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LOW-LEVEL FRONTAL WIND SHEAR FORECAST TEST.(U)
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REPORT NO. FAA-RD-77-184

LEVEL II

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LOW-LEVEL FRONTAL WIND SHEAR FORECAST TEST

BARRY RICHWIEN
ROBERT MCLEOD

APRIL 1978
SUMMARY REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research & Development Service
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16. Abstract

A summary report of low-level wind shear forecast tests for seven east-coast airports is provided. The tests were conducted between November 1976 and April 1977. The purpose of the tests was to verify and if possible improve upon a technique which forecasts significant low-level wind shear when (1) a $10^\circ F$ ($6^\circ C$) or greater surface temperature exists across a frontal zone and/or (2) a frontal zone has a surface movement speed of 30 knots or more.

Forecasts in the form of Low-Level Wind Shear Advisories were prepared for 3-hour periods at the Weather Service Forecast Offices responsible for forecasting for the test airports involved. The advisories were subsequently relayed to pilots through FAA communications nets.

The test results indicate that the forecast technique had limited success for warm frontal zones and that it is ineffective for cold frontal zones.

Certain mesoscale features resulted in more pilot reports of low-level wind shear than for the synoptic frontal systems.

Recommendations are made for the dissemination of shear advisories and for further investigations for improving low-level wind shear forecasts.

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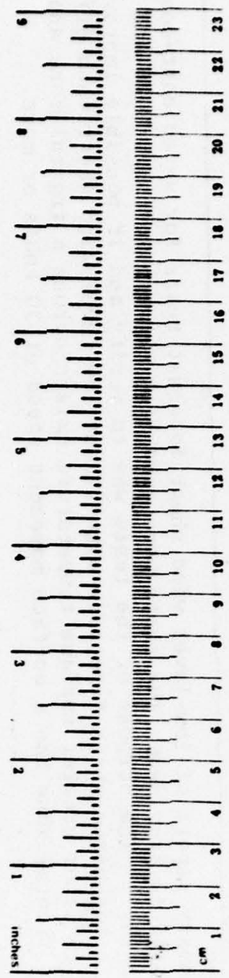
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

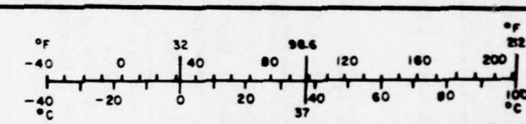
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in²	square inches	6.5	square centimeters	cm²
ft²	square feet	0.09	square meters	m²
yd²	square yards	0.8	square meters	m²
mi²	square miles	2.6	square kilometers	km²
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft³	cubic feet	0.03	cubic meters	m³
yd³	cubic yards	0.76	cubic meters	m³
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm²	square centimeters	0.16	square inches	in²
m²	square meters	1.2	square yards	yd²
km²	square kilometers	0.4	square miles	mi²
ha	hectares (10,000 m²)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m³	cubic meters	35	cubic feet	ft³
m³	cubic meters	1.3	cubic yards	yd³
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The work reported herein was supported by the Federal Aviation Administration under a Memorandum of Agreement between the FAA and the NWS. (Letter November 1, 1976 from Director, NWS to Director, Air Traffic Service, FAA.)

The authors' extensive and detailed report, which may be published at a later date, was summarized by Arthur Hilsenrod, Aviation Weather Branch, Systems Research and Development Service (SRDS) in coordination with Major J. Lindquist and F. Coons of SRDS, D. Cooley and E. Gross of the NWS, and the authors of the report.

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1. BACKGROUND

1.1 THE PROBLEM

Several major airline accidents of the past few years have been due, in part, to low-level vertical wind shear. Details on these accidents can be found in National Transportation Safety Board Accident Reports and in the Federal Aviation Administration (FAA) Wind Shear Program Plan* and will not be discussed here.

The contents of this summary deal only with the meteorology of low-level (below 2000 feet above ground level) wind shear and the forecasting of shear created by non convective atmospheric conditions. Other potential solutions to the wind shear problem are discussed in FAA ED-15-2A.*

1.2 WIND SHEAR DEFINITIONS

To clarify the use of terms for purposes of this report, the following definitions are offered.

1.2.1 Mathematical Definitions. The mathematical definition of wind shear is the vector (speed and direction) change of wind over some distance, d, in space or:

$$\frac{\Delta \vec{V}}{\Delta d}$$

Since V can be broken down into u, v, and w components and d into x, y, and z directions; there are nine possible components of shear. The x and y directional components we shall define as h. The most important shear components to aviation are the vertical shear of the horizontal wind, $\Delta V_H/\Delta z$, and the horizontal shear of the horizontal wind, $\Delta V_H/\Delta h$. To an aircraft on an approach glideslope, the actual shear experienced is some combination of both of these. When it is assumed that the shear is horizontally uniform (i.e., $\Delta V_H/\Delta h = 0$) in the vicinity of an airport,

* Federal Aviation Administration, Engineering and Development Program Plan - Wind Shear, Report No. FAA ED-15-2A, August 1977

only the $\Delta V_H/\Delta z$ term is important. One important exception is the shear of the thunderstorm gust front. The scale of the gust front is so small that conditions are not horizontally homogeneous. Furthermore, the remaining components of shear (i.e., $\Delta w/\Delta h$ and $\Delta w/\Delta z$) and the magnitude of w itself become important, i.e., updrafts and downdrafts.

1.2.2 Effect on Aircraft. A conventional way of discussing shear is in terms of its effect on aircraft. This is done by rotating the fixed coordinate system to fit the aircraft flight path. Then one speaks of longitudinal (head/tailwind) and cross wind (left/right) components of shear. These components cause airspeed and drift angle changes respectively.

1.2.3 "Positive" and "Negative" Shear. The International Civil Aviation Organization (ICAO) has offered the terms "positive" and "negative" shear in classifying the effect of shear on an aircraft, the former for causing increased airspeed and the latter for decreased airspeed. Since wind shear information in these terms may be misunderstood by the pilots, the FAA has directed that the use of the terms "positive" or "negative" wind shear be avoided by pilots and controllers. (Belanger, 1977).[1]

1.2.4 Significant Wind Shear. Finally, what is significant wind shear? Values of shear in an operational context are usually expressed in terms of knots per 30 meters (m) or 100 feet. D. Sowa* states (personal communication) that 5 knots/30m over a 100m depth is significant to air carrier operations. ICAO categorizes shear in the following manner (according to the 5th Air Navigation Conference):

Shear Intensity	Value
Light	0-4 knots/30m
Moderate	5-8 "
Strong	9-12 "
Severe	> 12 "

The above categorization, however, has not yet been generally accepted by aviation interests. Along with the above, one must consider the altitude at which the shear occurs. For example, on final approach to landing, moderate shear encountered by an aircraft at an altitude of 100m could be more dangerous than at 400m.

