

Study on Wake Vortex Electromagnetic Model and Radar Detection Trials

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✈ Wake Vortex EM Scattering Characteristics

Dielectric constant distribution

RCS-Frequency characteristic

RCS-Time characteristic

Radar HRRP of wake vortex

✈ Wake Vortex Radar Detection Trials

✈ Conclusions and Outlooks

✈ Introduction

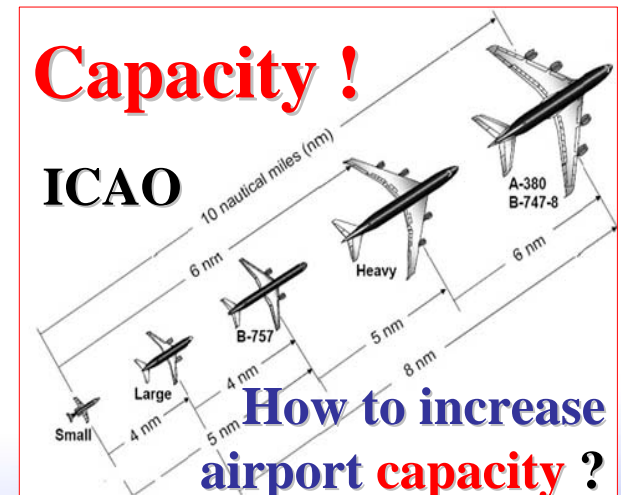
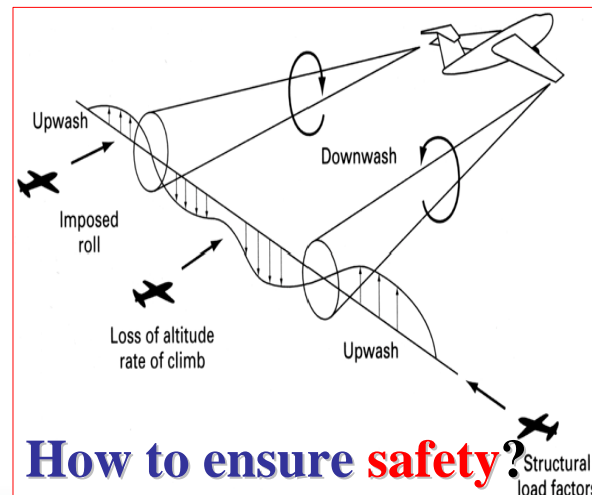
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In 2005, Beijing became the 2nd busiest airport in China and the 14th worldwide in terms of passenger numbers, overtaking Hong Kong as China's busiest air transport hub.

Passenger traffic growth(2005-2009) **Freight traffic growth(2005-2009)**

Poland	China	...
11.2%	9.6%	...

