Session VI. Airborne Doppler Radar / NASA

Signal Processing for Airborne Doppler Radar Detection of Hazardous Wind Shear as Applied to NASA 1991 Radar Flight Experiment Data

Dr. E. Baxa, Clemson University

Signal Processing for Airborne Doppler Radar Detection of Hazardous Windshear as Applied to NASA 1991 Radar Flight Experiment Data

Dr. E. Baxa, Clemson University

Outline

- Platform Stability Analysis - aircraft attitude variations

- Microburst Detection Without Conventional Ground Clutter Rejection
  - -autoregressive modelling
  - -microburst tracking

- Adaptive Filtering for Ground Clutter Rejection With Low SCR
  - - adaptive noise cancelling
  - - simulated microburst in real clutter data

- Analysis of Out-of-Range Returns

- Groundspeed Corrections From Radar Returns
  - -identification of error
  - -asimuthal bias

- Additional On-going Research Work

4th CMTAW meeting

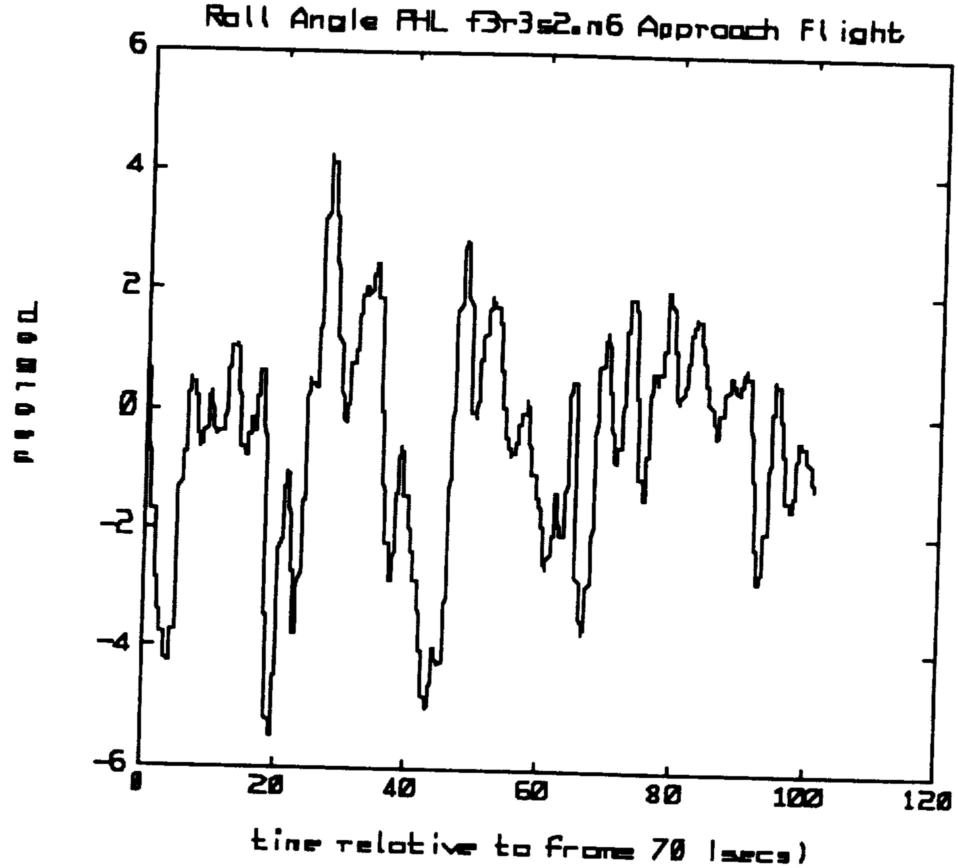
Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

Abstract

Radar data collected during the 1991 NASA flight tests have been selectively analyzed to support research directed at developing both improved as well as new algorithms for detecting hazardous low-altitude windshear. Analysis of aircraft attitude data from several flights indicated that platform stability bandwidths were small compared to the data rate bandwidths which should support an assumption that radar returns can be treated as short time stationary. Various approaches at detection of weather returns in the presence of ground clutter are being investigated. Non-conventional clutter rejection through spectrum mode tracking and classification algorithms is a subject of continuing research. Based upon autoregressive modelling of the radar return time sequence this approach may offer an alternative to overcome errors in conventional pulse-pair estimates. Adaptive filtering is being evaluated as a means of rejecting clutter with emphasis on low signal-to-clutter ratio situations, particularly in the presence of discrete clutter interference. An analysis of out-of-range clutter returns is included to illustrate effects of ground clutter interference due to range aliasing for aircraft on final approach. Data are presented to indicate how aircraft groundspeed might be corrected from the radar data as well as point to an observed problem of groundspeed estimate bias variation with radar antenna scan angle. A description of how recorded clutter return data are mixed with simulated weather returns is included. This enables the researcher to run controlled experiments to test signal processing algorithms. In the summary research efforts involving improved modelling of radar ground clutter returns and a bayesian approach at hazard factor estimation are mentioned.

Roll Angle vs. Time PHL f3r3s2.m6



4th CMTAW meeting

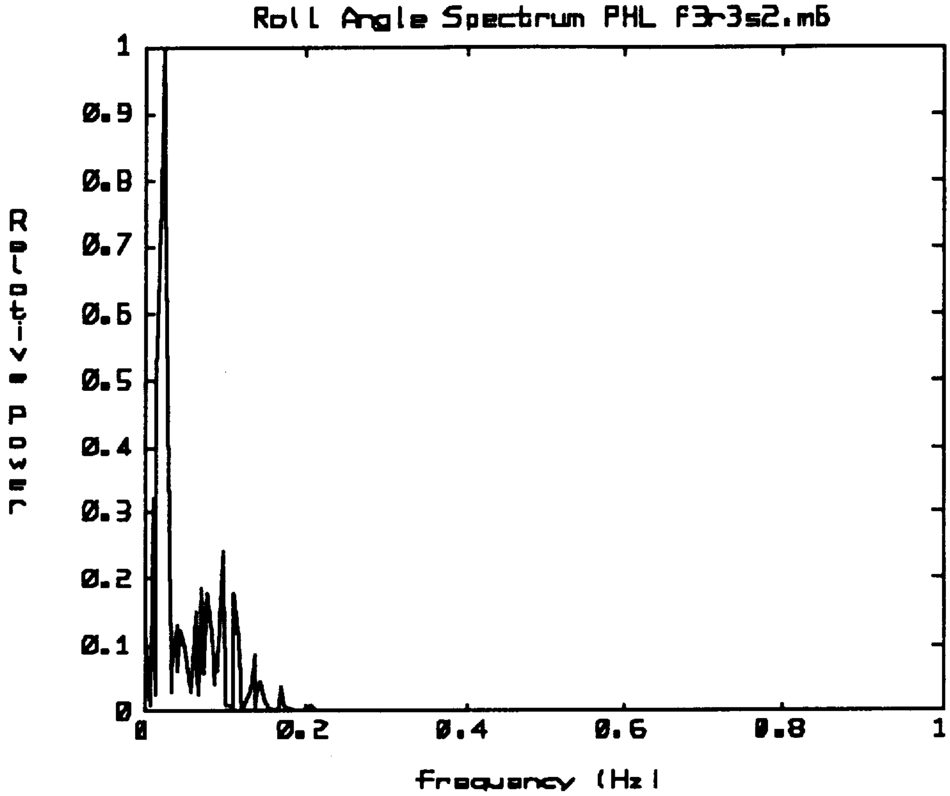
Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

NOTES

Roll angle variation with time during approach to runway 27 at PHL. Data were recorded from DATAC with each frame of radar data at a frame rate of 29.25 frames per second.

Roll Angle Spectrum PHL f3r3s2.m6



4th CMTAW meeting

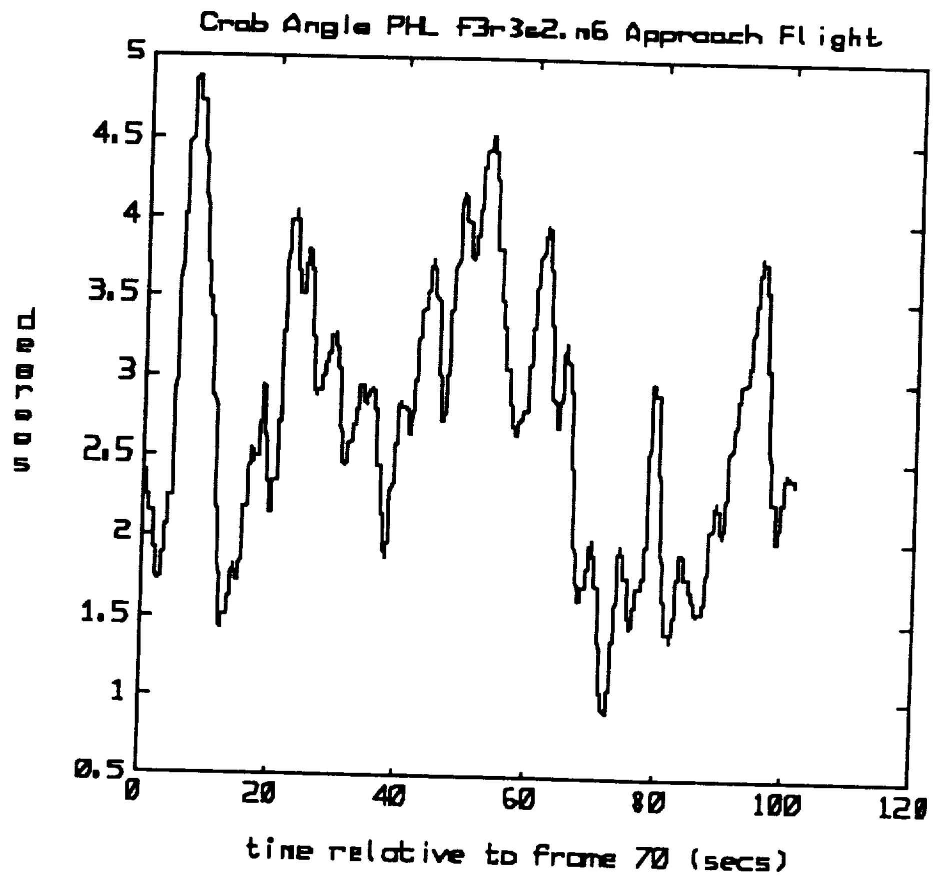
Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