---

* D. Sowa, Superintendent of Meteorology, Northwest Orient Airlines.

The reporting of significant shear is currently affected by the resolution of measurement. Higher values of shear will normally be found using, for example, an Acoustic Doppler system which vertically averages the wind over 30m intervals as compared to standard rawinsonde winds which are averaged over 300m.

1.2.5 Summary. In determining values of significant shear one must consider:

(a) Aircraft operating parameters
(b) Altitude of encounter
(c) Resolution of measurement

For purpose of this report, we shall adopt the threshold value of 5 knots per 30m as being the significant shear value. Similarly, "low-level" shall mean the airspace between the ground and about 600m (2,000 feet above the ground).

Detailed discussion of the relationships of the aircraft, pilot and wind shear are presented in articles by the Higgins and Roosme[10] (1977) and J. T. Frederickson (1977).[7]

1.3 METEOROLOGICAL CAUSES OF SHEAR

Most low-level shear can be considered as being caused by either friction or an airmass density discontinuity (i.e., a frontal zone). Even over the smoothest of surfaces, frictional drag always develops a shear layer near the ground. This situation is aggravated by obstacles to the flow such as buildings and hills, Fichtl et al., (1977)[6] provide a good description of these causes of shear.

Frontal zones (fronts) can be categorized as being either synoptic or meso-scale. Synoptic fronts (i.e., warm, cold, stationary fronts depicted on everyday weather maps) stretch for 100's to even 1,000's of km while meso-fronts such as the gust front, sea breeze, and coastal fronts (See Bosart, 1977)[4] extend only for 10's to 100's of km. The vertical scales of these fronts are similarly related. Synoptic fronts extend upward through most of the troposphere (about 10 km) whereas meso-fronts seldom extend above 1 km.

This report will deal mainly with the shear caused by synoptic-scale frontal systems. One other known cause of significant low-level wind shear is the low-level jet. It is not a frontal phenomenon and cannot be easily identified as a meso-or synoptic-scale phenomenon. Usually there is an inversion associated with a low-level jet and the maximum winds are often much higher than gradient. Bonner (1968)[3] used 2 years of wind data to establish the synoptic climatology of the low-level jet and found a frequency maximum over the southern Great Plains and a slight secondary maximum along the East Coast. Blackadar (1959)[2] attempted to show that jet profiles arise from an inertial oscillation of the ageostrophic wind (difference between the observed and the geostrophic wind) vector as air near the top of the friction layer is decoupled from the air below by the formation of a nocturnal inversion.

Green et al, 1977,[8] also provide a detailed discussion of the causes of low-level wind shear.

2. PURPOSE

Accurate and reliable forecasts of significant wind shear are required to warn pilots of potentially hazardous conditions.

A technique for forecasting wind shear has been offered by Mr. Daniel Sowa, Superintendent of Meteorology of Northwest Orient Airlines (1974).[11] According to Sowa, wind shear significant to aircraft operations would occur when the surface temperature difference across the front is at least 6°C (10°F) and/or the front moves at a speed of 30 knots or greater.

A test was initiated to determine the 1) effectiveness of this technique under National Weather Service forecast environment, 2) improvements that could be made on this technique, 3) methods of operational implementation of a satisfactory technique.

3. TEST PLAN

3.1 GENERAL PROCEDURE

A joint National Weather Service (NWS)-Federal Aviation Administration (FAA) plan was devised to achieve the purpose of the test.

Forecasts of low-level wind shears (called Low-Level Wind Shear Advisories) were issued for a period of 6 months from November 1976 through April 1977, 7 days a week between the hours of 0700 and 2200 Eastern Standard Time.

The forecasts were issued by three National Weather Service Forecast Offices (WSFO's) for their respective airports of responsibility. These WSFOs and airports were:

WSFO Washington, D.C.	Dulles International Airport (IAD) Washington National Airport (DCA)
WSFO, Philadelphia, PA	Philadelphia International Airport (PHL) NAFEC/Atlantic City Airport (ACY)*
WSFO, New York, N.Y.	John F. Kennedy International Airport (JFK) LaGuardia Airport (LGA) Newark International Airport (EWR)

Figure 1 is a map showing locations of the above airports, NWS upper air and surface Weather Observation Stations used in the tests.

The other participating office was the FAA Central Flow Control Facility (CFCF) which is located at FAA Headquarters in Washington, D.C. It's function is to maintain coordination between major airport traffic control towers and Air Route Traffic Control Centers (ARTCCs) to assure an expeditious flow of air traffic over the United States. CFCF is normally staffed with a contingent of four NWS meteorologists to provide meteorological support for the efficient control of air traffic. For purposes of this test, two additional NWS meteorologists were added.

All communications between CFCF and the test airports were made via dedicated telephone lines. They were already in existence between CFCF and the FAA facilities but additional lines had to be linked from WSFOs to CFCF.

Upon receipt of wind shear advisory from CFCF, tower personnel recorded them on the Automatic Terminal Information Service (ATIS) when possible. ATIS provides pilots the latest routine weather observations and NOtices to Airmen concerning airport conditions for use in landings or departures. If ATIS was not available, or could not be updated rapidly enough, the Wind Shear Advisories were verbally relayed to pilots by controllers on control frequencies, time permitting. This flow of information permitted maximum opportunity for interaction between pilots, controllers, and meteorologists. Figure 2 is a schematic diagram of the information flow. The Wind Shear Advisory was also sent out on the Aeronautical Radio, Inc.(ARINC) teletype circuit. This assured that major air carrier meteorological or dispatching offices also received the Wind Shear Advisories.

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* National Aviation Facilities Experimental Center.