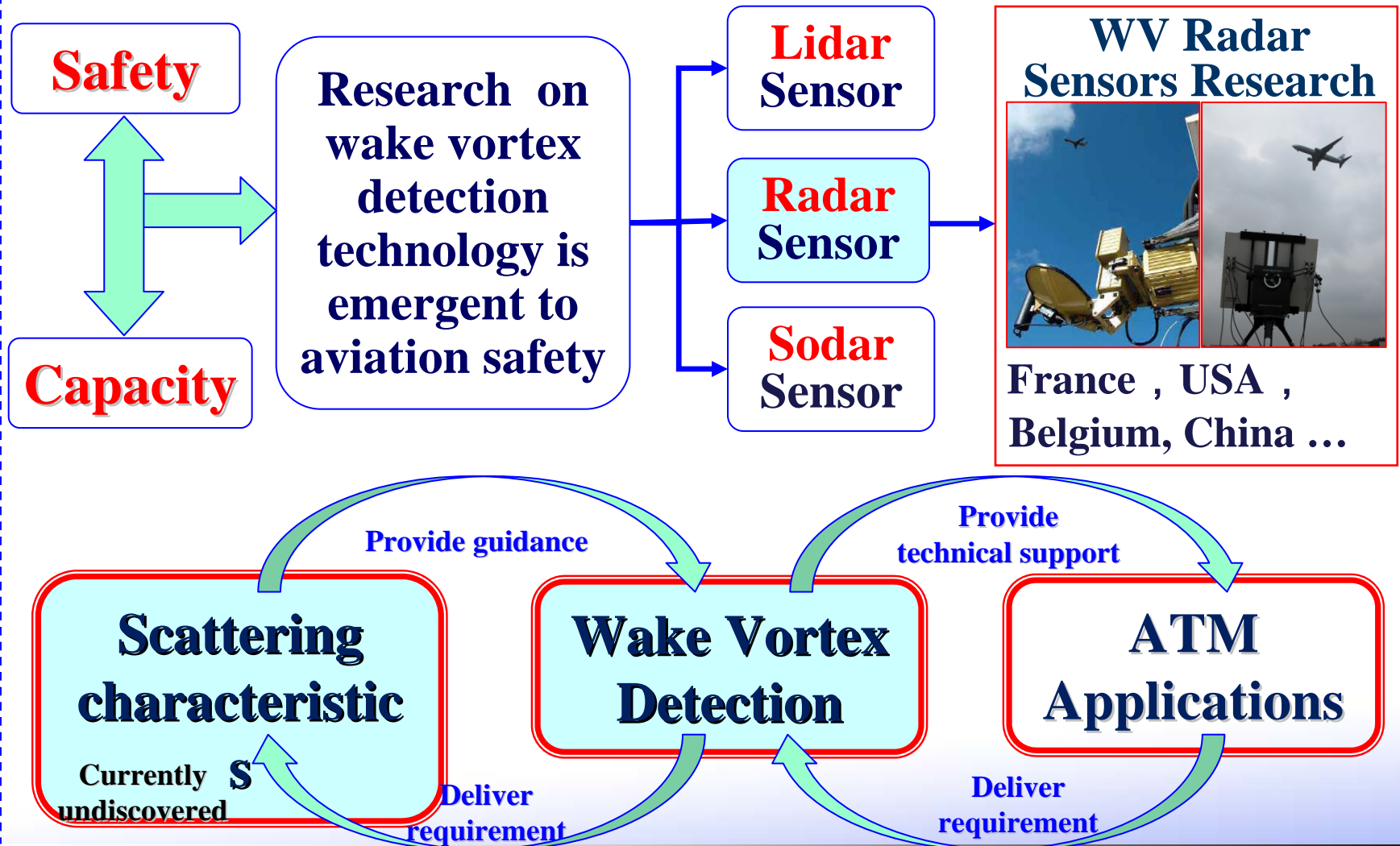
China	Qatar	...
14.4%	12.5%	...



✈ Introduction

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How to balance between Safety and Capacity?



Wake Vortex EM Scattering Characteristics

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Maxwell 1831-1879

Maxwell equations

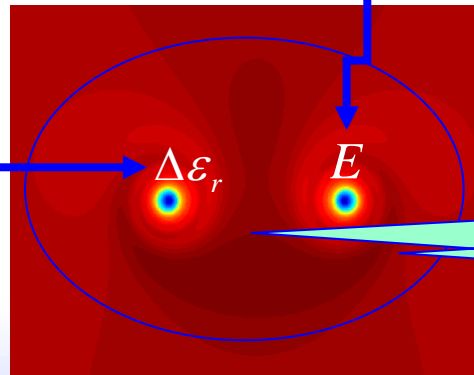
scattering

$$E_s(r) = -k^2 \iiint_{\Omega} \Delta \epsilon_r(r') [o \times o \times E(r')] \frac{e^{ik|r-r'|}}{4\pi|r-r'|} d^3r'$$

Dielectric constant distribution

Total electric field in the wake

3D highly oscillatory integrals



∫∫∫

receiver

Wake Vortex EM Scattering Characteristics

Dielectric constant distribution

The dielectric constant variation is modeled as a function with respect to the variation of **density** and that of **water vapor**:

$$\Delta \varepsilon_r = 1.552 \times 10^{-6} \left[\left(1 + 4668 \frac{q_a}{T_a} \right) R \Delta \rho + 7780 \frac{p_a}{T_a^2} \Delta q \right]$$

