Sabreliner Flight Test

for

Airborne Windshear Forward Looking Detection and Avoidance Radar Systems

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Abstract

An important aspect in the design of an airborne radar for low level windshear avoidance is the false alarm/alert rate. To be used and trusted by pilots, any indications and/or displays of false hazards must be infrequent. A "clean scope" design aims to preserve detection performance and eliminate distracting false alarms. For lookdown radar, urban discretes and ground moving vehicle traffic dominate the false alarm design problem. Depending upon their relative location, spatial extent, and relative amplitude, these returns will compete with microburst windshear observables and may furnish false alarm candidates.

Westinghouse conducted a flight test with its Sabreliner AN/APG-68 instrumented radar to assess the urban discrete/ground moving vehicle clutter environment. Glideslope approaches were flown into Washington National, BWI, and Georgetown, Del. airports employing radar mode timing, waveform, and processing configuration plausible for microburst windshear avoidance. The perceptions, both general and specific, of the clutter environment furnish an empirical foundation for begining low false alarm detection algorithm development.

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- Perspective
- Objectives
- Expansion of Issues
- Design of Tests
- Details of Flights

The next generation of commercial aviation weather radar may include a mode for forward looking detection of hazards due to low level windshear along the glideslope approach from a microburst for the purposes of detection and avoidance. This mode will dominate the design of the radar and will demand expertise in pulse Doppler radar technology. To succed in saving lives, this radar mode must be used and trusted by the pilots and be capable of sensing the presence of a hazard along the flight path prior to encountering the hazard. A hazard display should be a "clean scope", suppressing hazard indications from both mainbeam clutter and any ground moving discrete returns. Measures of a sensor to do this include its false alarm rate and minimum detectable hazard.

Concerns for defining this minimum detectable hazard for the airborne radar should include the temporal building of the hazard. To warn the first plane flying into a region just reaching a qualified hazard criteria is the objective. To wit, having a sensor which can detect/verify the presence of a mature microburst on-board a commercial airliner may be of less interest to the customer.

In our view, the NASA instrument radar will be capable of detecting and analyzing existing microbursts opportunistically encountered or scouted. If NASA flight tests are able to encounter microbursts, the data collected will serve to verify/refine their/our understanding of the meteorological mechanisms which drive the microburst. This gives confidence in predicting the observables for radar (or other sensors) at the point in time of concern for a significant range of microbursts, significant enough to be considered an important increment to safety.

The other aspect of the sensor design, suppression of false alarms, begins with a characterization of the radar clutter environment for those many times when a microburst is not present.

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Technical Direction

1. Furnish a superior radar sensor to detect evolving microburst windshear along the approach glideslope

2. "Superior" means:

   • Low false alarm rate and a "clean scope" hazard display

   • Confident detection of minimal significant hazards, i.e.,

   - Minimal windblown rain RCS

   - Minimal Doppler speed

Westinghouse had some reservations on the feasibility and/or low cost realizability of a lookdown coherent radar mode for detecting slow and small RCS returns in the presence of dense urban clutter and ground moving vehicular traffic. These reservations could be evaluated by a flight test under realistic conditions.

Westinghouse is a world leader in the research and development of airborne radar and maintains a fleet of aircraft equipped with radars for those purposes.

Sabreliner Flight Test
## for
Low Level Windshear Hazard Detection Mode

Object:

1. To assess the impact of vertically extensive urban discretes on the operation of a microburst windshear mode

2. To observe the qualitative presence and extent of ground moving traffic in the airport approach environment

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The Sabreliner is equipped for developing and improving airborne radar in a dynamic flight test environment. There is a capacity to arbitrarily configure the radar and program its processing. There is an ability to capture radar data at many different stages of the receive process, including A/D and FFT, complete with INS data on the aircraft position, movement, and orientation in navigation coordinates.

Sabreliner
AN/APG-68 Radar
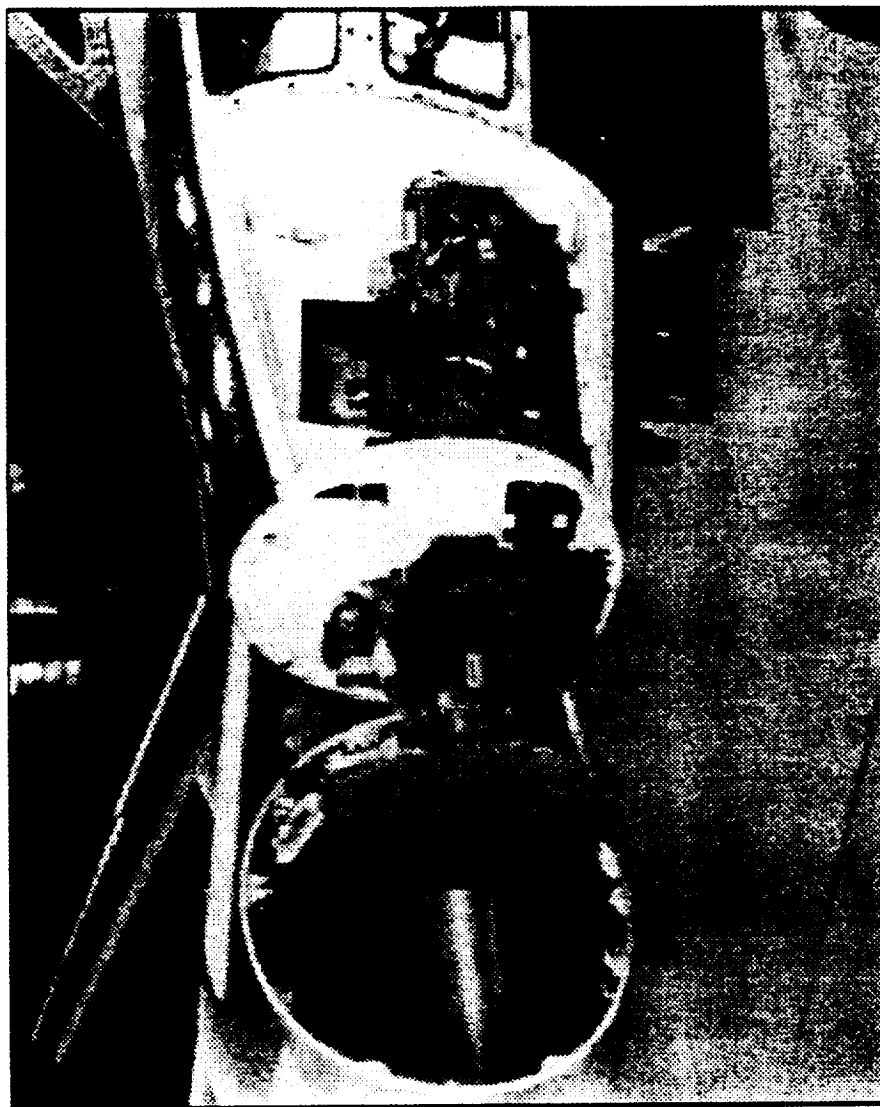
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Sabreliner Radar Furnishes Instrumentation and Capability Exceeding the Experiment

