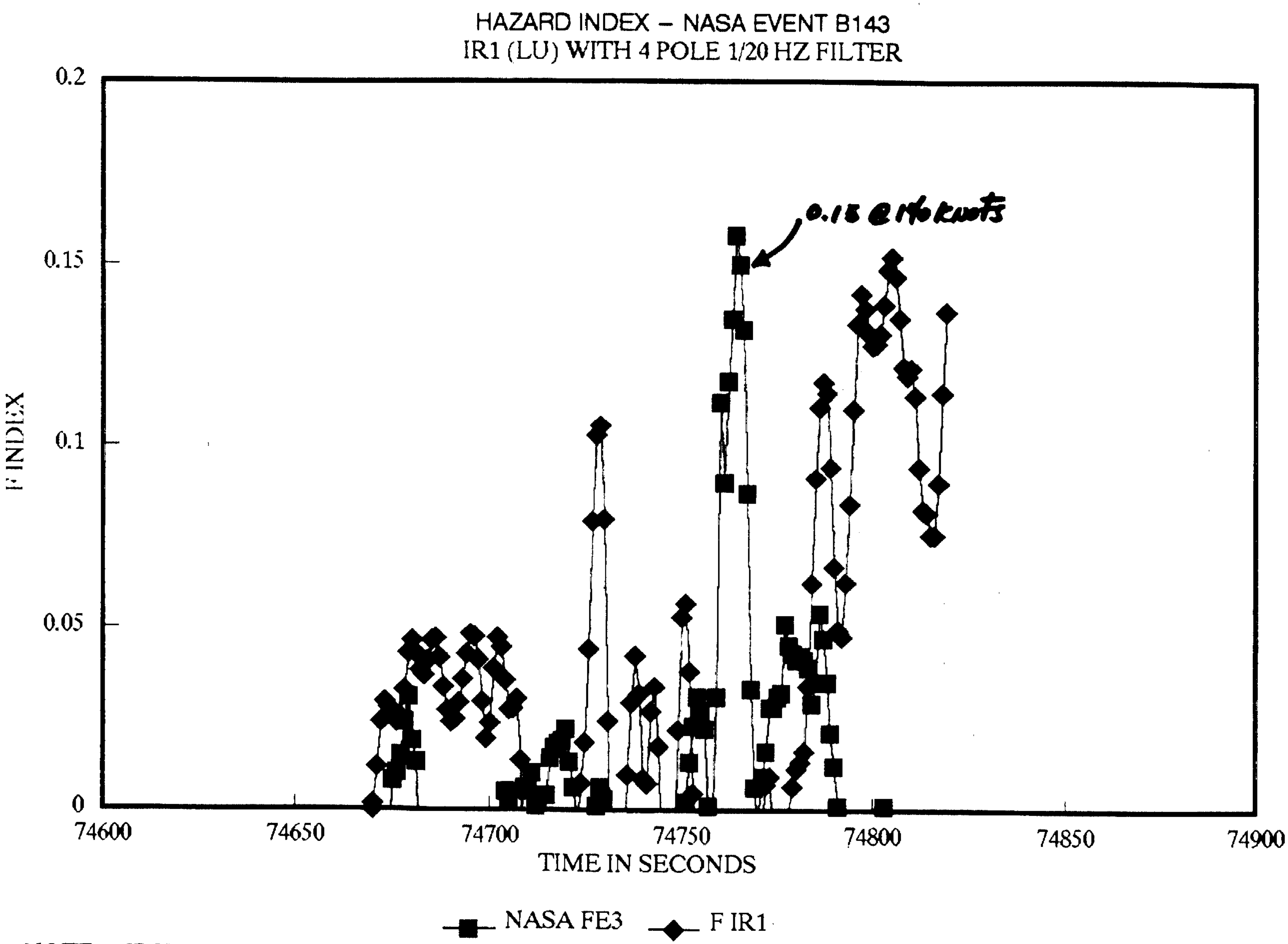
$F(TDWR)_{140KTS} = 0.13$*

$F(NASA)_{140KTS} = 0.15$*

$F(AWAS)_{140KTS} = 0.13$

*Preliminary - DH - 4/10/92

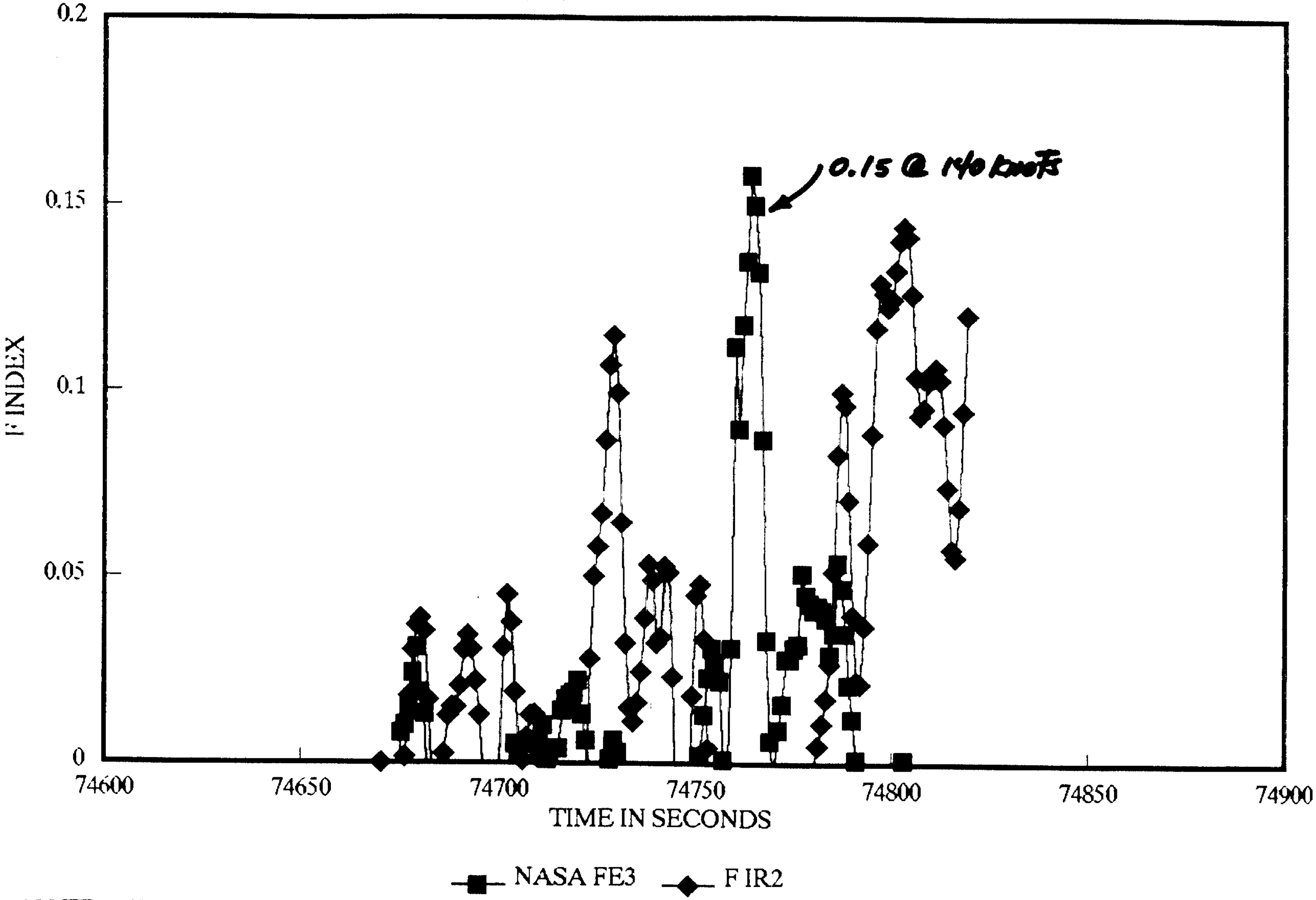
During the NASA penetration (B143), the IR sensor was not significantly blocked, and the IR performed as expected, when the data was adjusted for airspeed. After the data was adjusted to 140 knots, good agreement was provided among AWAS, the TDWR, and the NASA algorithm using inertial (wind) data. Noise level in the NASA algorithm is plus or minus 0.02.