Euler equation

Velocity model

Isentropic flow method

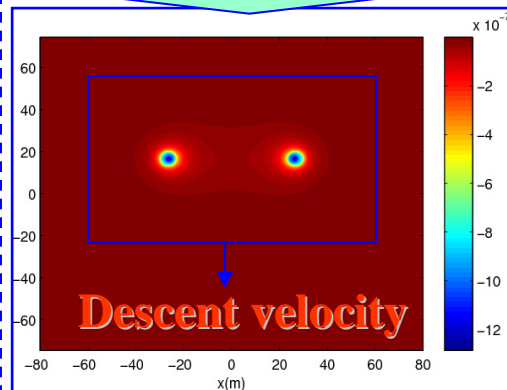
density

Velocity model

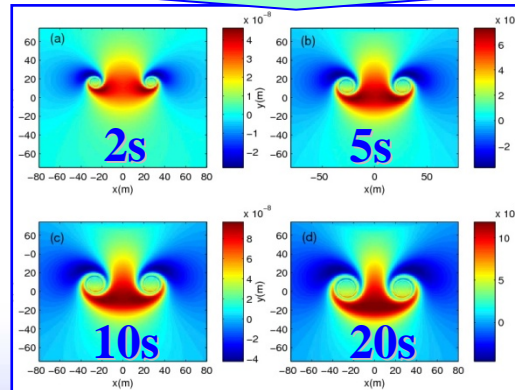
Convection-diffusion
equation

Water vapor

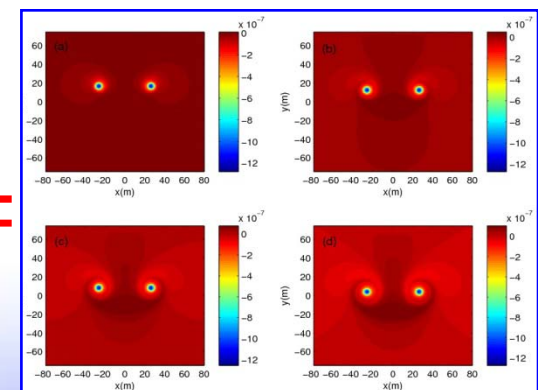
Total



+

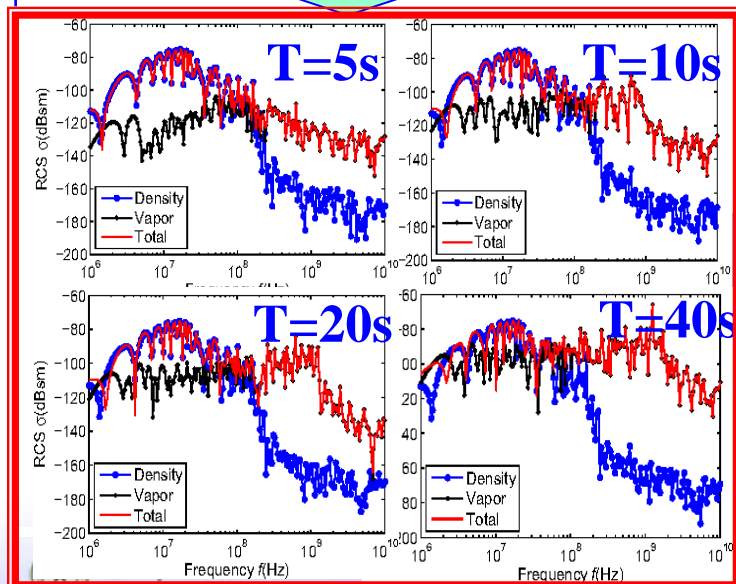