1. Programmable waveform and scan generation as desired. Choose from NASA range of PRFs.

2. "Instrumentation" capacity:

   • ERP exceeds anticipated/current weather radar products

   • Spurious free dynamic range provides sensitivity exceeding product baseline

   • Digital processing can mimic anticipated product waveform initial processing (programable pulsewidth and FFT)

   • Data recording for range gated FFT is good match for expected product scope of interest

   • Scan patterns and rates are programmable

   Flight test data furnishes a foundation for algorithm designs with empirically known clutter margins

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Radar processing makes assumptions about targets. In the case of target location and velocity, the radar assumes the target return is from the direction that the mainbeam is pointing and that the Doppler velocity is relative to the ground clutter patch, also in that direction (clutter positioning). Large stationary urban discretes (e.g. hangers, gantries, skyscapers, etc.) pose a problem when

    a) their returns lie above the noise level and
    b) their direction is different from the direction of the mainbeam.

(when their direction is different from the direction of the mainbeam, the Doppler frequency of their return is different, i.e.

$$f_{Doppler} = 2[v/\lambda] \cos(\theta)$$

where

    v = the speed of the aircraft
    λ = the wavelength of the carrier, c/f_o
    c = speed of light
    θ = the angle between the line of sight to the object producing the return and the aircraft velocity vector.
    f_o = rf carrier frequency)

Electronically positioning the return from mainbeam clutter to lie in the Doppler filterbank at zero velocity means that large returns from stationary objects could be interpretted at different velocities. For example, if the mainbeam is pointed along the velocity vector, a Doppler frequency

$$f_1 = 2 v/\lambda$$

is interpretted as non-moving. A return from a building abeam of the aircraft returns at a Doppler frequency

$$f_2 = 0$$

If large enough in amplitude to be perceived through the sidelobes of the antenna, it would be interpretted to be at a Doppler velocity -v . Scatterers stationary on the ground returning from angles closer to the nose would be interpretted as slower opening targets and those farther off the nose would be interpretted as faster opening targets.

For the microburst windshear application, urban discretes perceived through the sidelobes can potentially "compete" at the ranges and Doppler speeds of tailwind outflows.

An objective of the Sabreliner flight test is to assess this problem by putting an instrumented radar of excessive measurement capability in an urban discrete stressing environment and observe the level of returns in the Doppler filterbank.
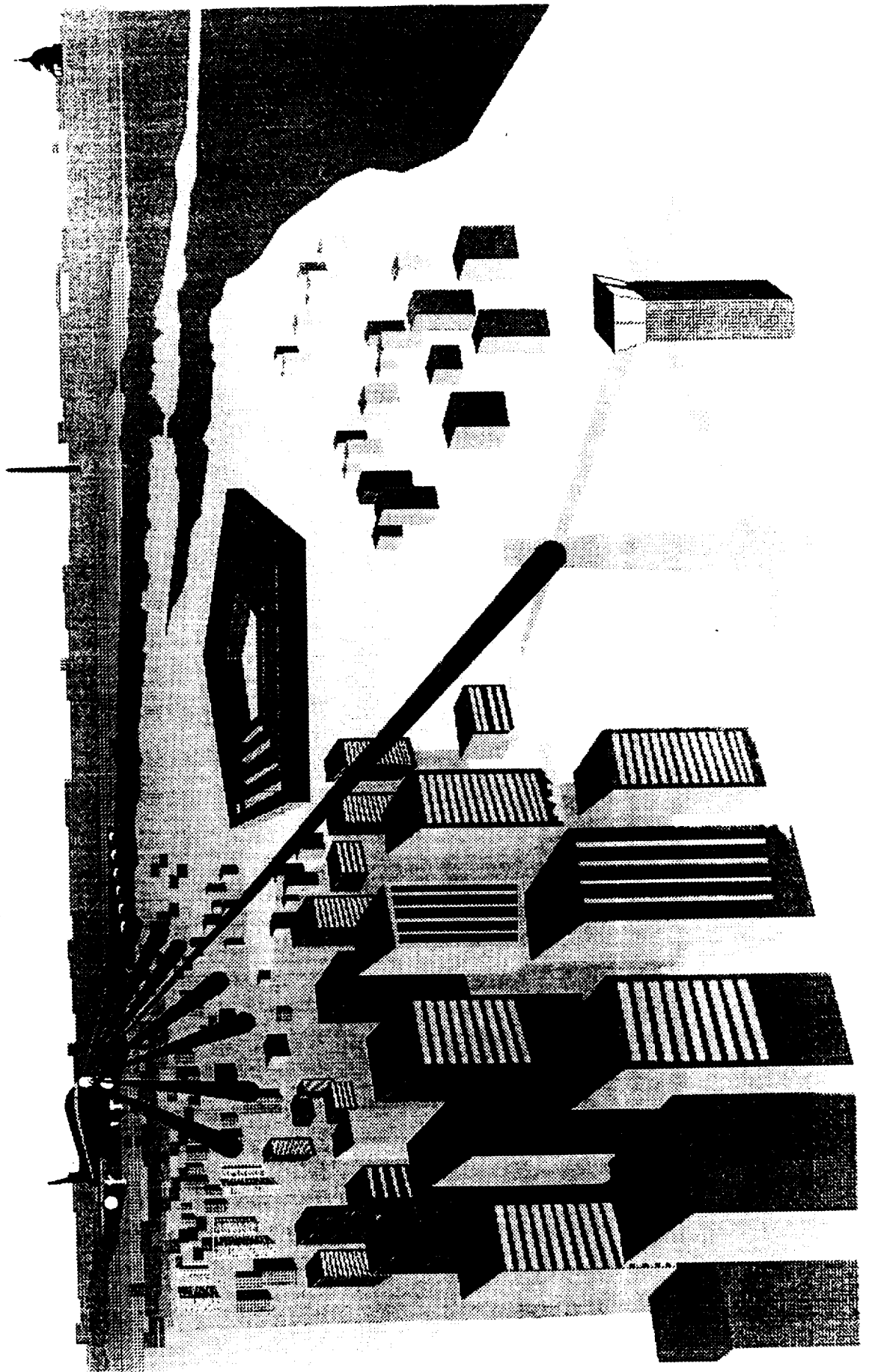
726