NOTES

Frequency spectrum of roll angle time variation during approach to runway 27 at PHL.
Data were recorded from DATAC with each frame of radar data at a frame rate of 29.25 frames per second.

Crab Angle vs. Time PHL f3r3s2.m6



4th CMTAW meeting

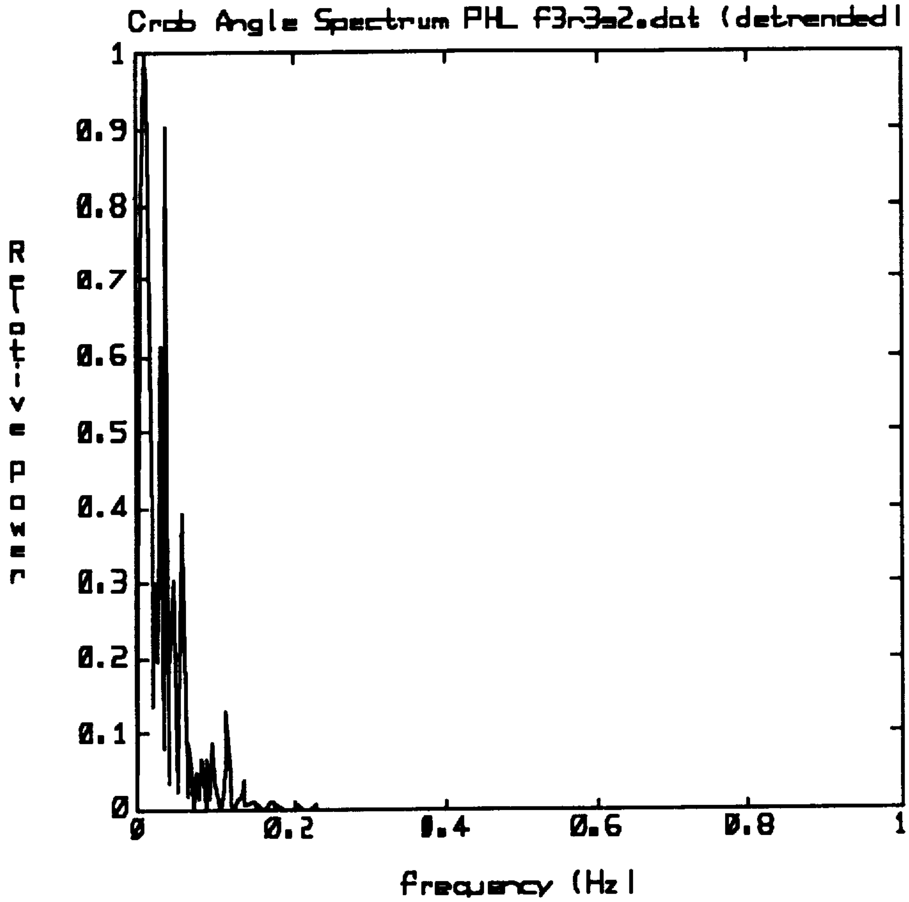
Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

NOTES

Crab angle variation with time during approach to runway 27 at PHL. Data were recorded from DATAC with each frame of radar data at a frame rate of 29.25 frames per second.

Crab Angle Spectrum PHL f3r3s2.m6



4th CMTAW meeting

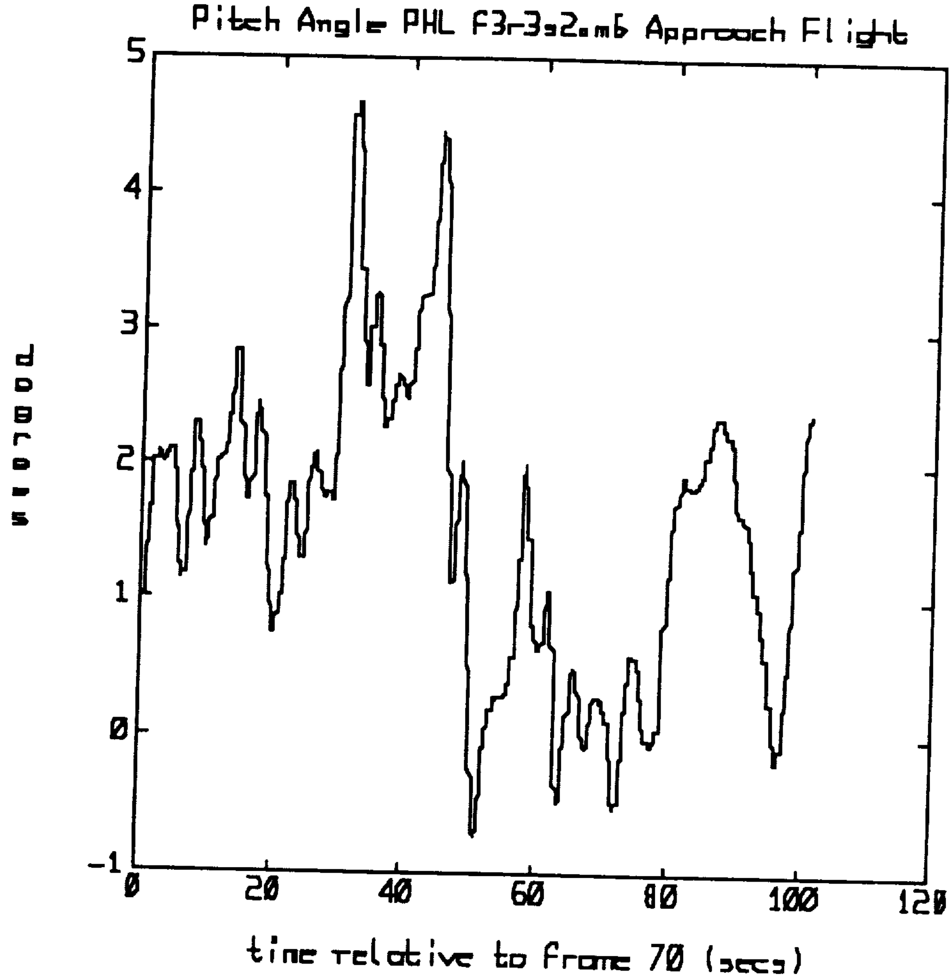
Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

NOTES

Frequency spectrum of crab angle time variation during approach to runway 27 at PHL.
Data were recorded from DATAC with each frame of radar data at a frame rate of 29.25 frames per second. Crab angle mean was removed prior to spectral analysis.

Pitch Angle vs. Time PHL f3r3s2.m6



4th CMTAW meeting

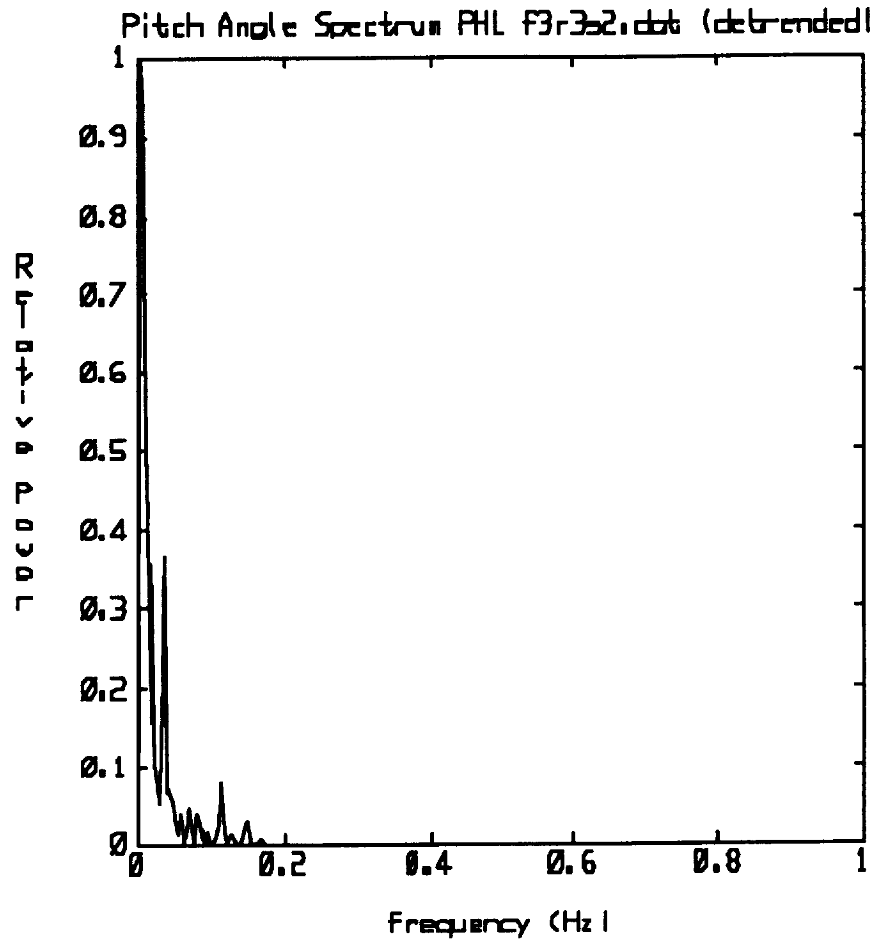
Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