NOTE: AIRSPEED CORRECTION APPLIED

Several post-flight tests were performed by computer on the data from this NASA test run. One was the use of a 4 pole 1/20 Hz filter on the raw data before entering it in the TPS algorithm. In addition, the NASA algorithm output was adjusted to 140 knots, even though the actual airspeed was about 235 knots average. This data is shown for the AWAS IR detector that looks up (LU) from the aircraft waterline by approximately 3 degrees. The predictive F indication from AWAS was considerably lower in magnitude than the inertial NASA F indication, which could be a result of the window still not being very clear. However, since the IR sensed the event about 34 seconds ahead of the inertial response, it appears that the IR was able to perform from a considerable distance in this case.

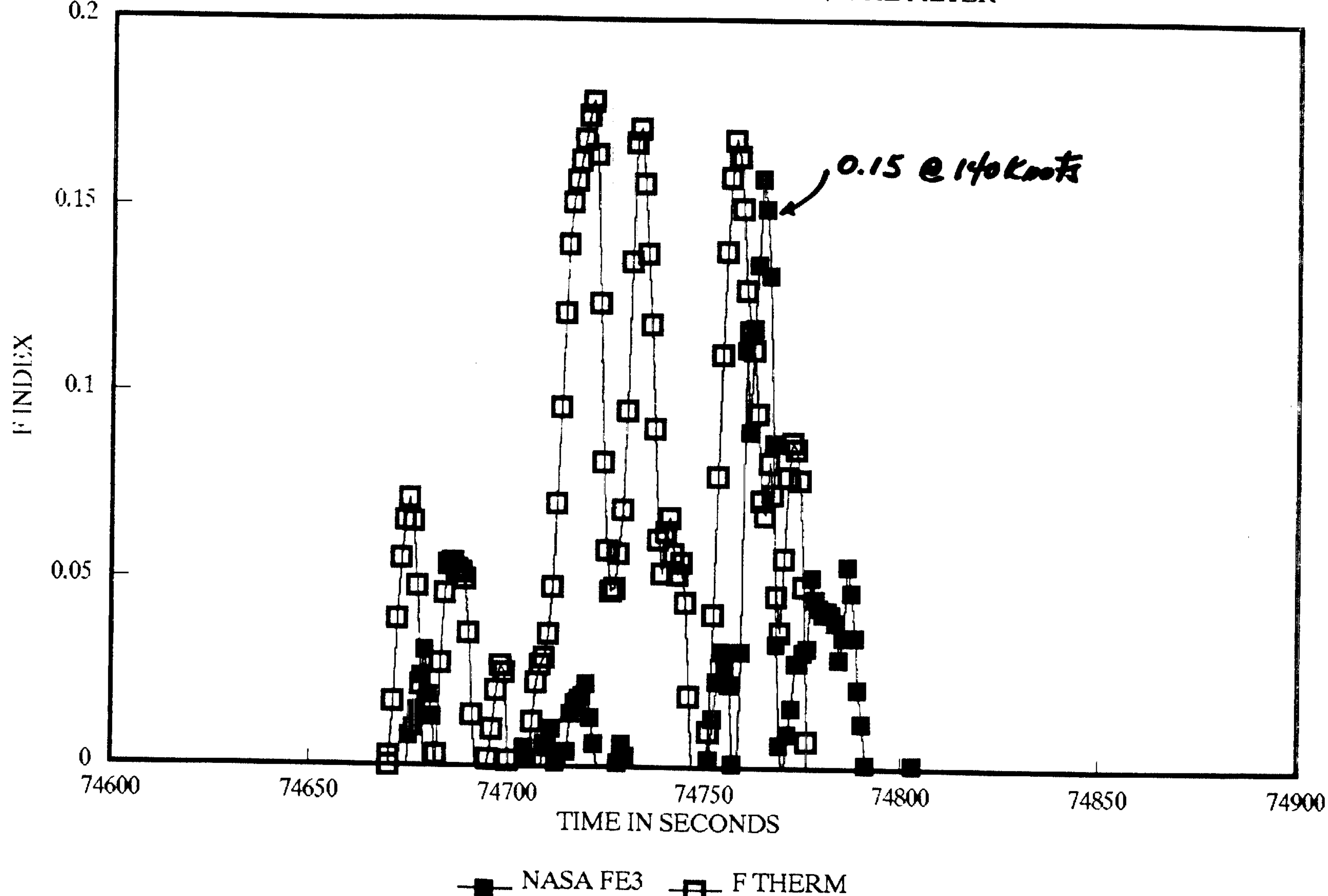
HAZARD INDEX – NASA EVENT B143
IR2 (LF) WITH 4 POLE 1/20 HZ FILTER



NOTE: AIRSPEED CORRECTION APPLIED

An identical treatment was given to the AWAS IR detector that was looking up from the waterline by only about 1 degree (LF). In this case the AWAS provided an F value of almost 0.12, and the airspeed corrected NASA algorithm provided a little over 0.15 for its F factor. The peak provided by the AWAS system preceded the NASA peak by about 34 seconds.

HAZARD INDEX – NASA EVENT B143
THERMAL INDEX WITH 4 POLE 1/20 HZ FILTER