Urban Areas May Appear as Spatially Extensive Features at Doppler Frequencies Competing With Tailwind Outflows

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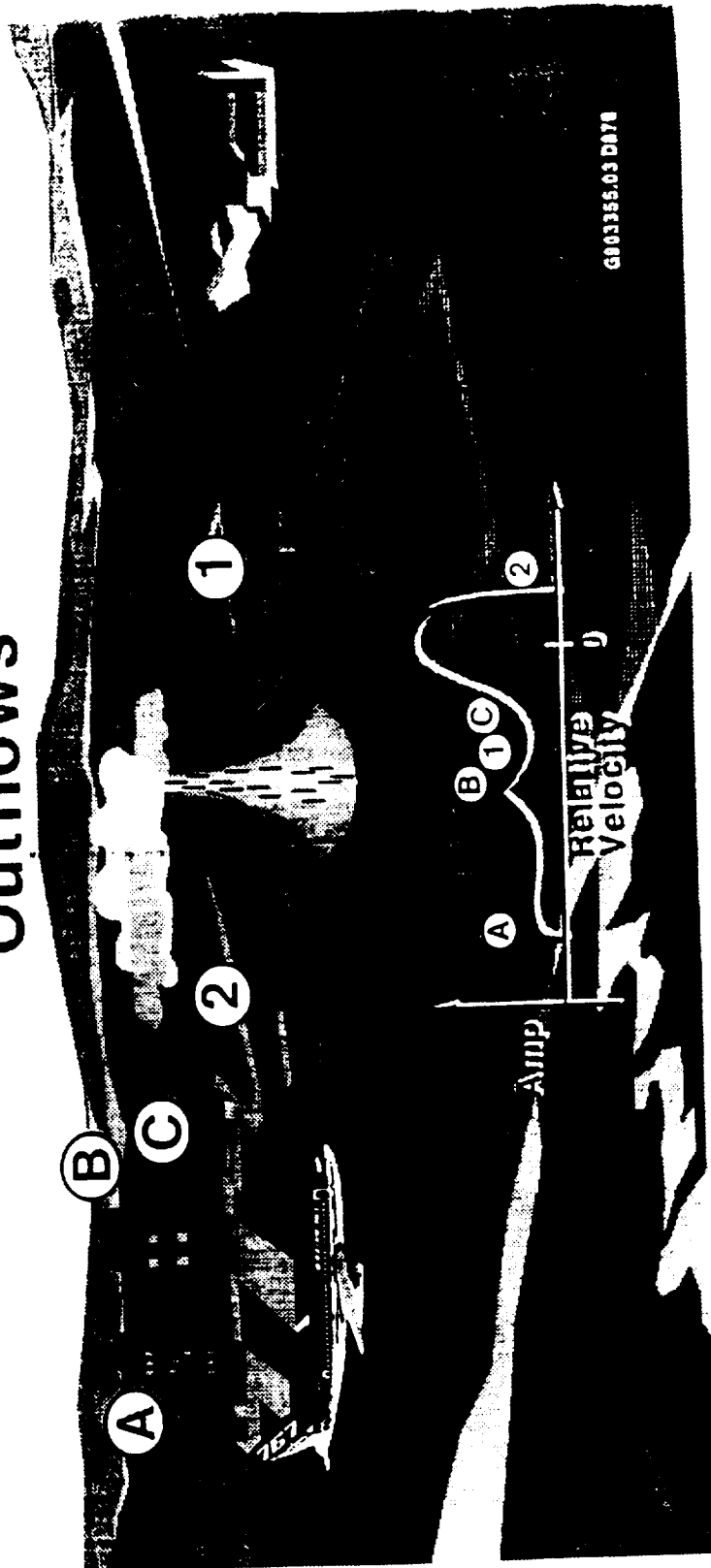
Some airports in dense urban environments may have approach airspaces which do not conform to standards. High rise buildings, stacks, and towers in the proximity of the approach pose potential projecting sources of urban discretes at close ranges which may compete with tailwind outflows in the filterbank.