NOTES

Pitch angle variation with time during approach to runway 27 at PHL. Data were recorded from DATAC with each frame of radar data at a frame rate of 29.25 frames per second.

Pitch Angle Spectrum PHL f3r3s2.m6



4th CMTAW meeting

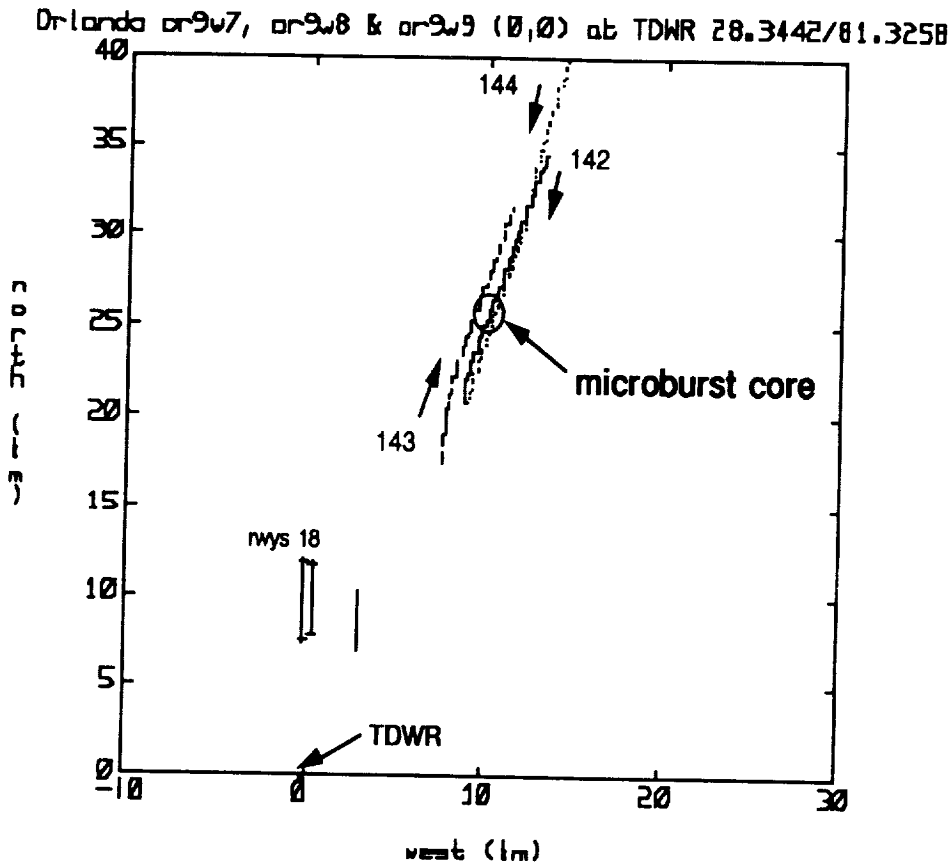
Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

NOTES

Frequency spectrum of pitch angle time variation during approach to runway 27 at PHL.
Data were recorded from DATAC with each frame of radar data at a frame rate of 29.25 frames per second. The mean value of pitch angle was removed before spectral analysis.

Orlando Flights Though Events 142,143,144



4th CMTAW meeting

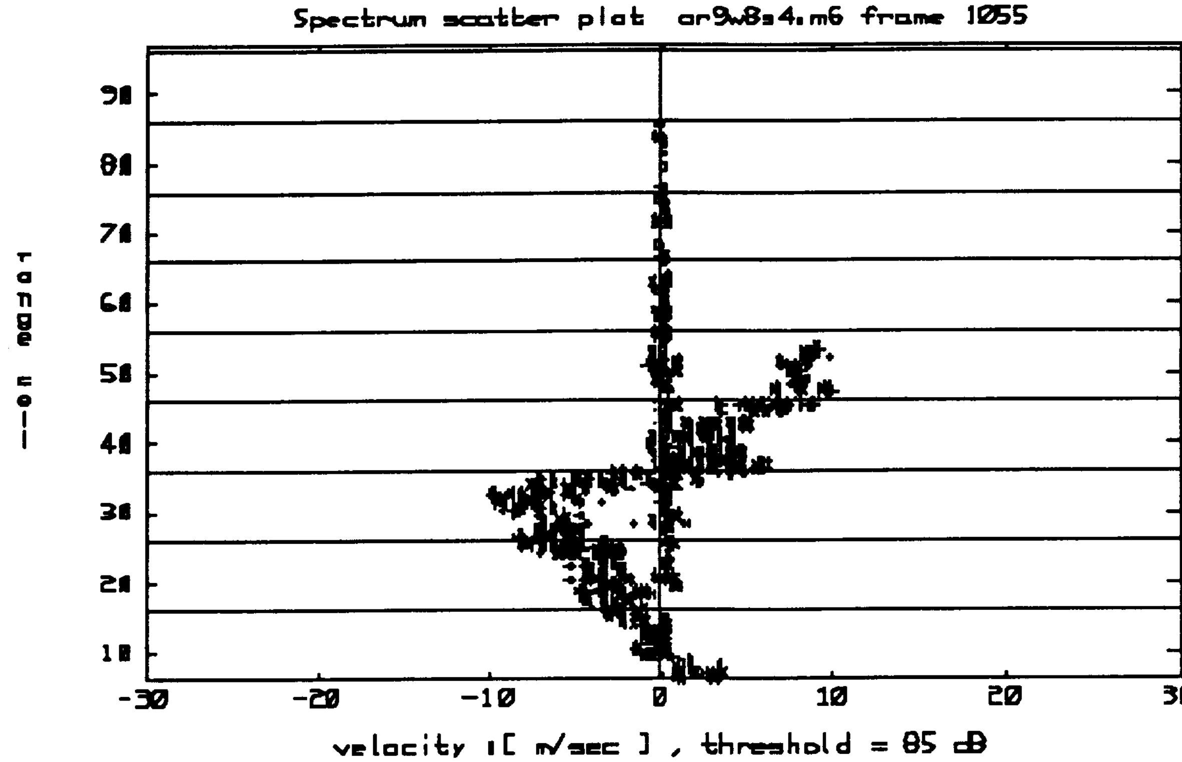
Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

NOTES

Ground tracks of three legs of the NASA flight through the microburst in Orlando on day 171. This event was numbered 142 on the first pass, 143 on the second, and 144 on the third. The aircraft was at about 1100 feet traveling in excess of 200 knots. The indicated position of the microburst is an estimate of the core position based upon radar data. The TDWR is at 0,0 on this plot.