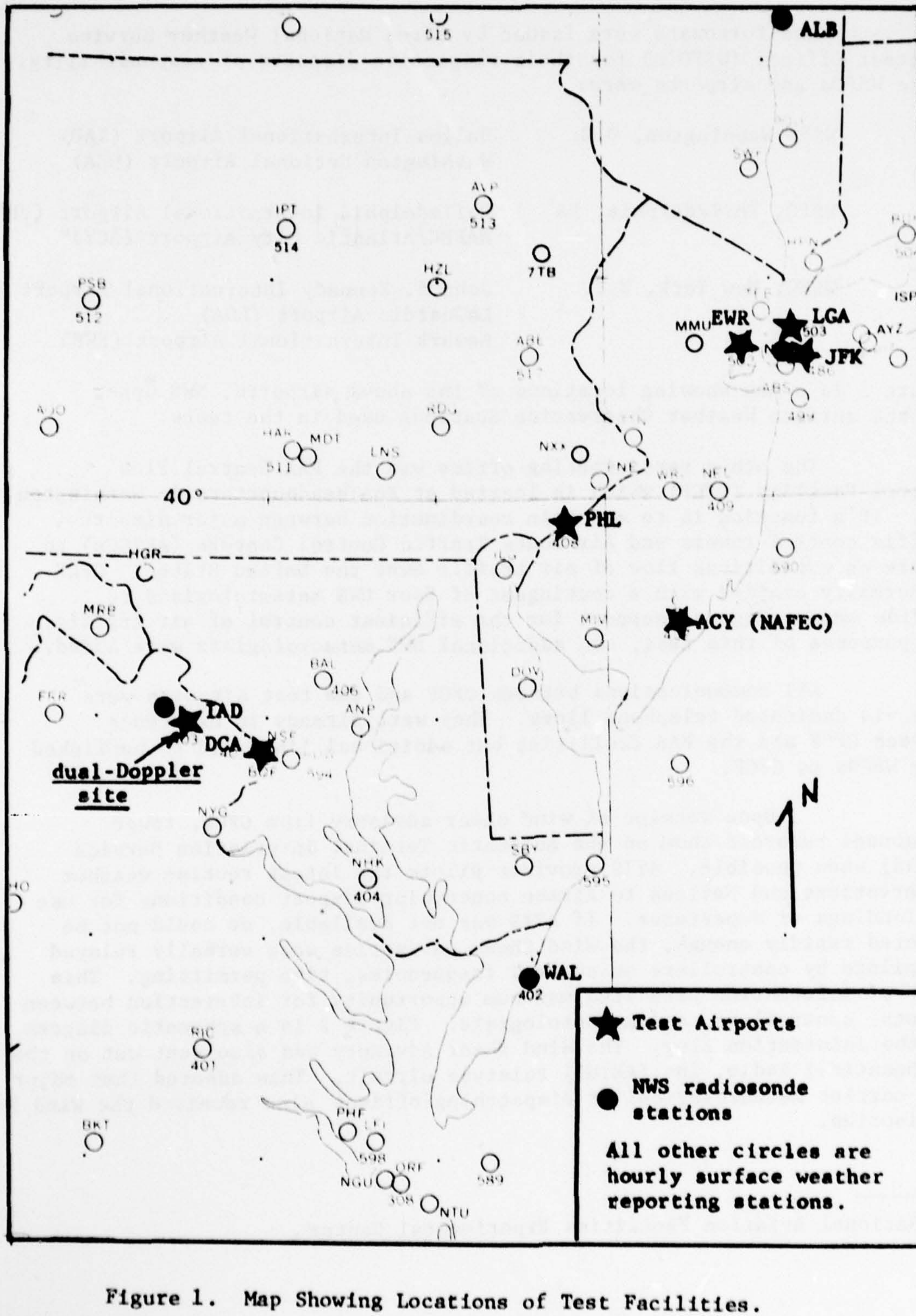

Figure 1. Map Showing Locations of Test Facilities.

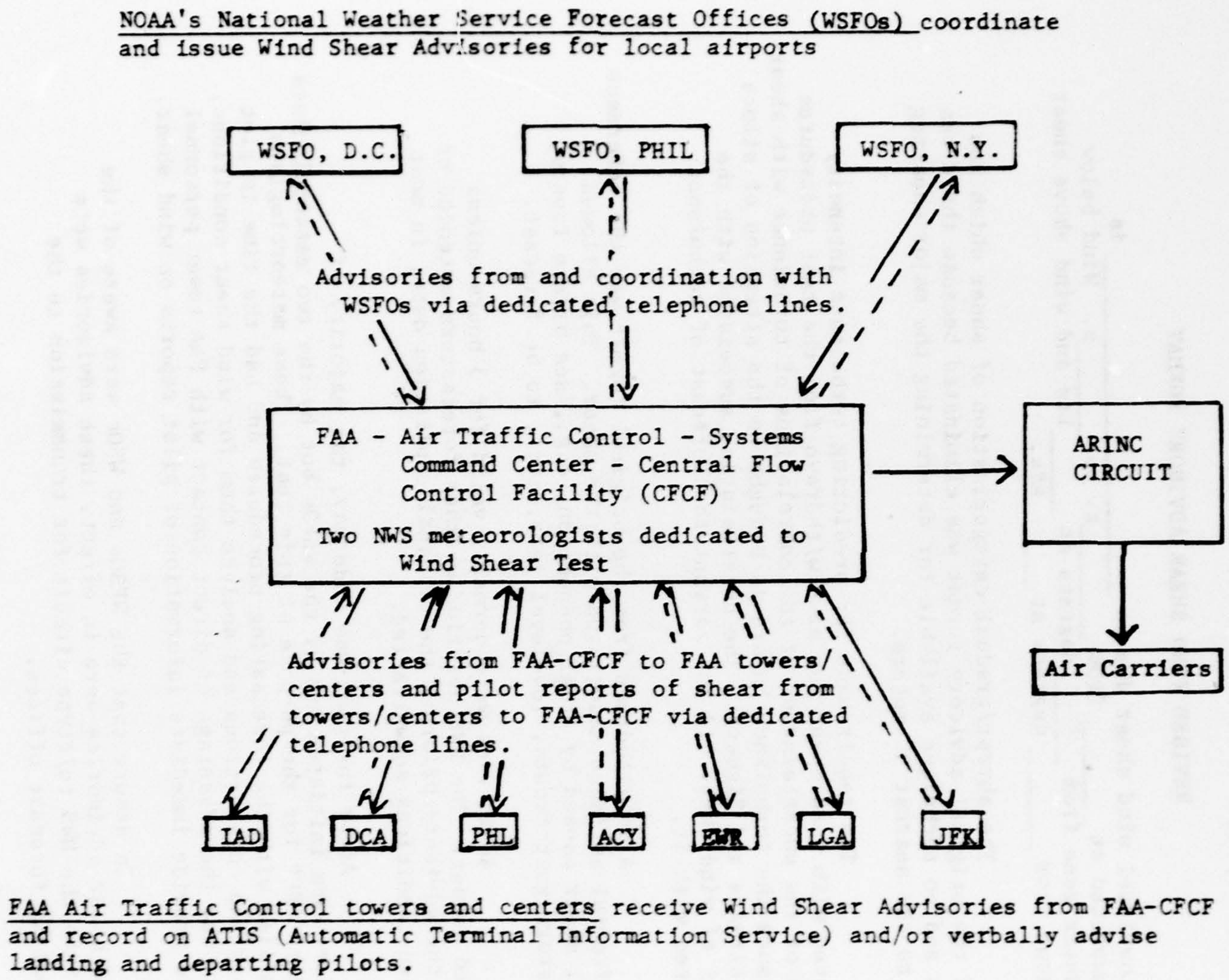

Figure 2. Information Flow Diagram for NWS-FAA Low-Level Wind Shear Forecast Test.