Urban Clutter May Project Vertically

Most airports are serviced by a network of roads which include high speed interstates. It is not uncommon for the glideslope to parallel and/or overfly such highways. Ground moving targets perceived by the radar through the sidelobes of the antenna may appear as small RCS targets distributed in range, Doppler, and space not unlike microburst windshear. An objective of the flight test was to assess qualitatively the perception of ground moving targets at the very close ranges in the sidelobes along the glideslope. This information will determine the complexity (i.e. there are additional/alternate means of rejecting returns not from the mainbeam direction) of the radar design for rejecting sidelobe and undesired movers.
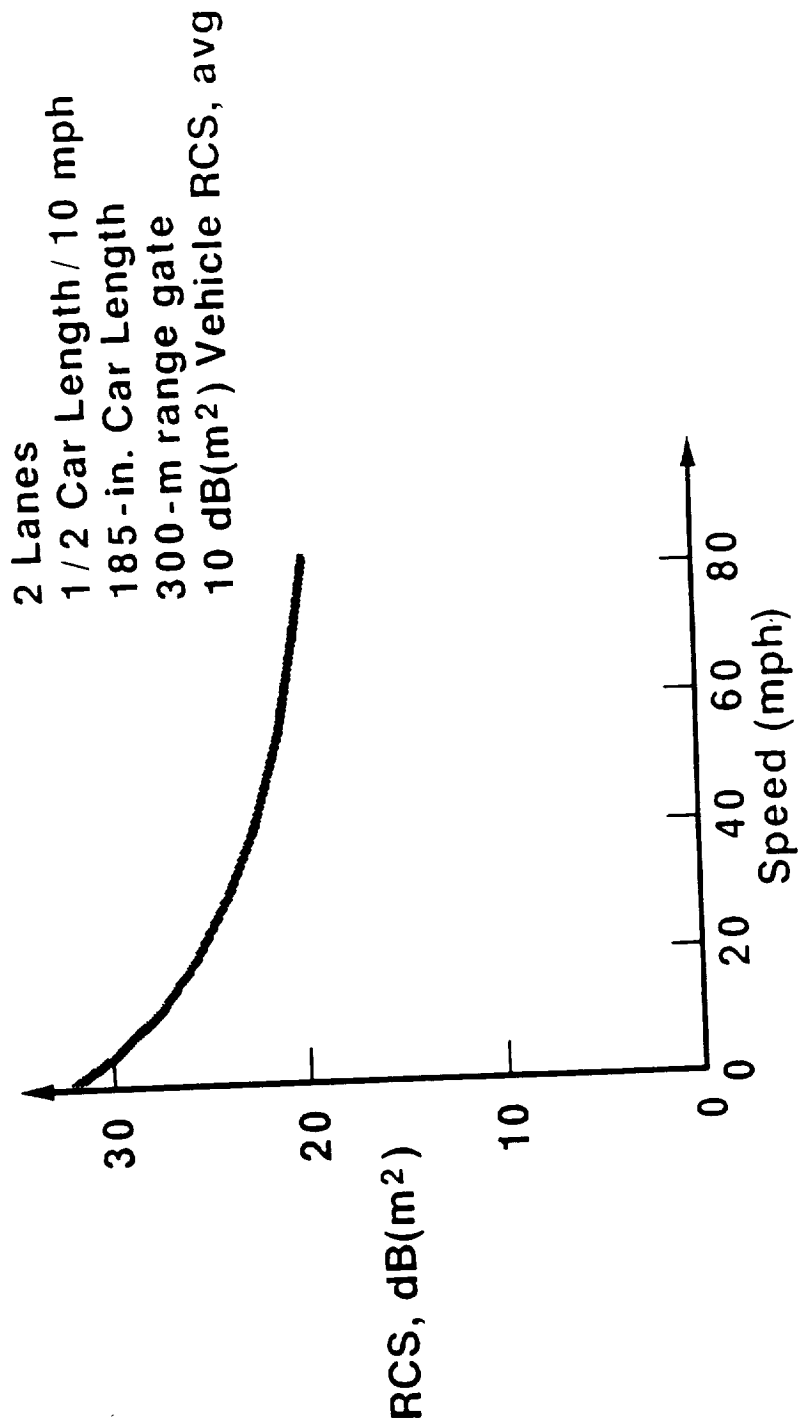
Ground Movers May Be Extensive and Competing

731
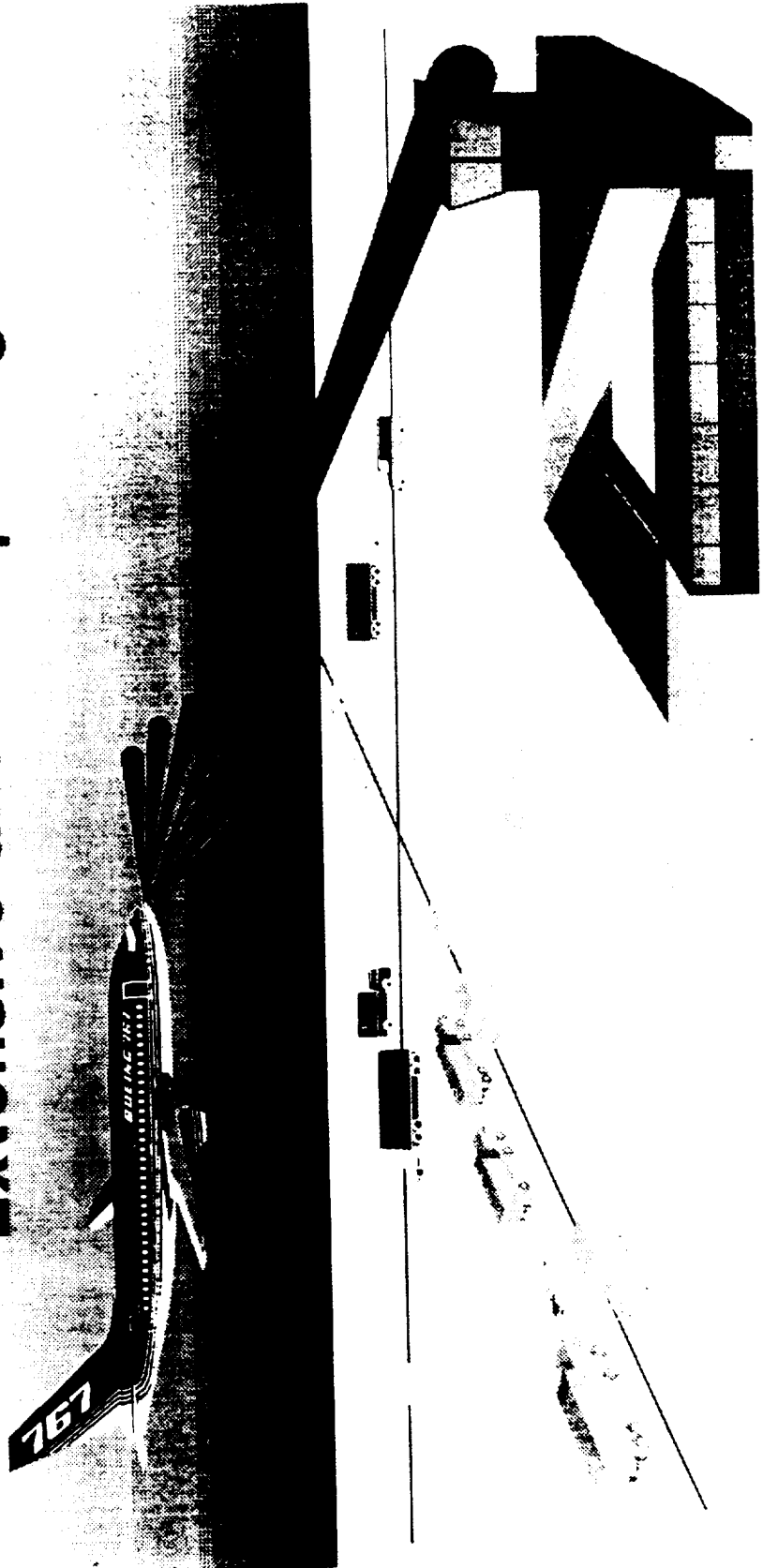
A simple model for vehicular traffic can suggest the RCS of a number of vehicles in a range cell moving at high speeds. The model considers the individual vehicles to combine in a Rayleigh fashion. Presumably, at higher speeds, there will be some increased spacing between following vehicles.