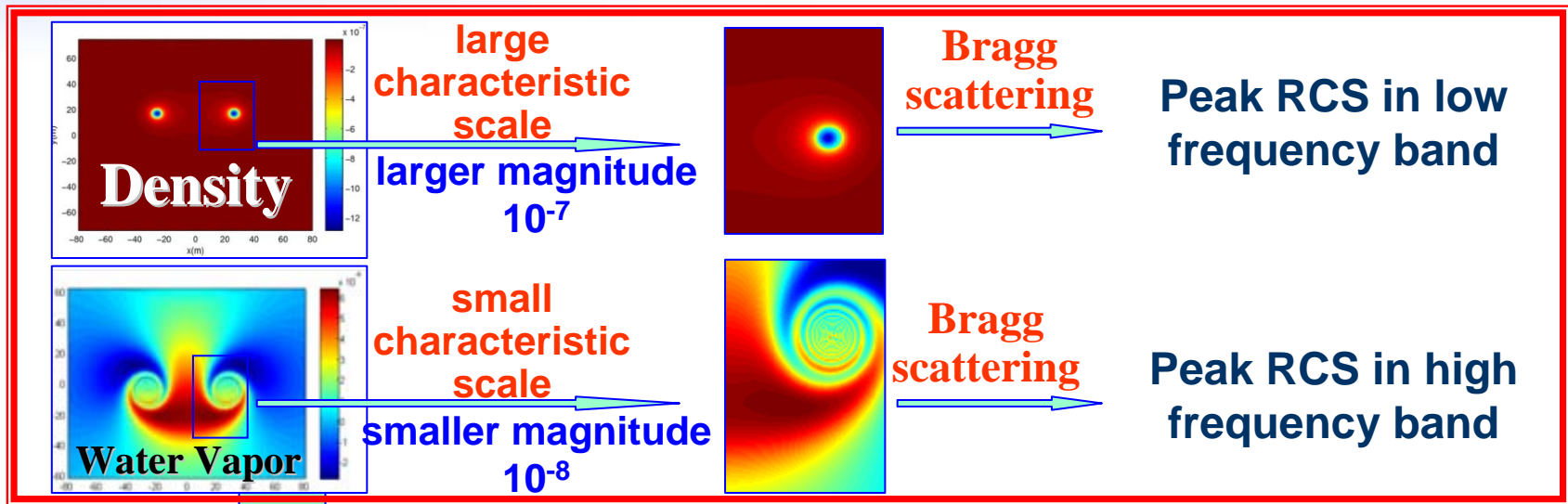


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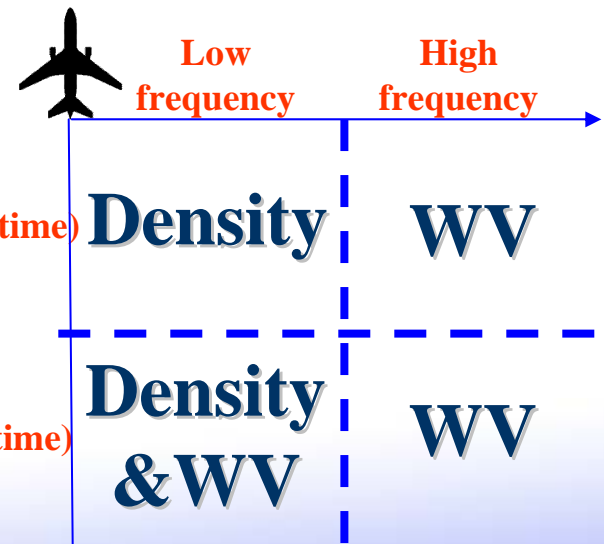
Wake Vortex EM Scattering Characteristics

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Near field
(short evolution time)

Far field
(long evolution time)