Event 143 Orlando 1991



4th CMTAW meeting

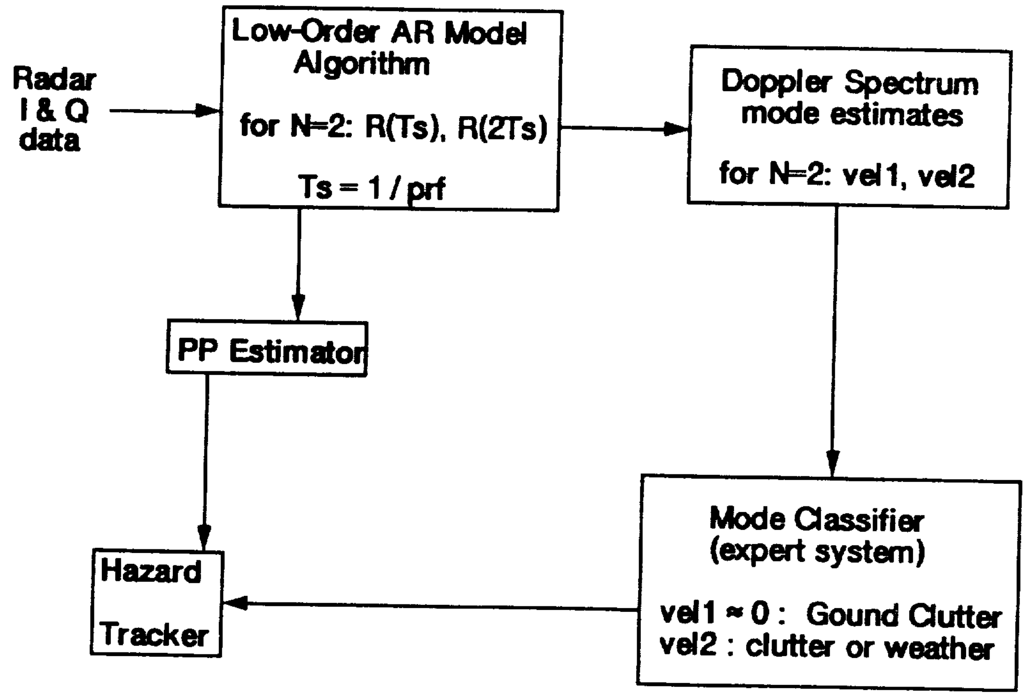
Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

NOTES

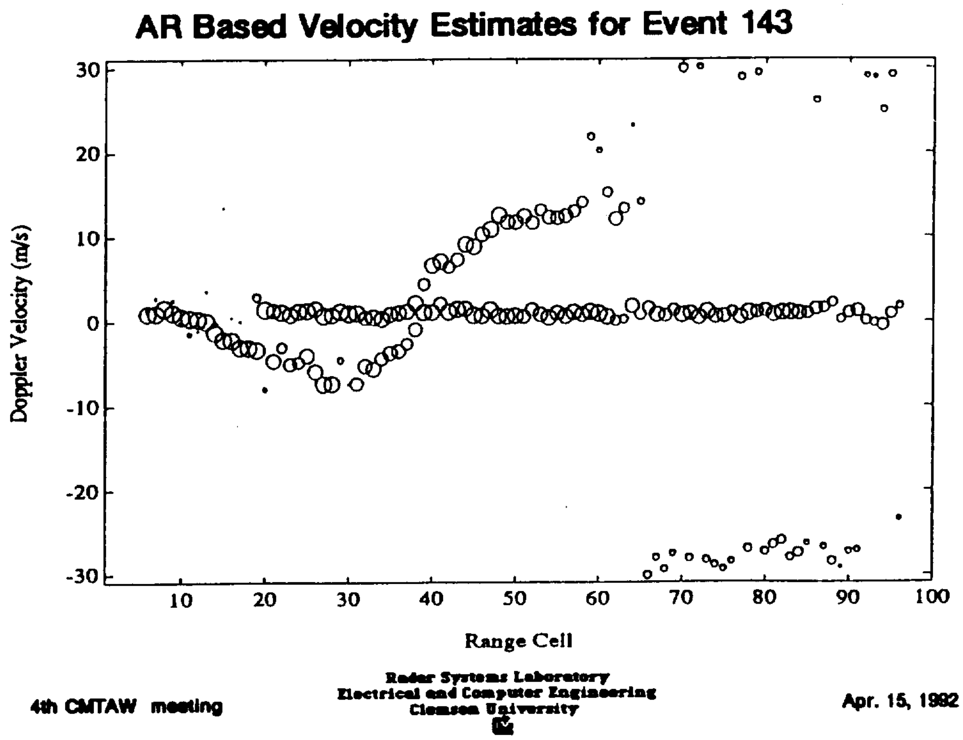
During the flight through event 143 at Orlando a snapshot of the radar return looking into the microburst is analyzed using a Fourier transform of the I & Q sequence (96 samples) taken at an antenna azimuth of -0.25 degrees. The aircraft was on the track labeled 143 on the previous slide and located at about 8 km west and 22 km north of the TDWR. The range cell at the zero crossing of the "s-curve" characteristic is about range cell 35 which is appoximately 5 km ahead of the aircraft. In the presentation the Doppler power spectrum has been thresholded and then a point density plot is used to indicate spectrum intensity. Doppler windspeed is on the abscissa. Range cells from 6 to 96 are indicated on the ordinate. No clutter rejection filtering has been used.

Autoregressive (AR) Modelling of Radar Return



NOTES

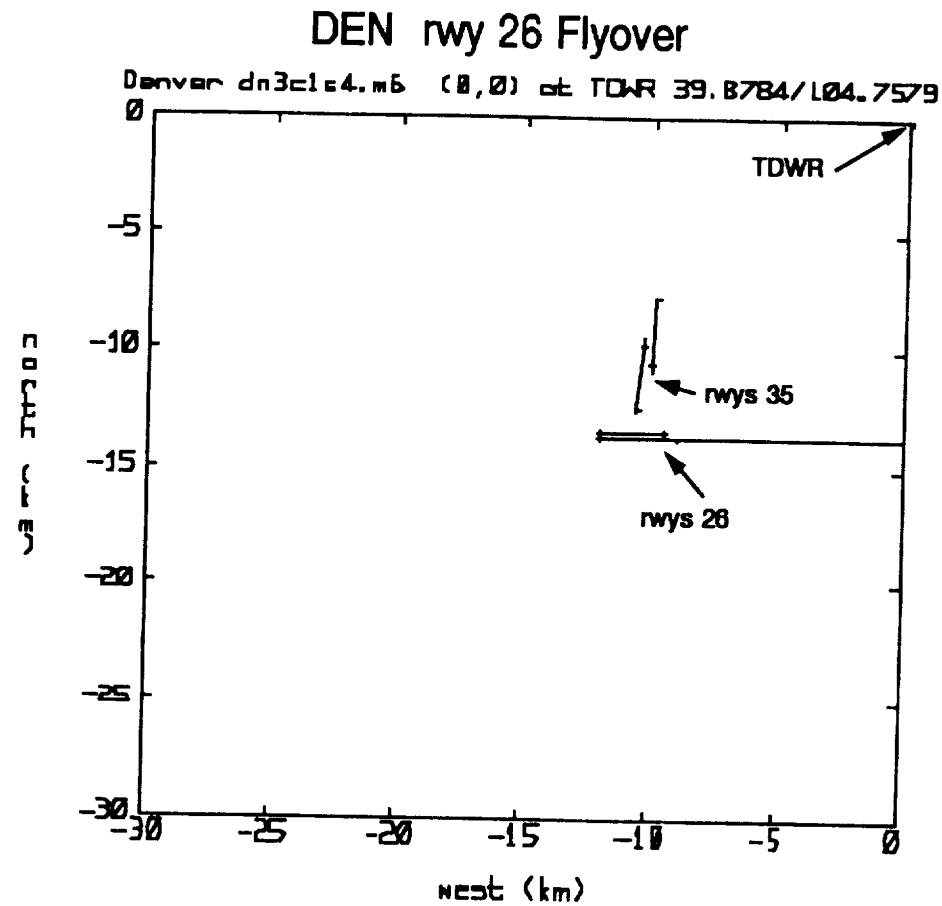
Linear modelling of the I & Q sequences as if they were the output of a linear all-pole model driven by white noise is being used to investigate the feasibility of detecting modes in the return Doppler spectrum without the use of clutter rejection filtering. In situations where the clutter is particularly strong or may tend to bias spectrum mean estimates even when attempts at clutter rejection are made, this method is viewed as a possible alternative. It also provides a method for estimating a spectrum as an alternative to the FFT. A second order AR model is comparable to the pulse pair algorithm in terms of processing load and can give a useful spectrum estimate for further processing.



NOTES

The snapshot of event 143 in Orlando at a time very near to that shown in the earlier scatter point plot is shown here after autoregressive modelling. Again no clutter rejection filtering has been used. The bubble center locations indicate the spectrum mode Doppler velocity estimates for each range cell. The size of the bubbles indicate relative mode strengths. The small bubbles near + 30 m/s and - 30 m/s in range cells 65 and above are indicative of returns at ranges where the return is weak with very little spectular structure. Investigation is continuing to use these methods coupled with an expert mode classification algorithm to detect hazardous windshear.

Ref: M.W. Kunkel, "Spectrum Modal Analysis for the Detection of Low-Altitude Windshear with Airborne Doppler Radar," Radar Systems Lab TR-15, ECE Dept., Clemson University, Feb. 1992.