NOTE: AIRSPEED CORRECTION APPLIED

The OAT based AWAS signal was also run through the 4 pole 1/20 Hz filter. This provided an F value of 0.18, and proceeded the NASA algorithm to the trigger point of 0.15 by 48 seconds. This F value for the thermal system was larger than anticipated, and responded sooner than would normally have been anticipated. Both of these effects could well have resulted from high airspeed through rain on the approach to the event. The smaller AWAS IR F values than the NASA values were in good agreement with the TDWR measurements.

TDWR PLOTS

REFLECTIVITY

2 MILES IN 1" / HR RAIN

The TDWR reflectivity data indicate 2 miles of flight in 1"/hour rain prior to contact with the event. This could account for the OAT response that was very early and large at this 235 knot airspeed. This would provide a signal that was about 26 seconds early.

NASA / TPS SUMMER PROGRAM 92

AWAS III

SW 2.1.2.1 = 3.2 NWA

If the AWAS is flown in the 1992 summer NASA B737 test program, the AWAS software will be upgraded to that presently being flown by Northwest Air Lines.

<u>TECHNICAL ISSUES</u>

- LOOK DISTANCE
- AIRSPEED CORRECTIONS
- MODE SELECTION OVERRIDE

There are a number of technical, as well as flight profile issues that must be resolved before further test flights into microbursts for the purpose of evaluating the AWAS in comparison with the NASA systems can be conducted. These are:

1. Change in the mirror/window installation.

2. Adjustment of airspeed effects in excess of the normal landing and take off airspeeds.

3. Overriding the AWAS automatic modes by NASA personnel.

RULES FOR SUCCESS / FAILURE

TPS PERSONNEL ON EVERY FLIGHT

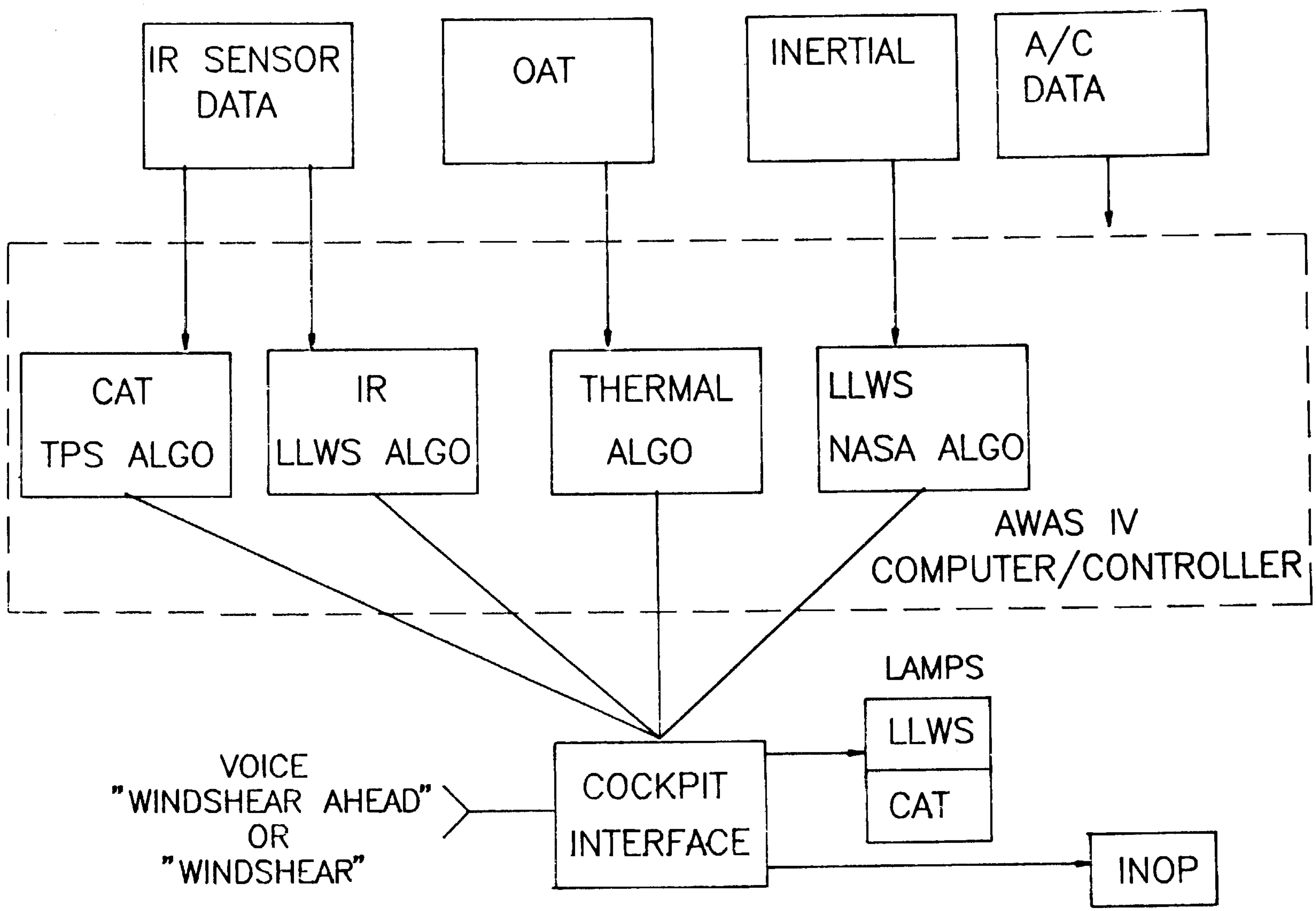
PREAGREED WRITTEN PROCEDURE

RECENT FAA DIRECTION (AWAS IV)

AWAS IV PREDICTIVE w/REACTIVE

The most recent FAA direction with respect to certification of AWAS is the development of AWAS-IV. This would combine the present predictive IR and OAT features with a reactive inertial system utilizing the NASA algorithm. The new combined system will provide prediction with the 100% detection (not protection) that is presently required.

AWAS IV PREDICTIVE WITH REACTIVE



10APR92

630275 REV X

The block diagram for AWAS-IV shows the added inertial data input to the NASA algorithm for LLWS. It also shows the IR sensor input at altitudes of 15,000 feet, and above, being used for the prediction of CAT (Clear Air Turbulence) events. The cockpit interface provides for aural warnings and lamps. The lamps would provide LLWS and CAT warnings. In addition, there would be a lamp to warn of inoperation of the AWAS system. It is critical for safety purposes that the pilot know if the AWAS is not operating.

IR FEATURE

THERMAL FEATURE

REACTIVE FEATURE
NASA ALGORITHM

CLEAR AIR TURBULENCE FEATURE

DISPLAY SECTION

LAMPS

INOP-ALERTS-CAUTIONS

Another aspect of the communication with the pilot is the providing of "cautions" when there is high probability of danger due to atmospheric conditions, but no specific event has been detected.

AURAL ALERTS

PREDICTIVE
2X "WINDSHEAR AHEAD"

THERMAL OR REACTIVE
3X "WINDSHEAR"

CERTIFICATION PLAN

STC PROCESS

NATIONAL WINDSHEAR TEAM
EQUIVALENT SAFETY FINDING

AWAS with REACTIVE
= REACTIVE + GUIDANCE

PREDICTIVE CERTIFICATION

USE FLIGHT DATA UND / NASA

USE FLIGHT DATA AA / NWA

The predictive certification will use flight data from the UND and NASA flights to determine the ability of the AWAS to predict events. The flight data from American and Northwest Air Lines flights will be used to determine the level of nuisance alerts.