A Model for RCS of Cells Containing Many Vehicles

(In a Range-Gated Doppler Cell)

2 Lanes
1/2 Car Length / 10 mph
185-in. Car Length
300-m range gate
10 dB(m^2) Vehicle RCS, avg

RCS, dB(m^2)

Speed (mph)

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The flight test must be designed to collect data which can be interpretted and addresses the issues raised. The PRF of the waveform was selected at 4KHz. to resolve vehicle traffic with ± 70 mph relative speeds. A 2 microsecond pulse allowed 16 range gates to be implemented, covering out in range 5.1 km. in unambiguous range. The second time around echo (STAE) range swath extends from 37.5 km. to 42.6 km. To determine whether, say, a moving target indication is from the sidelobes at unambiguous range or from the mainbeam at STAE ranges will require study of the elevation scan history (i.e. the change in illumination intensity at STAE ranges over the elevation contour is modest, but any peak sidelobes or mainbeam skirt effects will produce marked variation.)

The Results Must Be Comprehensible

(Use NASA Baseline Set of Parameters)*

1. Doppler Ambiguity (± 70 mph)

   $PRF \geq 2(2 \ v_{max}/\lambda)$

2. Range Ambiguity

3. Angle Dependencies (Scan History)

* Bracalante, et.al., "Airborne Doppler Detection of Low Altitude Windshear", AIAA/NASA/AFWAL Sensors and Measurement Technologies Conf., paper AIAA-88-4657, Sept 1988, Atlanta, Ga

Data was recorded for the approaches to three accessable airports.

Approaches to Georgetown, Delaware could easily be arranged with flight controllers. It posed a case benign in terms of second time around range ground moving target activity, urban clutter, and vehicular traffic around the airport. Instances or observations in the data should be easily interpretted from the features available from topographic maps.

The approaches to BWI in Linthicum, Maryland are relatively well know to Westinghouse personel. Although complex residential and road patterns abound, there is a general lack of pervasive complexity. The STAE ranges should include portions of asimuth scan including urban areas and high speed interstates. The final, low level approach to touchdown will over-fly representative worst case vehicular traffic in relative separable conditions.

The river approach to Washington National airport includes all the visions of hell to the imagination of an airborne radar engineer. There is a network of roads and freeways paralleling and underlying the approach with a deviance of high rise buildings, including the Washington Monument (height= 555 ft.). The STAE environment is generally rural and suburban but somewhat uncertain given the lag of updating maps to correspond to the development explosion.

Selected Airport Approaches for Data Collection

1. Benign
   - Georgetown, Delaware
     - Absence of urban clutter areas at unambiguous of STAE ranges minimal, isolatable ground moving traffic

2. Average
   - Baltimore Washington International Airport (BWI)
     - Approach includes a mix of resolvable clutter complexity; some vertically extensive clutter (Glen Burnie, radio towers, stacks ...; significant, radially lying interstates known for their speed

3. Worst Imaginable Case
   - Washington National Airport, D.C.
     - Approach glideslope overflys freeways and congested highways; Washington Monument, Crystal City and Pentagon; STAE is relatively benign (resolvable)

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The data was collected in piggyback priority with other tests on the same flight. The first approach was at Washington National. The approach was from the north on a typical summer weekday early afternoon. Permission did not include landing or touch and go, so the route deviated to follow the Potomac river and included a nearly direct line on the Washington Monument within instrumented ranges at about 2000 ft. altitude.

The map scale has been chosen to emphasize the features of the map at the second time around echo (STAE) ranges. In general, the ±20° scan in azimuth about the aircraft nose illuminated a swath about the Patuxent River in Prince Georges County and Anne Aurundel County with little indicated highway or suburban complexity. As the approach turned directly south, the STAE swath extended beyond Prince Georges County into Charles County, the Potomac River, Virginia, and the Chesapeake Bay.