4th CMTAW meeting

Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

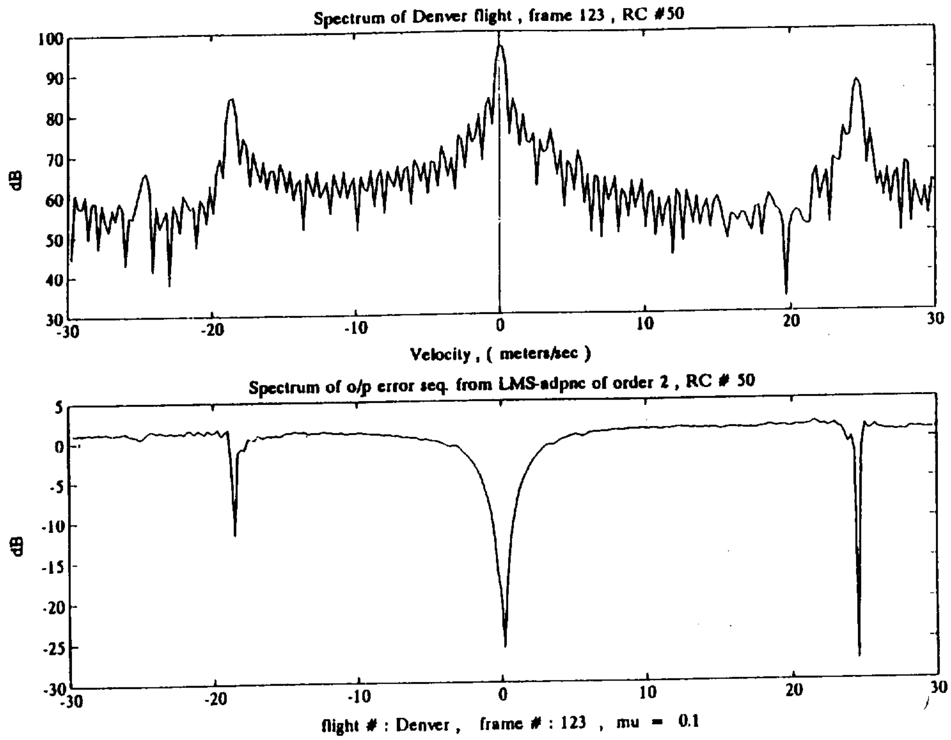
Apr. 15, 1992

NOTES

This is a ground track plot of one of several clutter flights over runway 26L at Denver Stapleton. Generally these flights were at altitudes of 1400 to 1500 feet at groundspeeds near 200 knots. Various antenna elevations were used. Results here include data from horizontal elevation (0 degrees) and -1 and -3 degrees (below horizontal). The position plot is relative to the location of the TDWR (0,0).

Ground Clutter Doppler Spectrum (DEN rwy 26 Flyover)

1440 ft alt., AZ=0, EL=-1



4th CMTAW meeting

Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

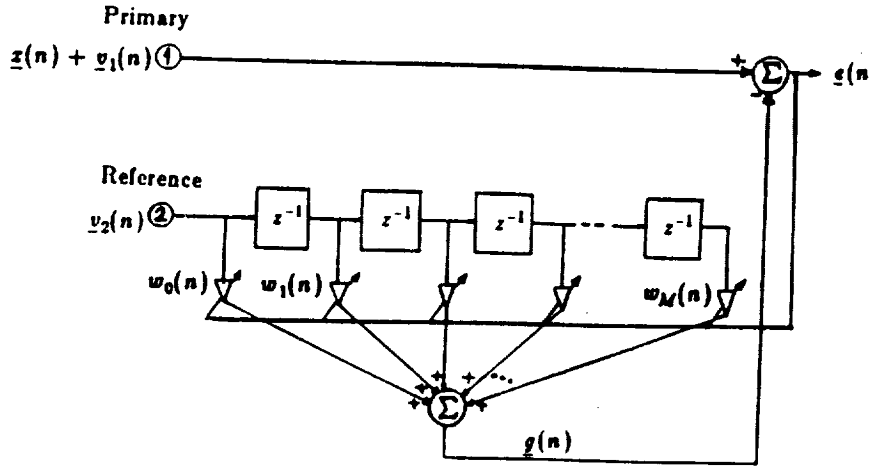
NOTES

A typical clutter FFT spectrum is shown which includes "discrete clutter" modes at about -18 m/s and +25 m/s in addition to the main lobe clutter near zero Doppler. These modes away from zero are due to returns from interstate highway I-70 which passes under runway 35. Also shown is the impulse response of a second order adaptive clutter rejection filter with the I &Q sequence used for the illustrated spectrum also used as a training sequence for the adaptive filter. Notice that the adaptive filter places notches at each of the strong clutter modes even with only a second order filter. The filter is an adaptive noise canceller using the LMS algorithm and is shown in block diagram form in the next figure.

Adaptive Noise Canceling with LMS Filter

LMS Algorithm: $w_i(n+1) = w_i(n) + \mu e(n) v_2(n-i), 0 \leq i \leq M$

where $e(n) = x(n) + v_1(n) - \hat{y}(n) = x(n) + v_1(n) - w_n^T v_{2,n}$.



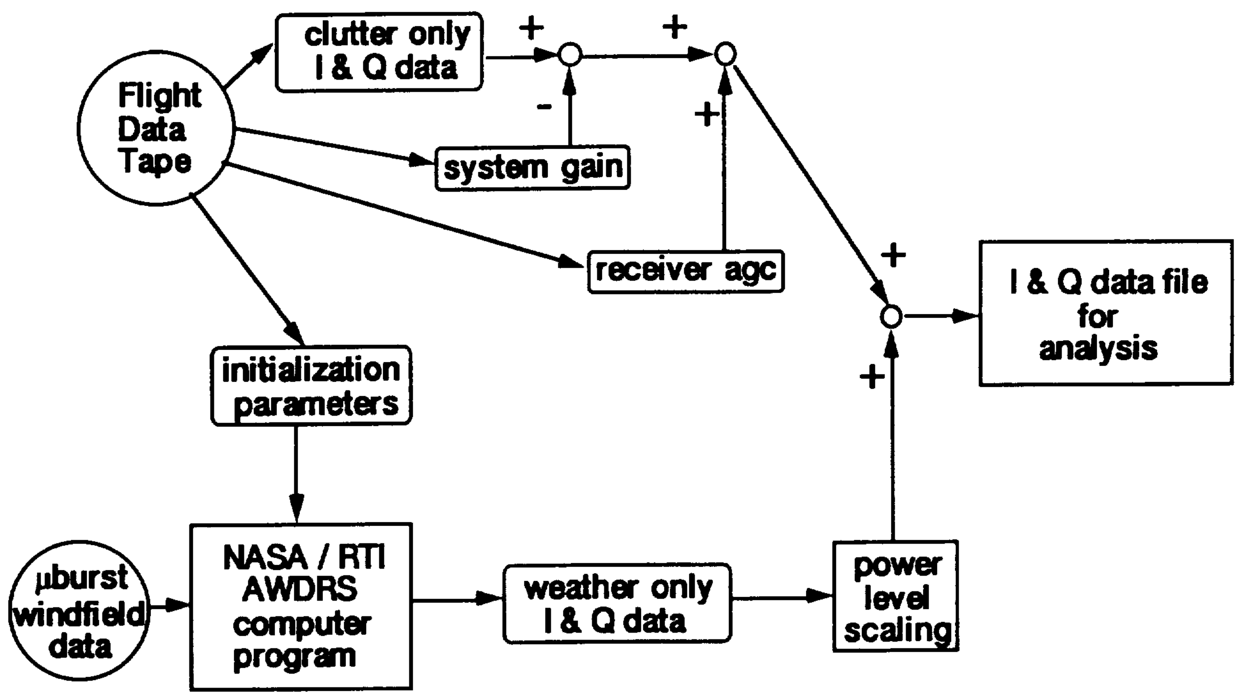
Tapped-delay-line model

Adaptive noise-canceler configuration summary.

NOTES

An adaptive noise canceller can be used to optimally reject clutter from a radar return if a reference clutter sequence is available and that sequence is highly correlated with the ground clutter po rtion of the primary return and uncorrelated with the weather portion of the primary return. As shown earlier a low order tapped delay type adaptive filter may be very effective and is being investigated as an alternative for very low signal to clutter ratio situations.