After some initial trials the following advisory format was adopted:

REVISED WIND SHEAR ADVISORY FORMAT

Low-level wind shear due to ______________________ is expected at ______ from ________z. to _______z. Wind below shear zone from ______ degrees at ______kts and wind above shear zone from _______ degrees at _____kts.

The abrupt/gradual categorization of shear which was part of the original advisory format was eliminated because there was no data and no technique available for determining the major shearing action to the nearest 30 meters.

The requirement for predicting turbulence intensity associated with wind shear was also withdrawn from the test procedures because of the uncertainties of the correlations of turbulence with shear and because the turbulence hazard is brought to the attention of pilots by NWS Airmets and Sigmets. The uncertainties associated with the forecast of wind shear did not warrant the forecast of turbulence associated with it.

Also withdrawn from the original format was the reference to the frontal surfaces associated with the shear. This allowed vertical shear caused by other phenomenon, e.g., sea breeze fronts, thunderstorm gust fronts, low-level jets, etc., to be forecast.

Advisories were normally valid for 3 hours unless cancelled sooner. The NWS aviation weather forecasters extended or amended the advisory prior to the original expiration date, in most cases when conditions so warranted.

After the test was underway, the majority of advisories were initiated not by the WSFOs but by the two meteorologists assigned to CFCF for the purpose of this test. These meteorologists were familiar with the forecasting procedures and had the time to plot hourly surface observations and analyze them for wind shear conditions. They also had the advantage of direct contact with FAA tower personnel who could provide immediate information of pilot reports on wind shear.

To assure that the WFSOs and WSOs were aware of the time wind shear advisories were in effect, these advisories were entered into the NWS teletype circuit for transmission to the participating forecast offices.

3.2 METHODS OF VERIFICATION

There were four methods used to verify Low-Level Wind Shear Advisories. They were: (1) Meteorologically instrumented FAA Aero Commander based at Atlantic City/NAFEC, (2) dual (Acoustic/Microwave radars) Doppler System near Dulles International Airport, (3) winds measured by NWS rawinsondes, and (4) pilot reports. A brief review of these methods are as follows:

(1) The NAFEC Aero Commander aircraft was equipped with an Inertial Naviagation System, Central Air Data Computer and meteorological sensors. This instrumentation permitted calculation of inertial winds at any altitude of a flight as well as vertical profiles of temperature, humidity and turbulence.

(2) The dual Doppler system (Hardesty et al, 1977)[9] utilizes the Doppler shift of sound waves to determine wind direction and speed at selected altitudes over the acoustic transmitter site. After precipitation begins, the system automatically switches to the microwave radar mode and uses the movement of hydrometers (rain, snow, etc.) to determine low-level winds. The system provides a 6-minute average wind for every 30 m of altitude to a height of about 500 meters.

(3) The usefulness of the NWS radiosondes were limited by the infrequency of observations (only every 12 hours) and winds reported at 300m (1000 feet) intervals. The reported winds were an average over a deep vertical layer. Strong surface winds diminished the representativeness of these winds further. Paradoxically, the existence of strong low-level wind shear made radiosonde winds unrepresentative for use in determining the existence of wind shear.

(4) Pilot reports provided the most consistent method of verifying the wind shear advisories. Unfortunately, pilot reports are subjective. Some of the subjectivity was reduced by requesting pilots to report indicated airspeed changes (Δ IAS) after experiencing wind shear.

3.3 LIMITATIONS OF VERIFICATION TECHNIQUES

Each of the preceding verification techniques supplied only limited information. NAFEC's Aero Commander was only able to honor 25% of requests for reconnaisance flights during periods when advisories were issued. The dual Doppler system was only available at Dulles International Airport and had no applicability to other test airports.

Collection of pilot reports was cumbersome. However, a form was developed that was used by FAA towers to provide the pilot reports including changes of indicated air speeds and runway in use. Pilot reports became the best method of evaluating wind shear advisories.

3.4 ADDITIONAL DATA FOR WIND SHEAR ANALYSIS

Additional information for characterizing the wind shear were obtained from the analysis of:

(1) Synoptic charts and radiosonde data obtained from the National Climatic Center, Ashville, N.C. These data clarified the synoptic situation that produced frontal shears.

(2) Runway logs from the seven test airports. These records helped determine the orientation of arriving and departing aircraft with respect to forecast wind conditions.

4. RESULTS OF TESTS

Table 1 provides a summary of advisory-event days. There were several events for which no advisories were issued but to which a significant number of pilot reports were attributed. Two of these events, one for February 5-6 and one for March 9-10, are discussed on page 19.

The following is a summary of the 22 events for which advisories were issued. The events of January 28 and February 24 are discussed in more detail on pages 15 and 16.

Event #1, 11/19/76 (Cold Front)

This was the first Low-Level Wind Shear Advisory of the test and results reflected our lack of expertise. The cold front decelerated unexpectedly as it approached DCA and passed the airport hours after the Advisory had expired. Proper synoptic analysis may have forecast the deceleration.

Event #2, 12/2/76 (Cold Fronts)

Two cold fronts were involved with this Event. Advisories were issued for the first. Doppler wind profiles from IAD showed 1) the front was at least as steep as 1/30 in the surface to 400m layer and 2) A rough estimate of the vertical shear across the front was <3 knots/30m, a light shear condition.

TABLE 1. SUMMARY OF ADVISORIES ISSUED

Event No.	Date	Airports	Type of Front	Estimated Speed of Front (Kts)	ΔT(°F) 100 NM	Type of Verification*
1	11/19	DCA	cold	18	14	none
2	12/2	IAD, DCA	cold	40	14	D,P
3	12/7	NYC	cold	20	14	P,
4	12/20	ALL	cold	25	10-20	D,P,R
5	1/10	NYC,PHL	warm	15-30	15-20	P,(R)
6	1/28	NYC	warm	20	12	P,(R)
7	1/28	ALL	cold	30	28-33	D,P
8	2/20	NYC	warm	25	7	R,P, (D)
9	2/24	NYC,PHL,ACY	warm	5-10	8-20	P,R,(D)
10	2/25	NYC		NA	NA	P,R,(W)
11	2/27	NYC	warm	5-10	20	P,R
12	3/4	ALL	warm	3-20	12-20	D,P,R
13	3/5	NYC,PHL,ACY	cold	20-30	8-10	P,(D)
14	3/13	NYC	warm	NA	14	P,R
15	3/16	IAD,DCA	cold	40	0-5	D,R,P
16	3/18	ACY,PHL,NYC	warm	<10	15-25	P,R
17	3/22	NYC	warm	20-25	12	P,R
18	3/28	DCA,IAD	warm	5-10	20	P,(D),R
19	4/2	IAD,DCA,NYC	warm	5-10	15-20	D,P,R
20	4/5	PHL,NYC	warm	5-10	15	P,(D,R)
21	4/24	PHL,ACY	stationary	$\pm$00	22	P,(R)
22	4/28	NYC	cold	25	20	(D)