Approach to National Airport

STAE Scale

CHESAPEAKE

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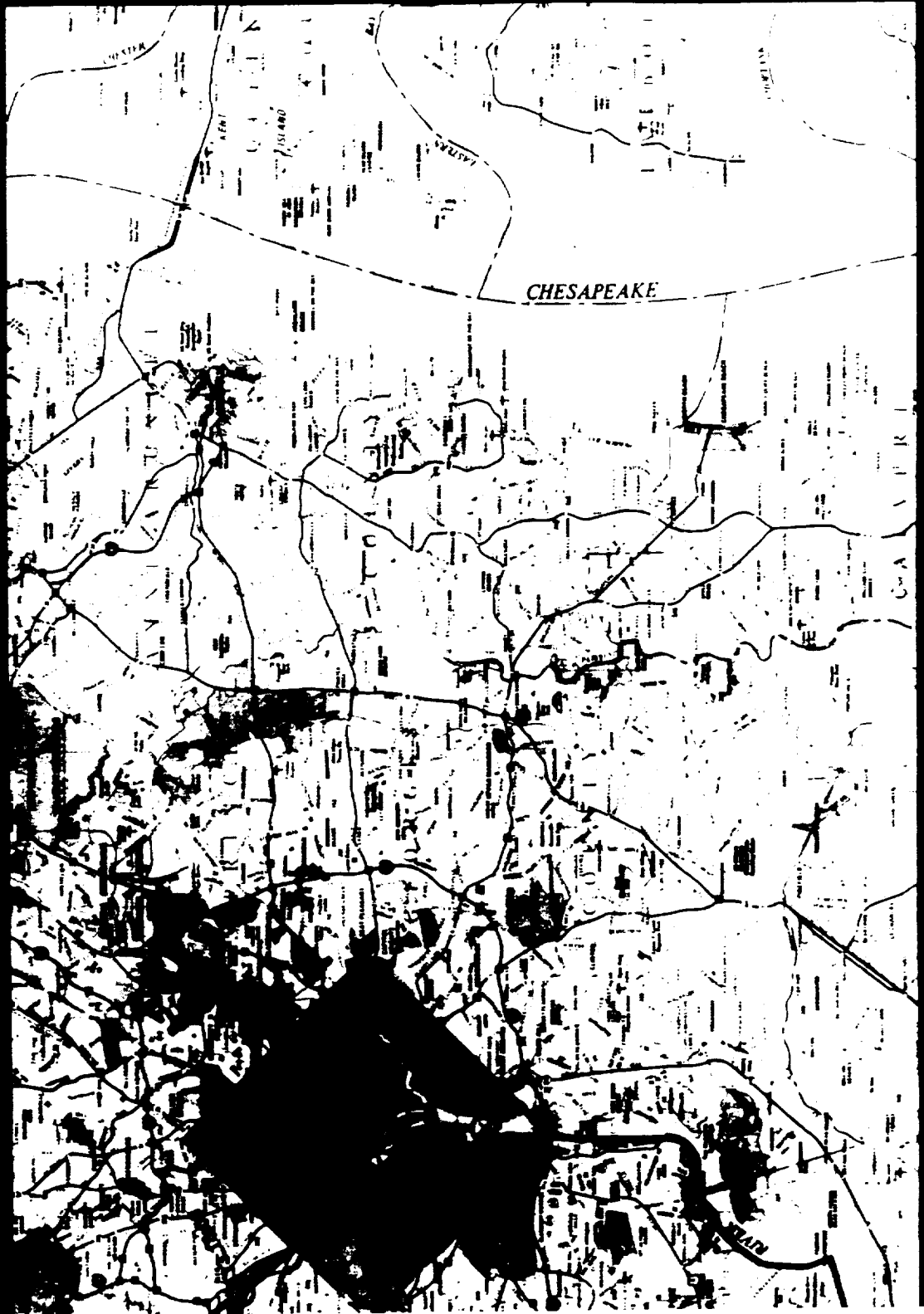
The approach to Washington National overflies a dense highway network of perplexing design. The sidelobes of the antenna almost always will illuminate the George Washington Parkway at ranges of data collection.

The scan pattern for the mainbeam is a four elevation bar scan near the glideslope. Each bar is successively lower and covers ±20° in azimuth in about 1 second. The whole 4 bar sequence takes a little over 4 seconds.

The lowest bar of the scan pattern begins placing the mainbeam at or near the unambiguous ranges of level ground just about the time (i.e. altitude) of the approach toward the Washington Monument. The mainbeam skirt illuminates I-95 and describes a progressive increase in ground moving target amplitude data as each bar is scanned.

The turn to the south over the Jefferson Memorial illuminates within unambiguous ranges Anacostia and its usually relatively uncongested freeways southwest of the Suitland Parkway interchange and bridges.

The flight route closely followed a 3° glideslope until just opposite the Pentagon, over the river at about 600 ft. The flight down the river includes mainbeam illumination of both the Anacostia freeway and Crystal City.

Approach to Washington National Airport
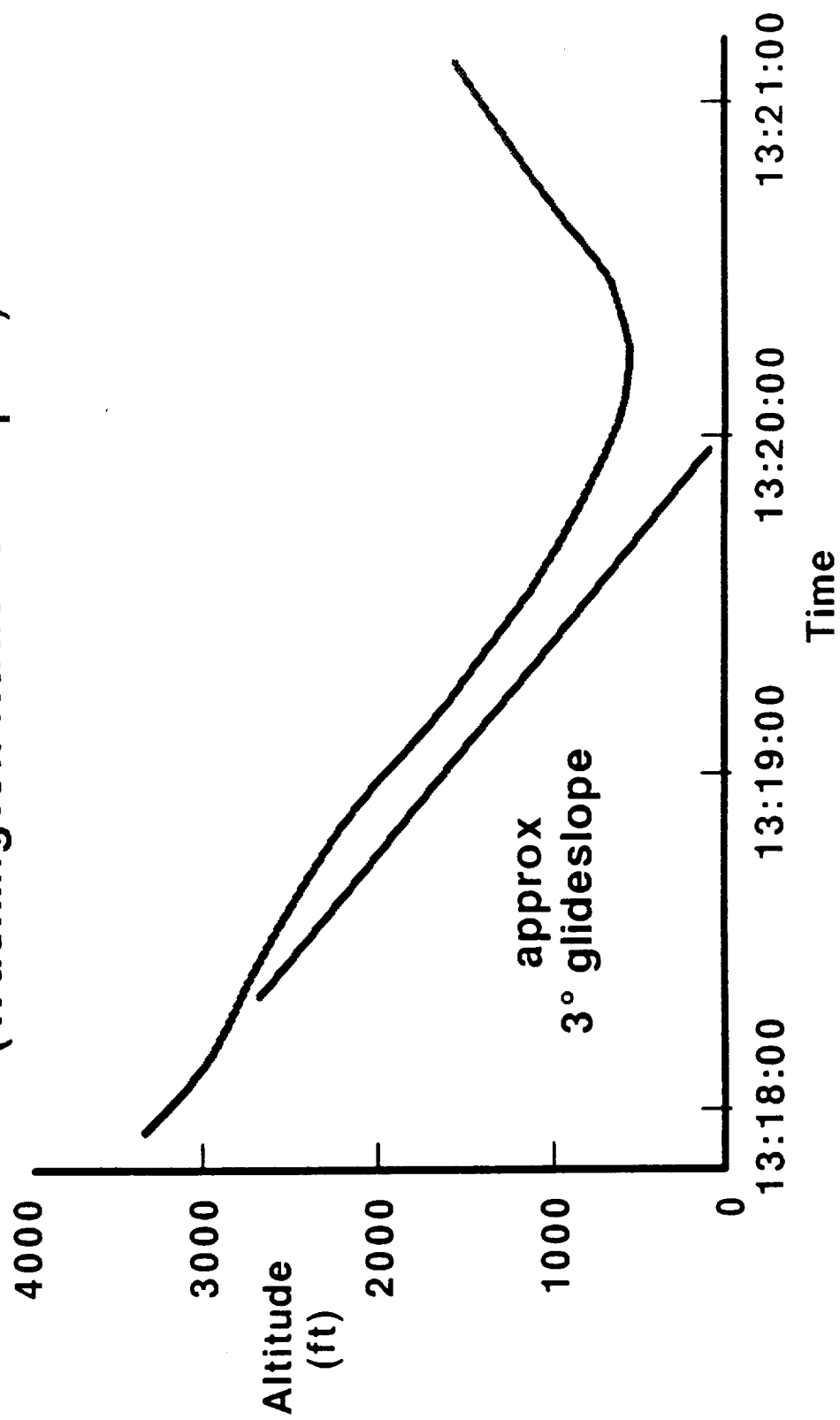(Unambiguous Range Scales and Detailed Features)