Analysis of Modelled Microbursts in Real Clutter

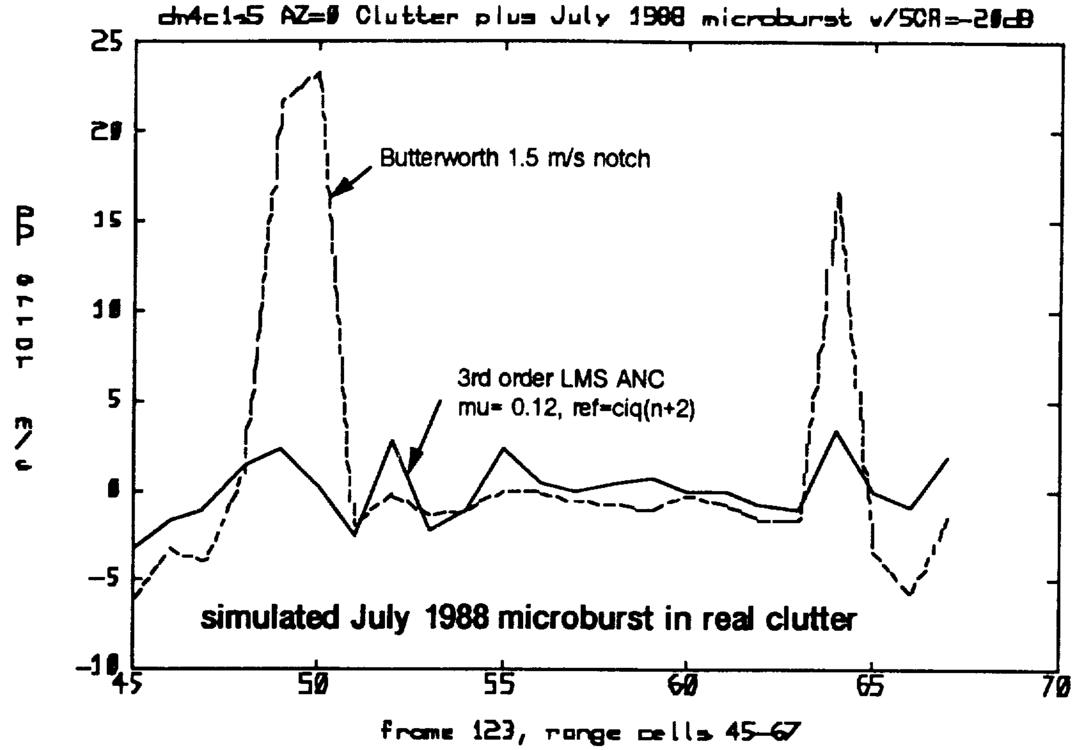


NOTES

To investigate very low signal to clutter ratio situations the NASA simulation model is being used in conjunction with actual recorded ground clutter returns. The simulation model is set up with a microburst windfield from a previously observed microburst. It can be placed at any location for which clutter data have been recorded. Simulated I & Q data are then simply added to the archived clutter I & Q data after proper scaling and used for analysis of signal processing algorithms. The weather signal to clutter ratio can be controlled as desired by the user.

Adaptive Noise Canceling Clutter Rejection Results

post clutter rejection filter pulse-pair mean estimate error



4th CMTAW meeting

Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

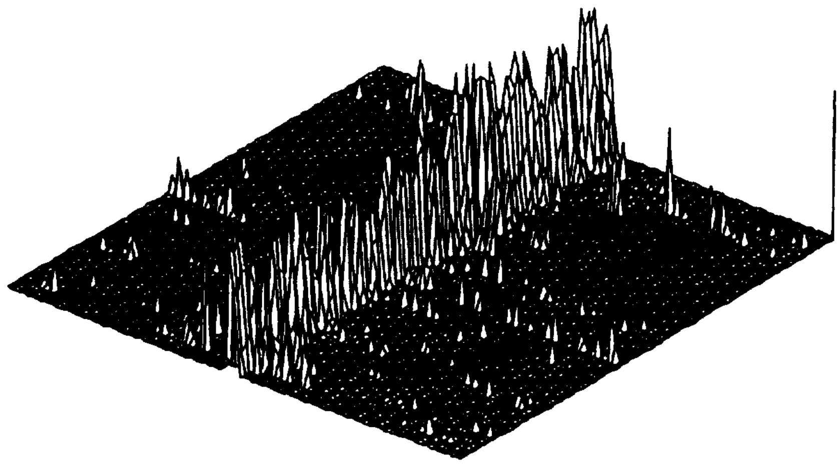
Apr. 15, 1992

NOTES

The LMS based adaptive noise canceller described earlier was used to investigate detection of the July 11 1988 Denver microburst in the presence of actual radar ground clutter data recorded in 1991. The weather return levels were scaled to maintain a constant average signal to clutter ratio of -20 dB in each range cell. The pulse pair estimate of Doppler spectrum mean was then computed after filtering with an adaptive noise canceller using the recorded and time delayed clutter data as a reference input. Results were compared to similar processing after filtering with a fixed 1.5 m/s notch Butterworth filter. The adaptive filter is much better where discrete clutter interference is present (near range cells 50 and 64). This should improve hazard factor estimates.

DEN rwy 26 Flyover, EL=0, 3755 prf, 1-14km

dn2clos1 Frame 153 rc 6-96 96 samples at PRF



norm 80-100dB -30,+30m/s Doppler velocity spectra

4th CMTAW meeting

Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

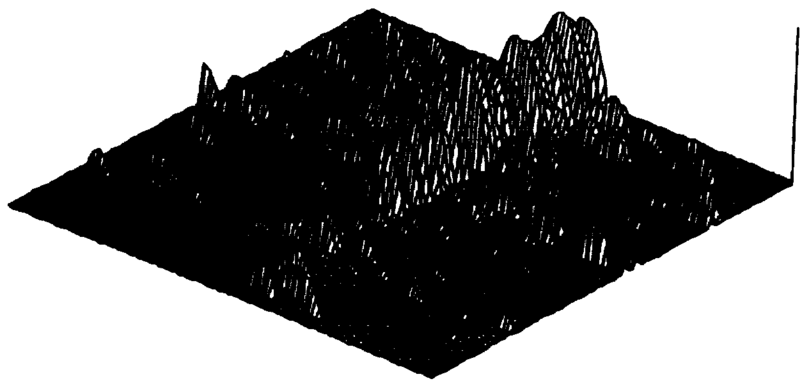
Apr. 15, 1992

NOTES

This and the next 8 slides analyze the effect of out-of-range returns in the Denver data when the aircraft was flying over runway 26 headed west with the radar antenna oriented toward the mountains.Three views show the radar Doppler spectra for range cells 6-96 at the 3755 prf. Data at 1877.5 prf were also recorded and analyzed to show what is in range cells 6-96 without second time around returns and what is in the extended range cells that aliases into the closer range cells when operating at the higher prf. Three different antenna elevation angles are shown. Out-of-range interference is significant at the horizontal elevation (EL=0) and is reduced to a negligible level at EL=-3 degrees. Some spectrum aliasing is also noted in the reduced prf plots since the Doppler range is halved to -15,+15 m/s.