* - In Order of Verification Usefulness

R - Radiosondes

D - Acoustic Doppler System

()- Limited Indirect Verification

P - Pilot and/or Tower Reports

W - Wallops Island Tower Winds

NA- Not Applicable

Event #3, 12/7/76 (Cold Front)

This Advisory was for a cold front which really was a "coastal front" that had started moving seaward behind a small low center moving northeastward along the Atlantic Coast. Most pilot reports of shear were attributed to causes other than the cold front including a low-level jet (LLJ). Evidence for the LLJ included (1) aircraft-reported winds of 70-80 knots within 600m of the surface and (2) earlier appearance of LLJ in Dulles Airport (IAD) Doppler profiles (which incidently coincide with a pressure jump event at IAD as described by Bedard, et al. (1977)).[8]

Event #4, 12/20/76 (Cold Front)

For this cold front event, frontal slopes were computed by using speed of front, time transpired since passage of front at surface and height of frontal surface at some later time. The height of the frontal surface determined from the radiosonde data yielded a slope of 1/19; using IAD Doppler profiles gave a 1/18 slope. These are conservative slope estimates. Perhaps the steepness of the front and resultant fast-rise of its surface is the reason why only one of 12 pilot reports of shear was directly attributable to the cold front.

Event #5, 1/10/77 (Coastal and Warm Fronts)

This event featured another small low pressure center moving northeastward along the Atlantic coast. Our meso-analysis showed a coastal front to which several pilot reports were attributed. In the NYC area, it became difficult to distinguish the meso-scale coastal front from the synoptic warm front for which the Advisory was issued.

Event #6, 1/28/77 (Warm Front)

Advisory was issued because of one pilot report of shear from JFK and slight indication of a warm front. The Advisory was continued even after apparent passage of the warm front because of continuing pilot reports of both shear and high winds within 600m of the ground.

Event #7, 1/28/77 (Cold Front)

The details associated with this cold front are discussed in Section 4.1.

Event #8, 2/20/77 (Warm Front)

Warm front Advisories for this day were issued mainly in reponse to pilot reports from JFK and in anticipation of the warm front moving closer. In retrospect, most shear pilot reports of the day again can be attributed to other causes including a low-level jet. Also, radiosonde data suggest that the frontal surface never did drop below 600m as the low center passed by to the south or east of the forecast area. These Advisories did not verify well. Aero Commander profiles showed some moderate (5 knot/30m) shear at ACY below 600m but an Advisory was not issued there.

Event #9, 2/24/77 (Warm Front)

The highlight of this warm front event is that there were many reports of low-level wind shear but more than half were attributed to causes other than the frontal surface including low-level jet and "cold sea inversion." This case is an excellent example of being right for the wrong reason. This event is discussed in more detail in Section 4.1.

Event #10, 2/25/77 (Non-Frontal Shear)

This Advisory-Event was the only one of its kind. The Advisory was not issued for shear due to a front but rather for "vertical wind shear." Therefore, we did not follow our usual verification procedure. There were, however, confirming pilot reports. The cause for the shear in this case was frictional slowing of strong northwest flow.

Event #11, 2/27/77 (Warm Front)

No warm front Advisory was issued for Dulles Airport because the warm front passed the airport before the daily test period began. It showed, unlike other cases, a substantial contribution of directional change to the total shear vector which had a maximum of about 7 knots/30m. There was also some evidence of a low-level jet. In the NYC area, where the Advisories were issued, there were surprisingly few pilot reports of shear. The ones that appeared to be associated with the warm frontal surface occurred just as the frontal surface appeared to interact with the cold sea-induced inversion.

Event #12, 3/4/77 (Warm Front)

This warm front prompted Advisories to be issued for all test airports. Most pilot reports were from NYC where, paradoxically, the test parameters would have predicted the least shear. As in Event #11, this appears to be due to some sort of interaction with the cold sea inversion at NYC. Another interesting aspect of this event was the orientation of the warm front in the interior section of the mid-Atlantic states where it paralleled the coast and persisted for many hours. The cold air was only about 100m deep - a meso-scale feature to which pilot reports of shear were attributed.

Event #13, 3/5/77 (Cold Front)

These cold front Advisories were issued almost completely in response to three pilot reports at DCA. The test parameters did not suggest there should be significant vertical shear with this cold front. A confusing aspect of this Event was that maximum possible shear, as shown by the IAD Doppler profiles, was less than what appeared to cause the reported Indicated Air Speed (IAS) changes at DCA. This may be attributed to the 6 minute averaging procedure used in the Doppler system readout, effectively filtering out the wind structure which probably caused the IAS changes. Doppler data showed the frontal slope as being between 1/45 and 1/60.

Event #14, 3/13/77 (Warm Front)

Although the actual Advisory cited a "warm front" as being the cause of expected shear, the Advisory was issued primarily for the following three reasons: (1) numerous antecedent pilot reports; (2) strong low-level winds from NWS radiosonde; (3) experience with cold sea inversion of 3 days earlier. Our best estimate of probable causes for the many pilot reports of shear on this day are numerous and quite uncertain.

Event #15, 3/16/77 (Cold Front)

This cold front was an excellent example of one which "overshot" a nocturnal inversion. The advisories were issued mainly because the front, estimated to be moving at about 40 knots, met the wind shear criteria on NMC analyses. In retrospect, this may have been a fictitious movement because the front "jumped" out ahead as the sun "burned off" the strong night time inversion. All pilot reports for this day, as in many of our other cold front events, were due to the frictional slowing of the strong flow hundreds of miles behind the front.

Event #16, 3/18/77 (Warm Front)

This warm front event features a low center which passed very near the test airports. It was so close that it was very difficult to know exactly what the winds were at 300-600m and how they were changing.

Event #17, 3/22/77 (Non Specific Frontal)

During this day a low pressure center moved NE along the Atlantic Coast and it was very difficult to know just how much the frontal surface lowered in between radiosonde ascents. Also, the thermal field showed poor alignment with NMC warm front. Our meso-analysis showed a hint of a coastal type-front.