COMPUTER MODELLING

TASS / DROEGEMEIER MODELS

GENERIC REACTIVE SECTION

FOLLOW AC 25-12

CONCLUSIONS

AWAS MODELLED FOR CONFIDENCE

AWAS FLOWN THROUGH EVENTS

AWAS FLOWN ON REVENUE
SERVICE (>5000 FLTS)

CERTIFICATION END OF 1992

AWAS IV
AVAILABLE
IN
1993

Development of the Advance Warning Airborne System (AWAS)
Questions and Answers

Q: Roland Bowles (NASA Langley) - You talked about designing to a 140 knot target airspeed. That means you have a design methodology because in fact you designed it for 140. Why can't we repeat that methodology and design it for 210?

A: Pat Adamson (Turbulence Prediction Systems) - I think it could be done. I don't think it could be done in time for this deployment. I also have a problem with spending a lot of energy designing something that we are not intended to use. Airplanes don't operate in that regime.

Q: Roland Bowles (NASA Langley) - We are showing on charts that we are taking data measured under one set of conditions and as you point out scaling it back to another. So it seems to me that you must have your own scaling relationship. I think it would be important to this audience for you to discuss what you think is the technical basis for relating an IR measurement to an airplane energy change?

A: Pat Adamson (Turbulence Prediction Systems) - I think it comes down to the forcing function of the event. A downdraft is cold air falling. If you look at the accident/incident data you see a sustained temperature drop over about thirty seconds as the aircraft penetrates the encounter. Now we don't use the actual aircraft temperature data, but we use the temperature gradient data as the forcing function for our algorithm. That is really the basis for it.

Q: John Hansman (MIT) - I was a little confused by your nuisance alert chart. On the American Airlines data, was that 20% of all the flight hours or flights you received some sort of nuisance alert?

A: Pat Adamson (Turbulence Prediction Systems) - That is correct.

John Hansman (MIT) - I am a little concerned from a display and human factors standpoint. If you have nuisance alerts at any significant level and you alert with a simple light in the cockpit, then you are going to run into fidelity or trust problems with the crew. Do you want to comment on that?

Pat Adamson (Turbulence Prediction Systems) - I totally agree with you. I think that it is an unacceptable alerting ratio. We decided to get at least 3,000 flights in our database before we made any significant software revision. So that we could look at the data. Right now on 3-2 we have one alert in 135 flights. We do not anticipate an alert any more often than the recommended nuisance alerting in the reactive systems. We have to get down to nuisance alerts of less than one per 2,500 flights or so, and that is where we think we are going.

Q: Jim Evans (MIT) - How do you discriminate between gust fronts, which are going to produce a gain in energy state, versus microbursts? They both have pools of cool air.

A: Pat Adamson (Turbulence Prediction Systems) - What we are looking at is a temperature gradient and a specific signature. I guess that is the best answer that I can give you.

Q: Jim Evans (MIT) - Have you attempted to fly through a lot of gust fronts and demonstrate that you are not generating an incorrect alert or do you view it as a correct alert?

A: Pat Adamson (Turbulence Prediction Systems) - I guess if the shear is high enough, even if it is a negative shear, I would be considering it a dangerous event.

Jim Evans (MIT) - When you go into a gust front you usually get a headwind increase but you do not have a tailwind, so you actually have an increase in energy state. It maybe a controllability issue, or a long landing, but it is not like the plane is going to get smashed out of the sky.

Pat Adamson (Turbulence Prediction Systems) - That's true. Looking at the work that Marilyn Wolfson did in your organization, her concern was that the dangerous events were associated with pre-existing gust fronts or thunderstorm outflows. Several of the gust front data show very high turbulence or vorticity associated with them. As it is right now, what we are trying to do is to use the temperature gradient and the signature to discriminate between severe events and non-severe events.

Q: Gerry Aubrey (United Airlines) - Do you have a threshold for what is the significant clear air turbulence you want to indicate?

A: Pat Adamson (Turbulence Prediction Systems) - We are working on that. The data that we are using for indication of severity is the vertical acceleration of the aircraft. We have been using 0.2 G or greater. But, the airlines do not seem to be interested in this small of a threat. They are much more interested in the larger one. We do not have much data where there is a severe event, even in some 5,000 flights.