DEN rwy 26 Flyover, EL=0, 1877.5 prf, 1-14km

dn2clos1 Frame 153 rc 6-96 16 samples at PRF/2



norm 70-100dB -15,+15m/s Doppler velocity spectra

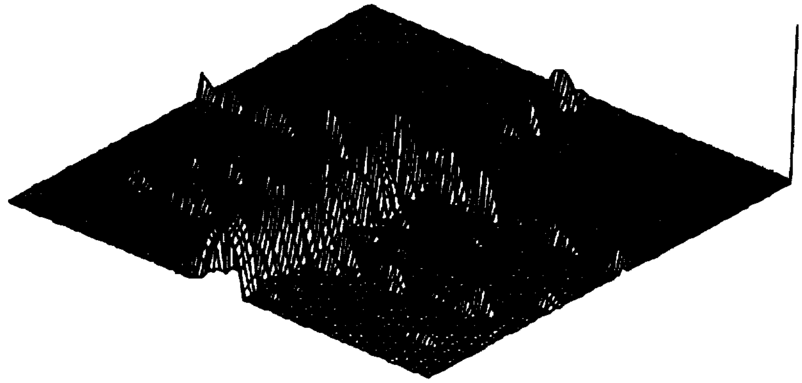
4th CMTAW meeting

Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

DEN rwy 26 Flyover, EL=0, 1877.5 prf, 42-56km

dn2clos1 Frame 153 rc 284-374 15 samples at PRF/2



norm 70-100dB -15,+15m/s Doppler velocity spectra

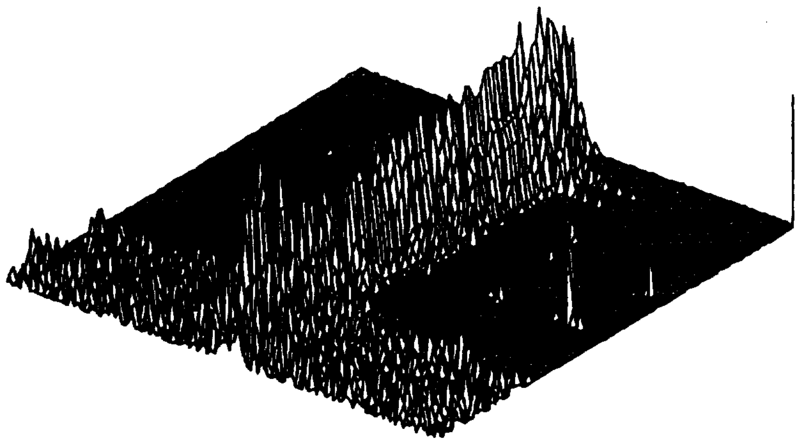
4th CMTAW meeting

Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

DEN rwy 26 Flyover, EL=-1, 3755 prf, 1-14km

dn4cls5 Frame 123 rc 6-96 96 samples at PRF



70-100dB -30,+30m/s Doppler velocity spectra

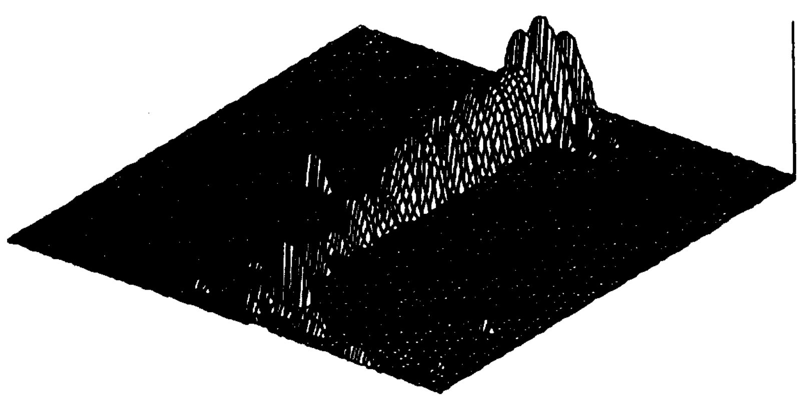
4th CMTAW meeting

Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

DEN rwy 26 Flyover, EL=-1, 1877.5 prf, 1-14km

dn4cls5 Frame 123 rc 6-96 18 samples at PRF/2



70-100dB -15,+15m/s Doppler velocity spectra

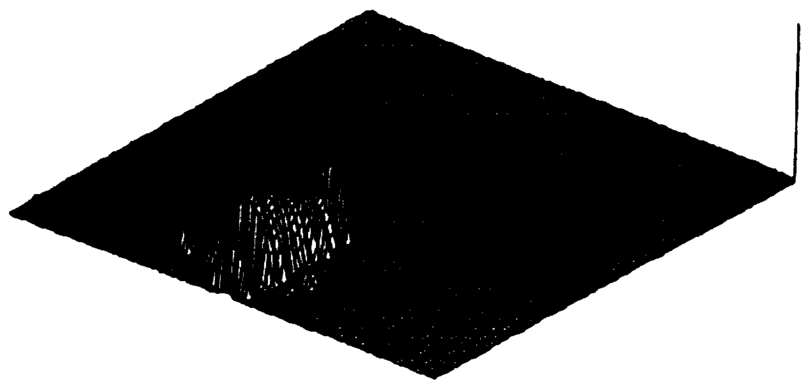
4th CMTAW meeting

Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

DEN rwy 26 Flyover, EL=-1, 1877.5 prf, 42-56km

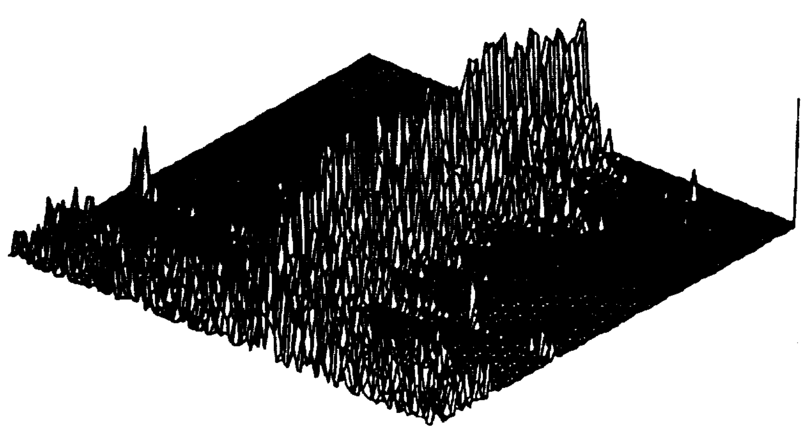
dn4cls5 Frame 123 rc 284-374 15 samples at PRF/2



70-100dB -15,+15m/s Doppler velocity spectra

DEN rwy 26 Flyover, EL=-3, 3755 prf, 1-14km

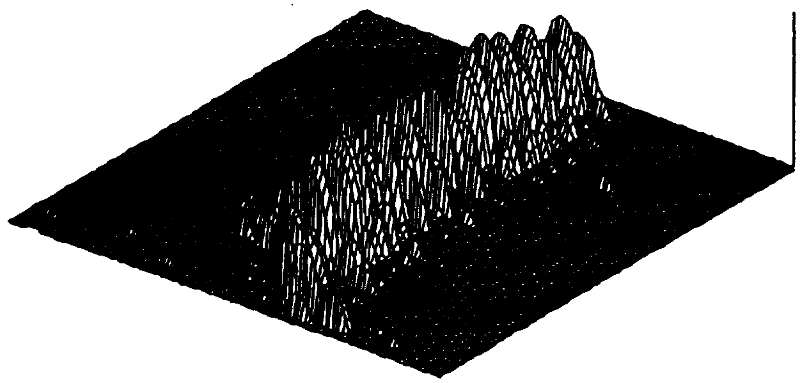
dn3cls3 Frame 210 rc 6-96 96 samples at PRF