741

The approach to Washington National initially followed a 3° glidslope. The approach followed the Potomac and deviated slightly, reaching about 600 feet over the river next to the runway.
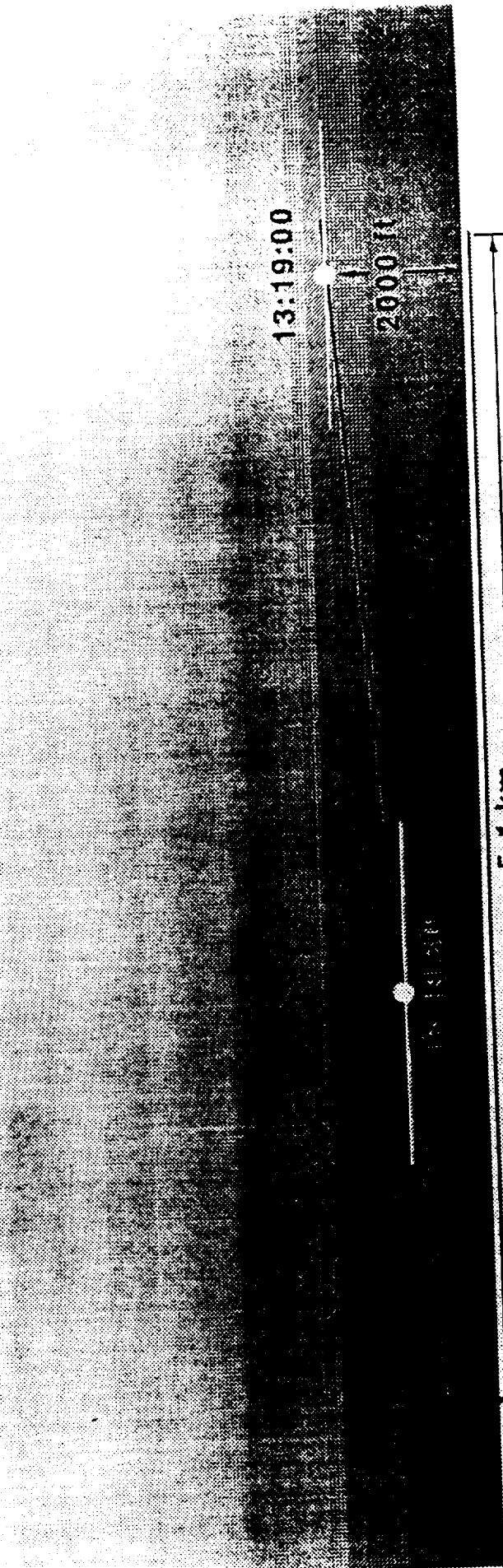
Altitude Profile During Approach
(Washington National Airport)

Altitude (ft)

4000

3000

2000

1000

0

approx
3° glideslope

Time

13:18:00   13:19:00   13:20:00   13:21:00

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Elevation Bar Scans of Succesively Steeper Depression Investigated Impact of Vertically Extensive Extensive Urban Clutter

13:19:00

2000 ft

5.1 km

Relative location of
Washington Monument (555 ft)
for 13:19:00

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Due to an equipment overheating problem, two approaches were conducted on BWI.

The first approach came up the bay and turned west, crossing the Curtis Bay and Marley Creek regions. The data shut-off occurred just short of Glen Burnie and the radio station towers.

The locations and aircraft orientation over the bay provide an excellent opportunity to confidently assess the STAE contributions of ground moving targets or STAE urban discretes. As the Sabreliner turns to the west, the scan illuminates various portions of the Baltimore beltway, I-83 to the north, and portions of Columbia and Northwestern Howard County along I-70.

The second approach was from along the Severn River looking diagonally across northwest Baltimore. Portions of the Baltimore beltway present near radial ground moving traffic perception at times just prior to rush hour.