Event #18, 3/28/77 (Warm Front)

Only a few pilot reports were received from this warm front where more were expected. The substantial temperature change across its surface apparently was due mainly to differential heating rather than to a dynamical frontal system. It was deduced that there was no significant shear with the front; thus, no additional Advisories were issued for test airports north of DCA. Also, the analysis showed a substantial warm front at least 3 hours before NMC analysis.

Event #19, 4/2/77 (Warm Front)

There are two highlights of this warm front event. The first was a poor NMC analysis of the warm front which lead to a detailed meso-scale analysis. The second was the Doppler profiles which showed light to moderate shear due principally to speed changes with very little directional changes. The profiles also indicated a slight low-level jet.

Event #20, 4/5/77 (Warm Front)

Excellent documentation of this warm front was provided by the IAD Doppler system. The profiles, once again, show only minimal contribution to vector shear by directional changes. Total shear was only light (<4 knots/30m).

Event #21, 4/24/77 (Stationary Front)

The results of this event showed that a large ΔT is not always sufficient to determine the vertical shear potential for a given front. The near-stationary nature of the front suggested that it was more of a static system than a dynamic moving front.

Event #22, 4/28/77 (Cold Front)

This last event featured what appeared to be a substantial wind shear producing cold front as determined by its ΔT. It moved through the NYC airports during a busy period and yet produced no pilot reports of wind shear. Analysis of IAD Doppler data showed the front to have a very steep slope (1/17-1/35) at IAD with very gradual directional changes with time and height. These could be partial answers to the paucity of pilot reports.

4.1 DISCUSSION OF SELECTED EVENTS

Event of January 28, 1977

Synoptic Situation: At 18Z, an unusually strong cold front from a low north of Lake Erie, extended southward to western New York, western

Pennsylvania and northern Georgia. The front was moving at 30 kts. and by 23Z was approaching eastern New York, New Jersey, and eastern Maryland (Figure 3). The temperature gradient across the front was 20 to 30°F.

PIREPS: At the time of frontal passage, aircraft landing in Washington, D.C. reported considerable turbulence. The Aero Commander experienced changes of IAS of 35 to 47 kts. However, the pilot believed that updrafts and downdrafts, rather than just vertical shear, caused the IAS changes. Other aircraft did not report IAS changes in the Washington area. In the Philadelphia area, two aircraft reported IAS changes attributable to the frontal boundary. At New York, four aircraft, penetrating the frontal boundary, reported no wind shear.

Meteorological Observations: Measurements from the Doppler radar and the Aero Commander aircraft showed the slope of the front to be 1/25 to 1/45. Thus, any vertical shear due to this frontal boundary would be short-lived due to the fast frontal movement. Perhaps this partially explains the lack of PIREPS on LLWS. Long after frontal passage, some reports of wind shear were received which probably resulted from wind speed changes encountered on final approach.

Event of February 24, 1977

Synoptic Situation: At 18Z a warm front extended in a general east-west orientation along the Pennsylvania-Maryland border and into southern New Jersey (Figure 4). Cool air lingered over the mountainous region and a mesoscale analysis of the area showed frontal perturbations. Sounding analysis showed the top of the cold air at New York at 2300 ft. at 12Z, February 24. It had lowered to 300 ft. 12 hours later at 00Z, February 25. The 12Z (February 24) sounding at Washington indicated the cold air had a depth of 1000 ft. The warm front passed Washington at 15Z.

PIREPS: Changes of IAS were frequent during landings at JFK Airport, New York, from 11Z (February 24) to 02Z (February 25). Shear reports at Philadelphia, however, were almost totally lacking. The runway at Philadelphia is 09-27. The shear was predominantly North-South; thus, changes of IAS were less likely in this cross-shear situation.

Meteorological Observations: The observations provided by the Aero Commander aircraft indicated the shear experienced by aircraft from 11Z to 19Z (February 24) at JFK were associated with the speed shear of a low-level jet phenomenon below the frontal surface. The shear problems were directly related to the frontal surface after 19Z as it approached