70-100dB -30,+30m/s Doppler velocity spectra

DEN rwy 26 Flyover, EL=-3, 1877.5 prf, 1-14km

dn3cl*3 Frame 210 rc 6-96 16 samples at PRF/2



70-100dB -15,+15m/s Doppler velocity spectra

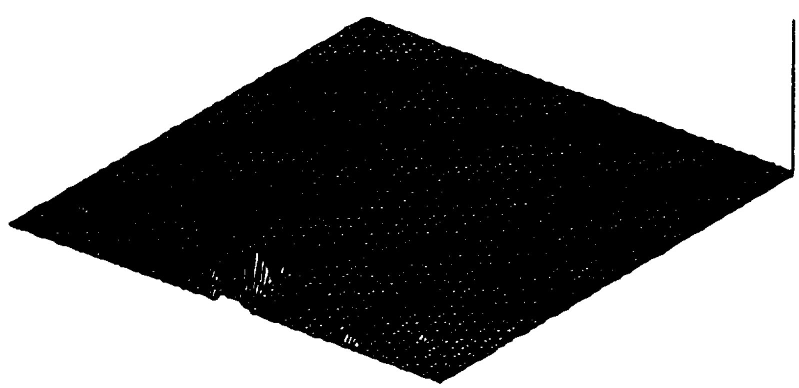
4th CMTAW meeting

Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

DEN rwy 26 Flyover, EL=-3, 1877.5 prf, 42-56km

dn3cl*3 Frame 210 rc 284-374 15 samples at PRF/2



70-100dB -15,+15m/s Doppler velocity spectra

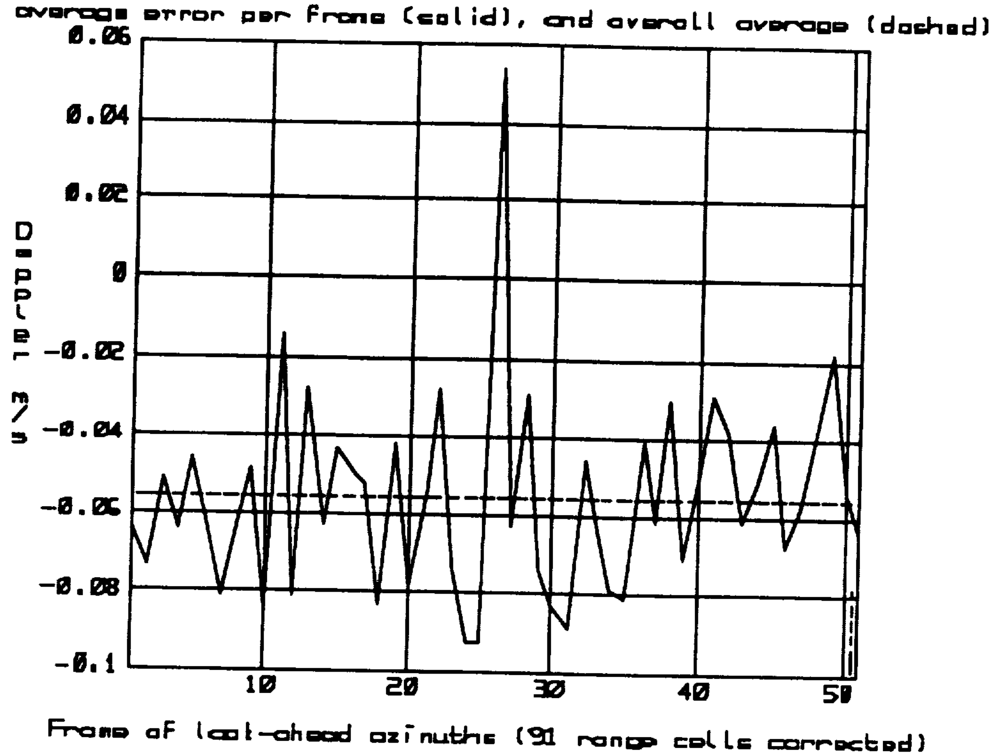
4th CMTAW meeting

Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

Mean Goundspeed Error from Radar Return - DEN

dn2c6as1.m6, EL=0, all times with corrected AZ ≈ 0, rc 6-96



4th CMTAW meeting

Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

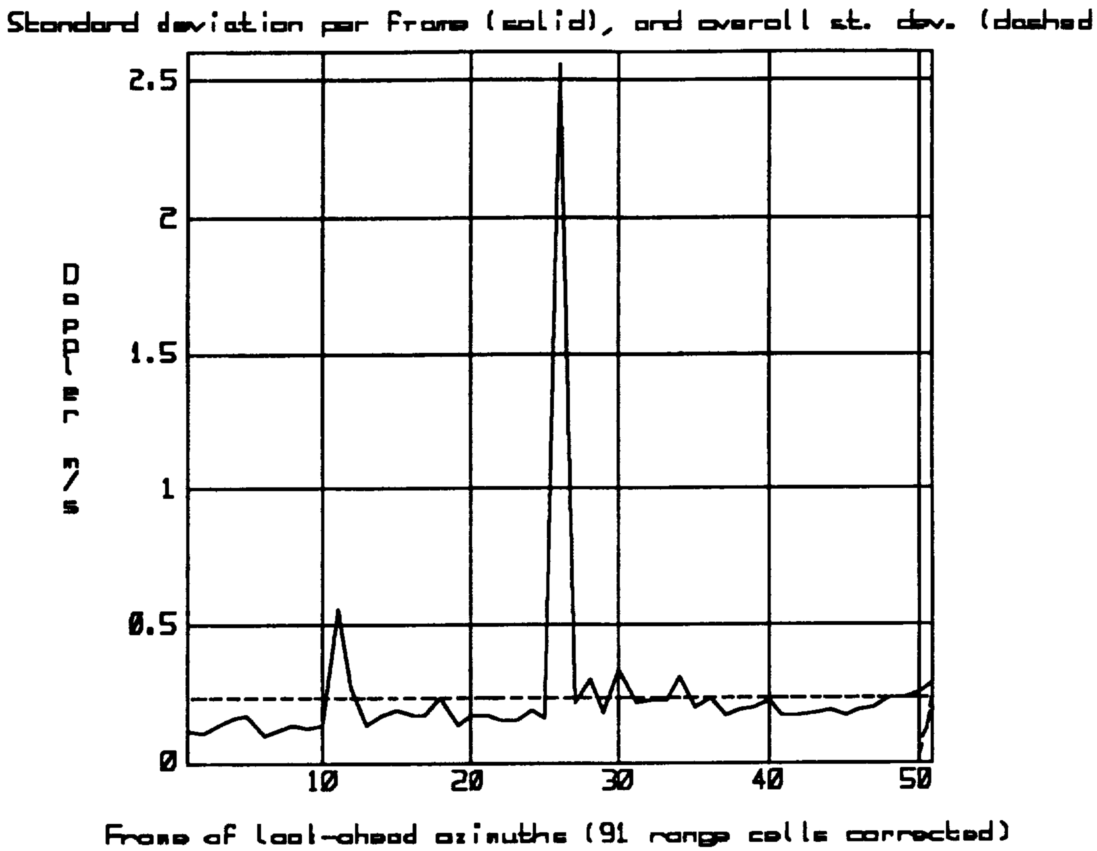
Apr. 15, 1992

NOTES

One of the Denver runway 26 overrflights is analyzed to determine any difference from zero of the Doppler location of the ground clutter mainlobe. This difference is interpreted as a difference between the groundspeed used to determine Doppler zero in the radar demodulation and the groundspeed as measured by the radar. In each frame of 128 radar pulses the spectrum peaks in all range cells have been averaged to get a "frame" mean. These are then plotted for each frame when the corrected antenna azimuth was 0 degrees. A slight bias of aproximatedly 0.055 m/s is noted.

St. Dev. Goundspeed Error from Radar Return - DEN

dn2c6as1.m6, EL=0, all times with corrected AZ ≈ 0, rc 6-96



4th CMTAW meeting

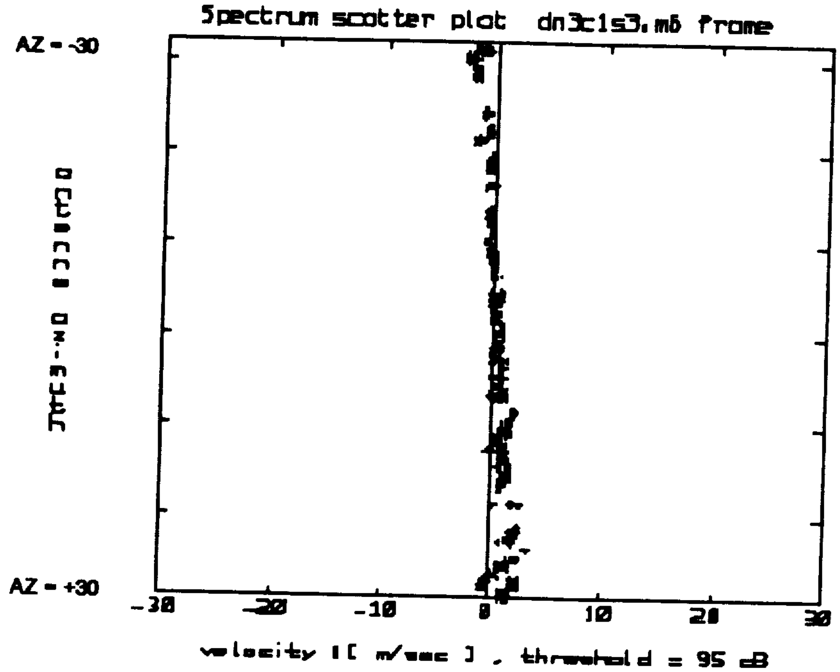
Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

NOTES

The situation described in the previous slide has been analyzed to estimate the standard deviation in the "groundspeed error" as determined from the radar measurement.

Groundspeed Correction Bias vs. Antenna Azimuth



4th CMTAW meeting

Radar Systems Laboratory
Electrical and Computer Engineering
Clemson University

Apr. 15, 1992

NOTES

During each flight experiment the airborne radar antenna was in a scanning mode, typically covering -30, +30 degrees azimuth relative to the A/C longitudinal axis. A small bias error in the ground speed that varied linearly as a function of azimuth angle was noted in virtually all data sets. This error remained after routine correction for the geometric variation of zero Doppler as a function of azimuth angle. In addition, the slope of this bias varied depending on the antenna scan direction. This figure illustrates a counterclockwise scan from a DEN rwy 26 flyover. FFT spectra of data records from 61 frames at 1 degree increments across the scan were thresholded so that the central ground clutter peak is represented as a cluster of points showing how the Doppler spectrum peak varies with azimuth angle. All data are from the range cell where the antenna boresight intersects the ground.

Additional On-going Research Work

1. Real time algorithm development

2. Adaptive clutter rejection filtering

3. Modelling of weather radar returns
   - autoregressive modelling
   - linear models based on fractals
   - non-linear models based on chaotic systems theory

4. Optimal Bayesian methods for Hazard Factor estimation
   - use Doppler spectra as windspeed probability density
   - transform to F-factor probability density
   - estimate "most probable" F-factor map in protection volume

4th CMTAW meeting | Radar Systems Laboratory, Electrical and Computer Engineering, Clemson University | Apr. 15, 1992

References

Baxa, E.G., Jr., " Airborne Pulsed Doppler Radar Detection of Low-Altitude Windshear - A Signal Processing Problem," Digital Signal Processing 1, pp. 186-197, Academic Press, October 1991.

Kunkel, M.W., "Spectrum Analysis for the Detection of Low-Altitude Windshear with Airborne Doppler Radar," Radar Sys. Labs. TR-15, ECE Dept., Clemson Univ., Clemson, SC 29634-0915, February 1992.

Baxa, E.G., Jr. and Lee, J., "The Pulse Pair Algorithm as a Robust Estimator of Turbulent Weather Spectral Parameters Using Airborne Pulse Doppler Radar," NASA CR4382, DOT/FAA/RD-91/17, 1991.

Keel, B.M. and Baxa, E.G.,Jr., "Adaptive Least Square Complex Lattice Clutter Rejection Filters Applied to the Radar Detection of Low Altitude Windshear," Proc. Int. Conf. Acoust., Speech, Sig. Proc., ICASSP-90, Albuquerque, pp. 1469-1472, Apr. 1990.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1992	Conference Publication

4. TITLE AND SUBTITLE
Airborne Wind Shear Detection and Warning Systems - Fourth Combined Manufacturers' and Technologists' Conference

5. FUNDING NUMBERS
WU 505-64-12-01

6. AUTHOR(S)
Dan D. Vicroy, Roland L. Bowles, and Robert H. Passman, compilers

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23665-5225

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
NASA CP-10105, Part 1
DOT/FAA/RD-92/19-I

11. SUPPLEMENTARY NOTES
Dan D. Vicroy and Roland L. Bowles: NASA Langley Research Center, Hampton, Virginia
Robert H. Passman: Federal Aviation Administration, Washington, DC

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified—Unlimited
Subject Category 03

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Fourth Combined Manufacturers' and Technologists' Conference was hosted jointly by NASA Langley Research Center (LaRC) and the Federal Aviation Administration (FAA) in Williamsburg, Virginia, on April 14-16, 1992. The meeting was co-chaired by Dr. Roland Bowles of LaRC and Bob Passman of the FAA. The purpose of the meeting was to transfer significant ongoing results of the NASA/FAA joint Airborne Wind Shear Program to the technical industry and to pose problems of current concern to the combined group. It also provided a forum for manufacturers to review forward-look technology concepts and for technologists to gain an understanding of the problems encountered by the manufacturers during the development of airborne equipment and the FAA certification requirements. The present document has been compiled to record the essence of the technology updates and discussions which follow each.

14. SUBJECT TERMS
Microbursts; Wind Shear; Aircraft Hazards; Doppler Radar; Infrared; LIDAR

15. NUMBER OF PAGES
621

16. PRICE CODE
A99

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

PRECEDING PAGE BLANK NOT FILMED