Aircraft Wake RCS Measurement.

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ABS: next page.
A series of multi-frequency radar measurements of aircraft wakes at altitudes of 5,000 to 25,000 ft. was performed at Kwajalein, R.M.I., in May and June of 1990. Two aircraft were tested, a Learjet 35 and a Lockheed C-5A. The cross-section of the wake of the Learjet was too small for detection at Kwajalein. The wake of the C-5A, although also very small, was detected and measured at VHF, UHF, L-, S-, and C-bands, at distances behind the aircraft ranging from about one hundred meters to tens of kilometers. The data suggest that the mechanism by which aircraft wakes have detectable radar signatures is, contrary to previous expectations, unrelated to engine exhaust but instead due to turbulent mixing by the wake vortices of pre-existing index of refraction gradients in the ambient atmosphere. These measurements were of necessity performed with extremely powerful and sensitive instrumentation radars, and the wake cross-section is too small for most practical applications.

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AIRCRAFT WAKE RCS MEASUREMENTS

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OUTLINE

• BACKGROUND

• RADARS AND AIRCRAFT

• RADAR DATA EXAMPLES

• WAKE SIGNATURES
  – STRENGTH
  – POSSIBLE MECHANISMS
  – ARE WAKES USEFUL "TELL-TALES?"

• SUMMARY
AIRCRAFT WAKE STRUCTURE AND RADAR SCATTERING

- **WAKE STRUCTURES**
  - SENSITIVE TO AIRCRAFT CONFIGURATION
  - INITIALLY LAMINAR FLOW DECAYS TO TURBULENCE
  - UP TO 10 TO 20 km LONG

- **POTENTIAL SCATTERING MECHANISMS**
  - REFRACTIVITY VARIATIONS
  - EXHAUST HEAT AND MOISTURE MIXING OF ATMOSPHERIC STRATA
  - VORTEX DYNAMICS
  - EXHAUST PARTICULATES AND AEROSOLS
AIRCRAFT WAKE SIGNATURE
PRIOR MEASUREMENTS AND CALCULATIONS

EXTRAPOLATION

![Graph showing RCS per unit length versus frequency with extrapolation](image-url)
AEROMET LEARJET 36 FLY-BY
25 MAY 1990

GATES LEARJET 36
WING SPAN      12 m
MASS, EMPTY    4300 kg
MASS, MAX T.O. 8300 kg
FUEL FLOW AT
45,000 ft      1100 lbs/hr
439 MAW C-5A FLY-BY
15 JUNE 1990

LOCKHEED C-5A GALAXY
WING SPAN 68 m
MASS, EMPTY 150,000 kg
MASS, MAX T.O. 350,000 kg
FUEL FLOW AT 40,000 ft 18,000 lbs/hr
FLIGHT PATH AND DATA RECORDING
TEST RUN AT 5,000 ft ALTITUDE

WIND

60 s (6.7 km)

15 km

240 s (27 km)

RADAR SITE
S-BAND RANGE-DOPPLER SLICE THROUGH C-5A WAKE

5,000 ft ALTITUDE
60 s (6.7 km) AFTER PASSAGE OF AIRCRAFT

DOPPLER (m/s)

RELATIVE RANGE (m)

WIND
S-BAND RANGE-DOPPLER SLICE THROUGH C-5A WAKE

5,000 ft ALTITUDE
240 s (27 km) AFTER PASSAGE OF AIRCRAFT

RELATIVE RANGE (m)

DOPPLER (m/s)

WIND
C-5A WAKE DATA

WAKE RCS PER UNIT LENGTH (dB sm/m)

DISTANCE (km)

1984 NOAA S-BAND DATA

-110.0

-100.0

-90.0

-80.0

-70.0

5,000 ft

20,000 ft

VHF

UHF

L-BAND

S-BAND

C-BAND
AIRCRAFT WAKE SIGNATURE
PRIOR MEASUREMENTS AND CALCULATIONS

EXTRAPOLATION
C-5A DATA AT 5 kft
C-5A DATA AT 10 kft
C-5A DATA AT 20 kft

FREQUENCY (GHz)

TOTAL WAKE RCS OVER 10 km (dBsm)