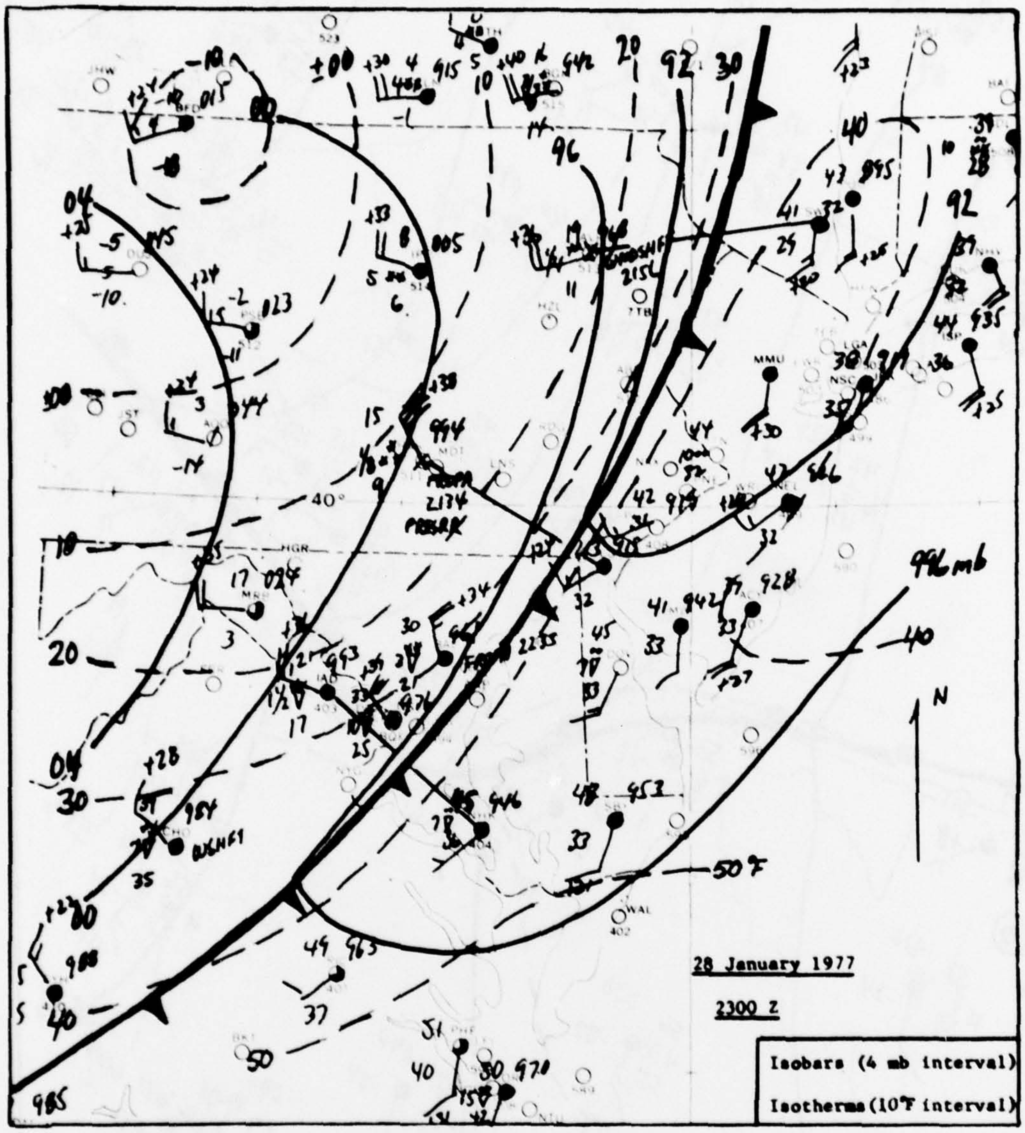

Figure 3. Local Area Surface Chart, 28 January 1977 at 2300z. Temperature gradients are 20-30°F between surface stations.

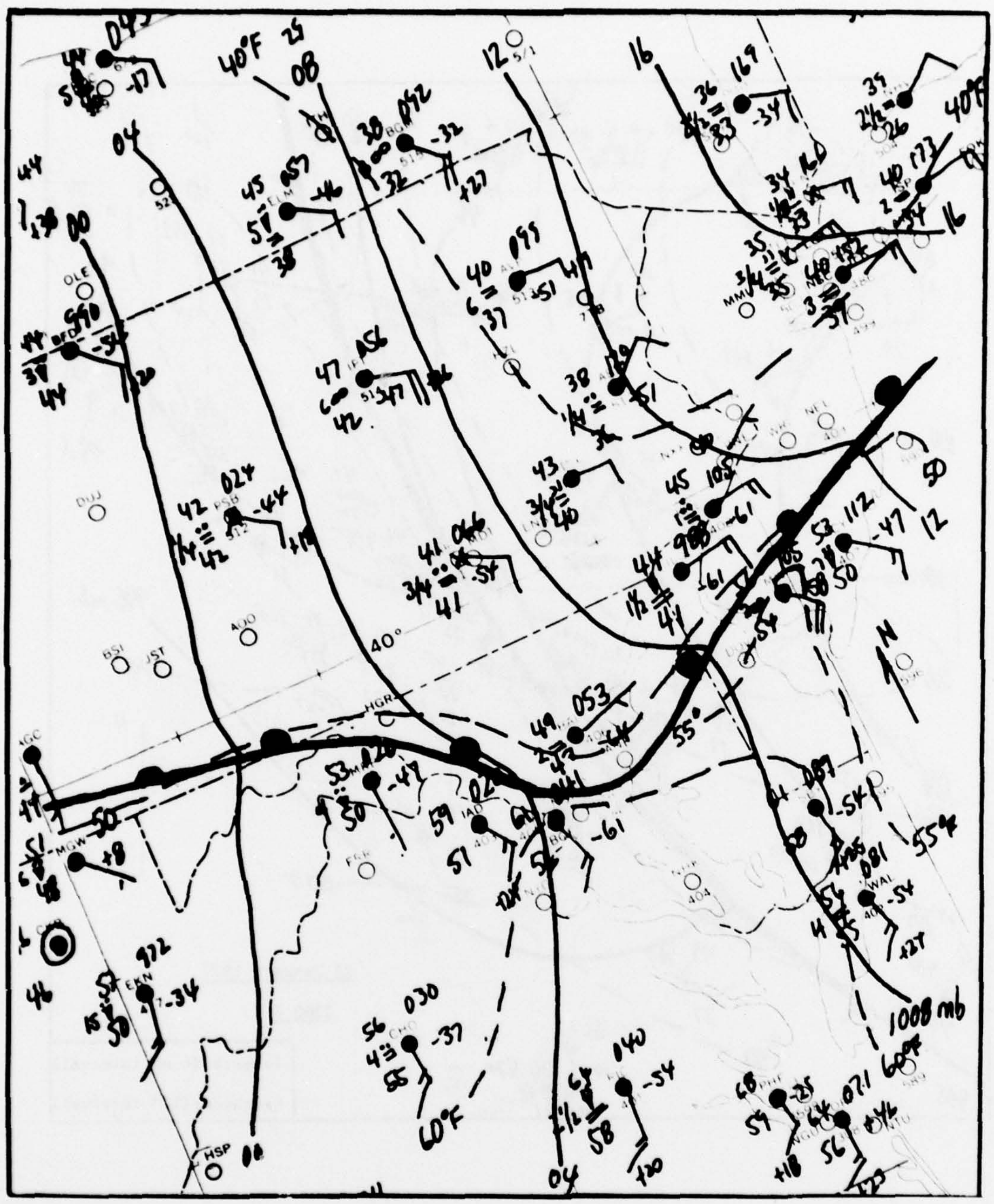

Figure 4. Local Area Surface Chart 24 February 1977 at 1800z. Temperature gradients are 10-12°F between surface stations.

New York. The magnitude of the IAS changes for the low-level jet were comparable to those of the warm front encounters. This warm front had a surface temperature differential across the front of 10-20°F and moved at 5 to 15 kts. It was typical of most warm fronts studied during the test period.

Event of February 5-6, 1977 (Non-Advisory)

Synoptic Situation: An intense low pressure system was located off the New England coast. The airfields in New York City, Philadelphia, and Washington, D.C. were all under the influence of strong N.W. flow. The geostrophic wind gradient was 50 to 60 kts.

PIREPS: Several PIREPS were received between 18Z (February 5) and 06Z (February 6) with 10 to 20 kt. changes of IAS. These shear encounters were generally below 300 ft. AGL.

Meteorological Observations: No frontal discontinuity was present. It is concluded that the frictional slowing or obstacle blockage of the strong gradient wind caused this shear. Because this was a non-frontal situation and wind shears were not forecast, the Aero Commander aircraft was not alerted to make supporting measurements. The IAD Doppler radar was not in operation.

Event of March 9-10, 1977 (Non-Advisory)

Synoptic Situation: A strong high pressure cell was located off the Virginia and N. Carolina coast. The eastern seaboard was under south to southwesterly flow and no synoptic fronts were in the area. A local area analysis showed a strong temperature gradient along the coast (Figure 5). Because of the intense cold during the winter of 1976-77, coastal water temperatures were still in the 30°F's. Thus, the south to southwest winds created a mesoscale "sea-trajectory" front.

PIREPS: There were several reports of wind shear with changes of IAS of 10 to 15 kts.