Approach to BWI
STAE Features

The first approach to BWI overflew the Cheasepeake Bay and approached from due east. Points of specific interest over land where the approach near the Solley Road power plant and stack and the Glen Burnie downtown area. The sidelobes contain residential traffic in radial geometries.
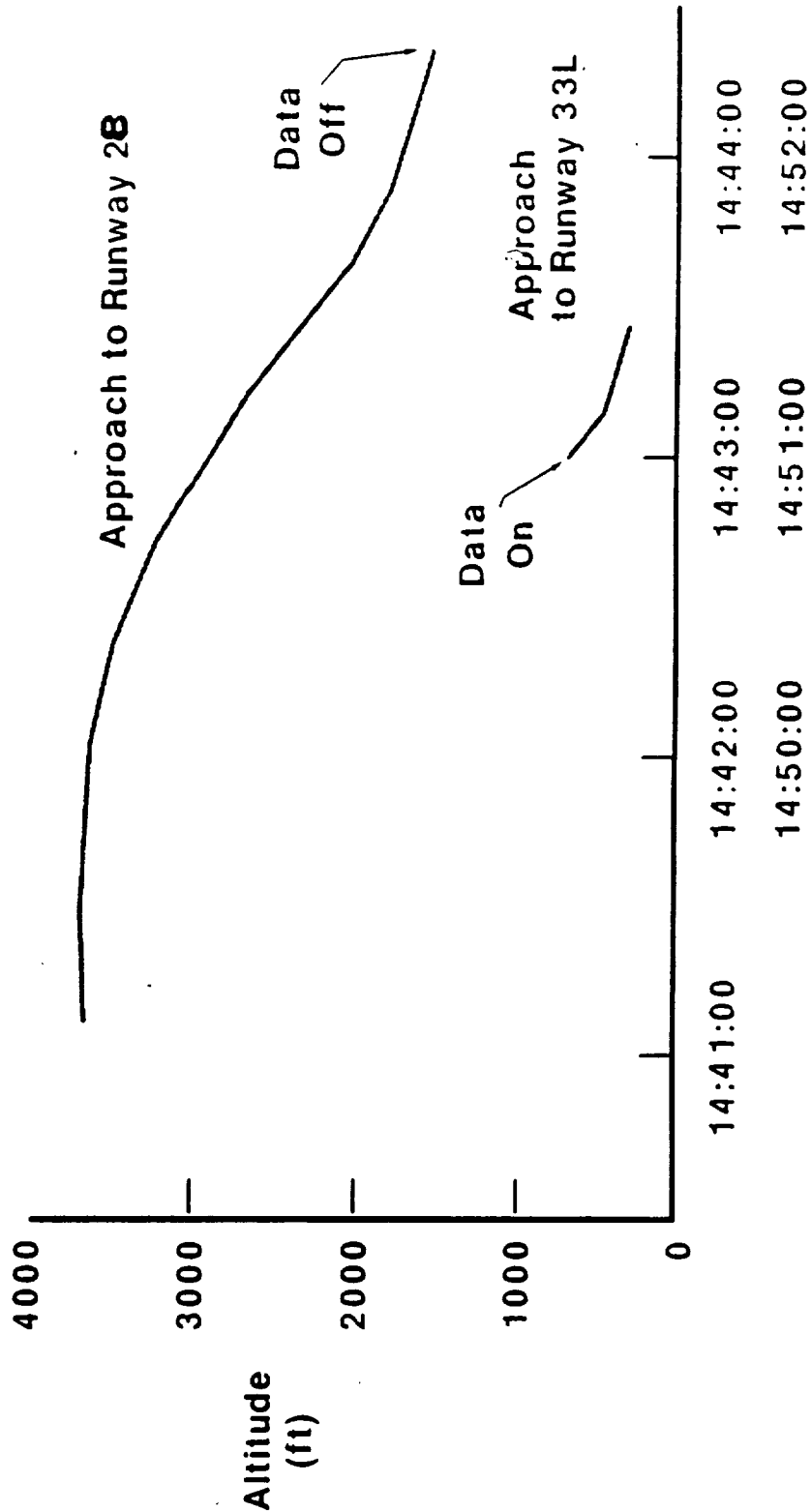
The second approach to BWI began gathering data about 2 n.miles out over Rt.3, which is a limited access divided highway. Data was collected nearly to touchdown. Interstate traffic was overflown initially. The final stages passed over light commercial business areas and tangential traffic patterns. The instrumented range included the limited access highway on the other side of the airport and the Westinghouse site.

BWI Approach

Detailed Map Features at Unambiguous Range

Approach to BWI
(Altitude Profiles)

Altitude (ft)

4000
3000
2000
1000
0

Approach to Runway 28

Data Off

Approach to Runway 33L

Data On

14:41:00
14:42:00 14:50:00
14:43:00 14:51:00
14:44:00 14:52:00

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The altitude profiles for the appoaches to BWI contained no significant vertically extending discretes.

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- Westinghouse knows the importance of clutter in radar design

- Westinghouse has gathered realistic clutter data

- Westinghouse will design for sensitive detection and robust clutter rejection

1. Westinghouse has conducted a flight test with equipment superior to the experiment to gather data and assess the problems of clutter and ground moving traffic in and around airports.

2. This data furnishes instances of stressing clutter environments in which an airborne radar for the detection of microburst windshear hazards must work in a low false alarm manner.

3. Westinghouse intends to design and produce a superior, cost effective sensor for the detection of low level microburst windshear hazards with sufficient warning time to the pilot for avoidance. Our design will be based for detection of microburst observables according to the NASA-Langley models of "wet" and "dry" microburst at different, key stages of their lifecycles.

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Saberliner Flight Test - Questions and Answers

Q: ERNEST BAXA (Clemson University) - Can you comment on clutter spectral characteristics of the Washington, DC overflights? Do you feel that urban clutter will be distinctly differed from non-urban?

A: BRUCE MATHEWS (Westinghouse) - The term "clutter spectral characteristics" to me or to Westinghouse Airborne Radar people means strictly a geometric Doppler sense. So it is really the amplitude distribution of Rayleigh scatterers geometrically in a range gate that sets up the Doppler spectrum for them. What did I expect the amplitude distribution of urban clutter to look like? It was pretty much what we expected I guess. It's the discrete distribution of urban clutter that makes it confounding and that's the difference with non-urban clutter.

Q: WAYNE SAND (NCAR) - What did you learn from these flight tests? Can you maintain a clear screen in these environments?

A: BRUCE MATHEWS (Westinghouse) - We are still looking at that data so I can't really comment very much further on that.