Q: Kim Elmore (NCAR) - I would like to follow up on something that Jim Evans was talking about, and that is discrimination between a gust front event and a microburst event. Specifically in the Denver area, because that is where I have most of my experience, we find that the gust fronts tend to be colder events generally than the microburst. As I understand it, that would set off even a louder bell?

A: Pat Adamson (Turbulence Prediction Systems) - It depends, we look at not only the temperature drop but the signature that as we would encounter that event at 140 knots. If the temperature gradient is too high or too short in time it would discriminate against it.

Q: Kim Elmore (NCAR) - O.K. so if it is too high or too short or too big a gradient then you tend to throw that out?

A: Pat Adamson (Turbulence Prediction Systems) - That is correct.

Q: Pete Sinclair (Colorado State University) - I think the answer to that question is going to end up in the scanning procedure that will come out later on. We will be able to scan across the gust front and see quite a different configuration than a small microburst. My question is how do you keep the system clean and abrasion free? How do you keep it clean without a sealed system where the mirror and the whole system is internally sealed?

A: Pat Adamson (Turbulence Prediction Systems) - Actually, that has been sort of a revelation. When we first put this on we were worried about that. The mirror is heated. It has 120 watts of heat, with heavy gold plate on it, and the window is flush against the skin. The natural cleansing action of the rain and the warm mirror seems to be very effective. On American Airlines we have a coated window, we went to material that was supplied to us by Ball Brothers Aerospace and we now have five months on that installation without having to clean it or touch it. So, the natural cleaning action and the rain with the warm mirror seems to be very effective. We have been very surprised at how well that has worked.

Q: Paul Robinson (Lockheed) - You say an IR measurement is based on the detection of cold air in descent and this terminal effect is the driver of the microburst. However, the structure of the microburst requires the presence of the ground causing added divergence. This is an inertial effect. How can a purely thermal measurement detect this danger?

A: Pat Adamson (Turbulence Prediction Systems) - Essentially what we do is we assume that a sustained cold air downdraft, as sensed by an aircraft platform, is going to do one of two things: first, if it is above the outflow it is going to detect the core of the event. When I say sustained, I am expecting that temperature change that I derived to exist over about thirty seconds. I am not looking for a single little pulse of cold air, I am looking for a sustained temperature drop that I calculate as I traverse say a mile and a half at normal aircraft speed. That cold air is going to hit the ground and diverge. The second condition is if in fact I am in the outflow, I expected the outflow as I move through this mile and a half spatial realm is cold. That is basically how I do it.

Q: Paul Robinson (Lockheed) - By inferring the wind from the temperature you can possibly detect a microburst type hazardous shear. Can you ever get a hazardous shear without that temperature change?

A: Pat Adamson (Turbulence Prediction Systems) - Can you ever? Probably.

Q: Paul Robinson (Lockheed) - It is the shear that is going to effect the aircraft, so if your instrument won't pick up the temperature change, but the shear is still there, then it would not work as a predictive system.

A: Pat Adamson (Turbulence Prediction Systems) - The way I went at that, Paul, was I actually took aircraft incident data and I used the algorithm that I have against each and every event that I could get my hands on. I got the data from the NTSB. For example, yesterday I looked at the data from event 143, Fred Proctor was good enough to share his model as well as the actual aircraft data. In every case that I have found so far, and that is probably about sixty cases including the JAWS actual airborne penetrations, if I use the algorithm I could calculate the shear from the temperature drop. I assume that the cold air that is falling is going to flow out in the outflow over a sustained time, not a single little pulse, but over time. That is how I do it.

Q: Paul Robinson (Lockheed) - Using NASA's In Situ algorithm do you alter the systems properties based on the output of this algorithm?

A: Pat Adamson (Turbulence Prediction Systems) - We are certainly looking at that. I think there is some real benefit in taking advantage of a combined system. If you are going to have a reactive algorithm on board with a predictive system, I think you should look at the system as a combined system. We have not really sorted out all the details on that. When you look at the operational aspects, and that is a lot of what we have been trying to do with the airlines, the nuisance issue is equally as important as being able to predict the event. If you have high nuisance obviously it is useless to be able to predict the event, because the pilot won't believe it. We do not want to repeat that particular lesson. So yes we are trying to best understand how to combine these systems and make it a better system between the two.