Meteorological Observations: Rawinsonde observations along the coast showed a 43°F (6°C) temperature inversion with a top at 1000 to 1200 ft. There appeared to be no inland inversion. The temperature gradient was 10°F/10n mi. in the New York area. While there was little directional shear in the vertical wind profile, there were indications of some speed shear. Again, observations from the Aero Commander and the Doppler radar were not available.

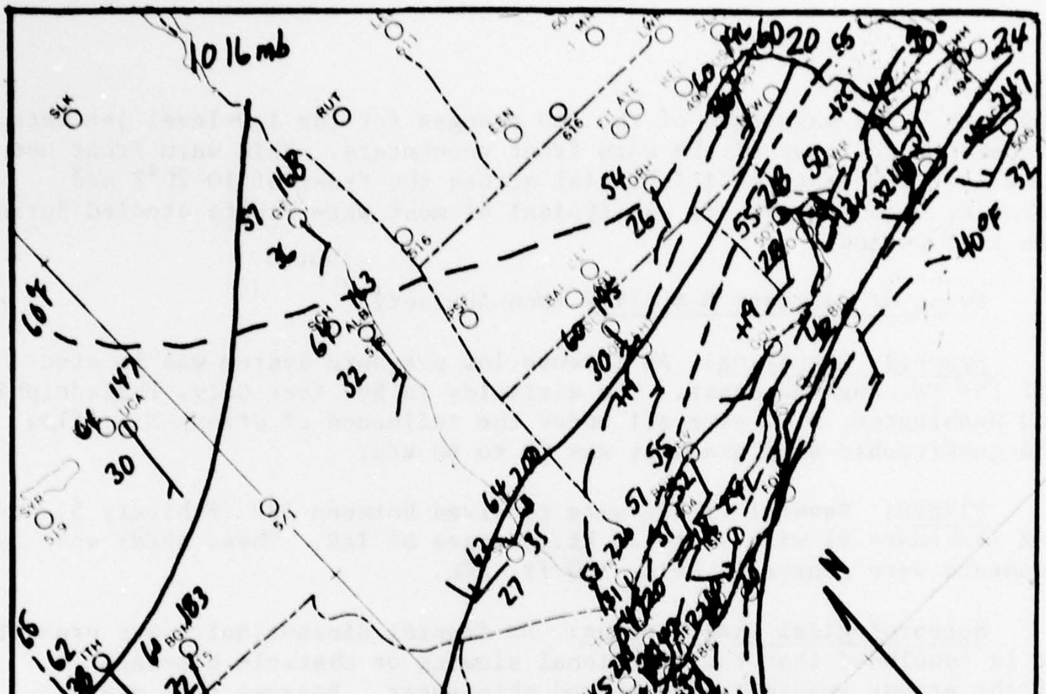

Figure 5. Local Area Surface Chart 9 March 1977 at 2200z. Temperature gradients are 12-20°F over short distances.

5. CONCLUSIONS

A summary of the probable causes of the pilot wind shear reports is given in Table 2. The table indicates that on 20 advisory - event days on which fronts were indicated as the cause of wind shear, fully 2/3 of all pilot reports received were not attributed to fronts. Instead these were attributed to low-level jets and/or inversions and frictional effects. Since it was difficult to distinguish between low-level jets and inversions, these categories were combined in this table.

Using pilot reports, no correlation was found between indicated airspeed changes with the observed speed of the front. This may have been due to the infrequency of fast moving (>30 Knot) fronts. Also, there was little correlation between pilot reports of indicated airspeed changes with the observed temperature gradients.

The analysis of the pilot reports suggest that reports of significant shear were due more to wind speed rather than wind direction changes.

In addition, these conclusions were reached:

a. Potentially dangerous low-level wind shear conditions result from meteorological features smaller than synoptic scale. These meso-meteorological features probably contribute to reports of changes of indicated air speeds not expected from the synoptic features.

b. Frictional effects affected the frontal slopes in the boundary layer. During this test, cold fronts had slopes of 1/20 to 1/50 and warm front slopes were in the 1/100 to 1/400 range.

c. Synoptic scale surface charts have limited value for identifying low-level wind shear. Hourly plots of data and mesometeorological analysis contributed to improved forecasting of the wind shear.

6. RECOMMENDATIONS

Based on the tests conducted, the following are recommendations that can be expected to improve the forecasts of wind shear at terminals:

(1) Limit the zone of the forecast to the terminal volume of approximately 10 miles radius and 600 meters in height.

TABLE 2. CATEGORIZATION OF WIND SHEAR PILOT REPORTS FROM EASTERN U.S. RECEIVED DURING 20* ADVISORY-EVENT DAYS DURING 6-MONTH TEST (PERCENTAGE OF TOTAL IN PARENTHESES)

	Total Number of Pilot Reports	Number Attributed to Advisory Front	OTHER CHANGES		
			Low-Level jet and/or inversion	Friction and/or obstacles	Other Causes
8 Cold Front Advisory Days	52	10 (19%)	12(23%)	21(40%)	9(18%)
12 Warm-Stationary Front Advisory Days	165	69 (42%)	56(34%)	24(15%)	16(9%)
All 20 Advisory Event Days	217	79(36%)	68(31%)	45(21%)	25(12%)

Of the 389 wind shear-related reports received on Advisory-Event Days during 6-month test, only 94 or approximately 25% appeared on Service A.

* Pilot reports from Events 10 and 14 not included because no front per se was involved.

(2) Provide sufficient manpower at WSFOs to perform the required meteorological analysis for issuing forecasts on wind shear.

(3) Minimize the time for issuing the forecasts by means of direct access to the using facilities, e.g., direct communications to airport towers.

(4) Issue low-level wind shear advisories for any front when:

(a) Temperature gradient 20°F per 100 n.m. and
(b) The wind at some critical level exceeds a threshold value, e.g., 40 knots at 600m (2,000').

Timing of frontal shear obviously depends on speed of front and slope of front. Latest observed slopes should be used. If not available, slopes should be assumed to fall in the following ranges: cold front, 1/25 - 1/50; warm front, 1/200 - 1/400.

Extreme care should be exercised with cold fronts because their faster movement and steeper slopes imply a short-lived shear event at a given airport.

(5) Issue Advisories when the surface winds exceed a threshold value of approximately 30 knots. For example:

"LOW-LEVEL WIND SHEAR EXPECTED AT DCA FROM 01Z TO 04Z. WINDS AT 800 FEET FROM 290° AT 60 KNOTS AND SURFACE WINDS FROM 290° AT 30 KNOTS."

(6) Verify Wind Shear Advisories by pilot reports and tower winds where available.

(7) Conduct additional investigations into the mesometeorological causes of wind shear associated with:

(a) Frontal conditions
(b) Coastal land/sea interfaces
(c) Sea breezes
(d) Low-level jets
(e) Inversions

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