RCS PER UNIT LENGTH (dBsm/m)
## SUMMARY OF C-5A WAKE SIGNATURE DEPENDENCE

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DEPENDENCE</th>
<th>CONCLUSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DISTANCE</td>
<td>INCREASES FOR CA. 10 km, THEN TRAILS OFF</td>
<td>RELATED TO TURBULENCE</td>
</tr>
<tr>
<td>FREQUENCY</td>
<td>LARGELY FLAT, FALLING OFF AT C-BAND</td>
<td>NOT PARTICULATES</td>
</tr>
<tr>
<td>ALTITUDE</td>
<td>DECREASES WITH HEIGHT; NOT SEEN ABOVE 27 kft</td>
<td>RELATED TO LOW-ALTITUDE CLIMATE</td>
</tr>
<tr>
<td>ENGINE THRUST</td>
<td>NONE: IDLE TO MILITARY RATED THRUST</td>
<td>WEAK EXHAUST CONTRIBUTION</td>
</tr>
<tr>
<td>FLAP SETTING</td>
<td>NONE: ZERO TO HALF FLAPS</td>
<td>INDEP. OF DETAILED VORTEX STRUCTURE</td>
</tr>
<tr>
<td>AIR SPEED</td>
<td>NONE: 100 kn VARIATION</td>
<td>INDEP. OF DETAILED VORTEX STRUCTURE</td>
</tr>
</tbody>
</table>
POSTULATED MECHANISM

• TURBULENT MIXING OF ATMOSPHERIC INDEX OF REFRACTION GRADIENTS
  – CONSISTENT WITH RCS DEPENDENCE ON
    ALTITUDE
    THRUST
    TIME
    FREQUENCY

• STRENGTH DEPENDS ON CLIMATE
  – STRONGEST IN TROPICS NEAR SEA LEVEL

• EXHAUST HEAT AND MOISTURE MAY GIVE LOWER LIMIT
SUMMARY

• PRIOR WORK SUGGESTED A VERY SMALL WAKE RCS

• AT KWAJALEIN
  - ENGINE EXHAUST COMPONENT NOT DISCERNIBLE
  - DOMINANT ATMOSPHERIC MIXING CONTRIBUTION

• NO USEFUL "TELL-TALE"
  - STRONG CLIMATE DEPENDENCE
  - LARGE AND COMPLEX SYSTEM
  - CLEAR AIR TURBULENCE CLUTTER
### WSMR V. KWA Wake RCS Measurements

<table>
<thead>
<tr>
<th>Radar</th>
<th>MoTR</th>
<th>ALCOR</th>
<th>ALCOR/MoTR</th>
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<tbody>
<tr>
<td>Peak power</td>
<td>1 MW</td>
<td>3 MW</td>
<td>5 dB</td>
</tr>
<tr>
<td>Beam width</td>
<td>1°</td>
<td>5°</td>
<td>-14 dB</td>
</tr>
<tr>
<td>Duty factor</td>
<td>0.1%</td>
<td>5%</td>
<td>17 dB</td>
</tr>
<tr>
<td>Range</td>
<td>3 km</td>
<td>15 km</td>
<td>-14 dB</td>
</tr>
<tr>
<td>Beam-filling loss (100 m wake)</td>
<td></td>
<td>-10 dB</td>
<td></td>
</tr>
</tbody>
</table>

Relative sensitivity to wake $C_r^2$:
- MoTR more sensitive
- -16 dB

### Aircraft

<table>
<thead>
<tr>
<th>A-7</th>
<th>LEARjet 36</th>
<th>C-5A</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 kts</td>
<td>10 kts</td>
<td>330 kts</td>
</tr>
</tbody>
</table>
QUESTION #3

Can a radar detect and quantify the VORTEX STRENGTH?

OBVIOUS ANSWER - IN PRINCIPLE - YES, WITH ENOUGH RANGE OF ANGULAR RESOLUTION?

MY QUESTION FOR THE AERODYNAMISTS?
WHAT IS ENOUGH RESOLUTION?
E.G. lm range by 50 m (cross range)
ATMOSPHERIC DATA FOR WAKE RCS MEASUREMENTS

Rawinsondes
WSMR AM, PM
KREMS 1130, from Kwaj.

Weather reports
Met. station, before 2 after 5
Met. station on Kwaj, Mornings, before missions.