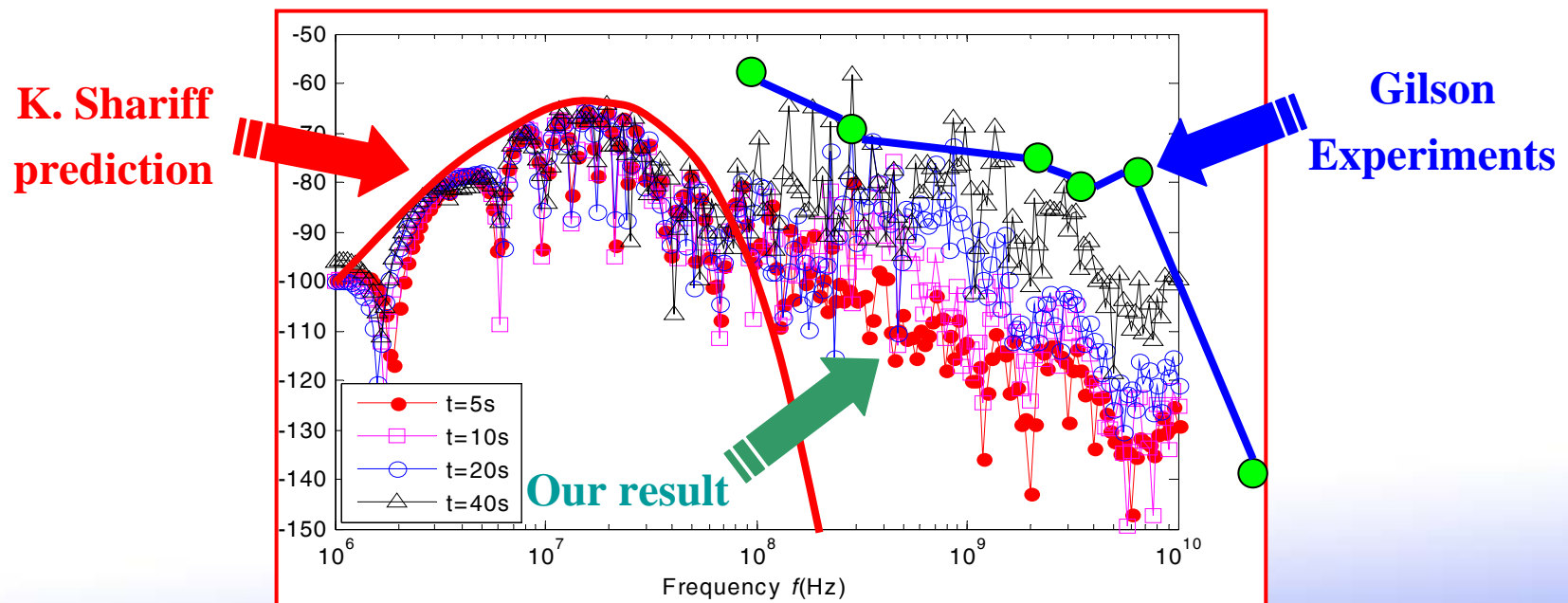
Determination factor for RCS

✈ Wake Vortex EM Scattering Characteristics

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RCS-Frequency characteristic

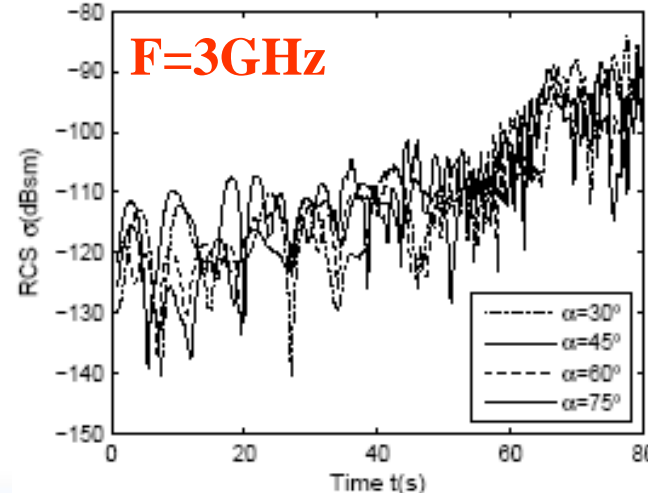
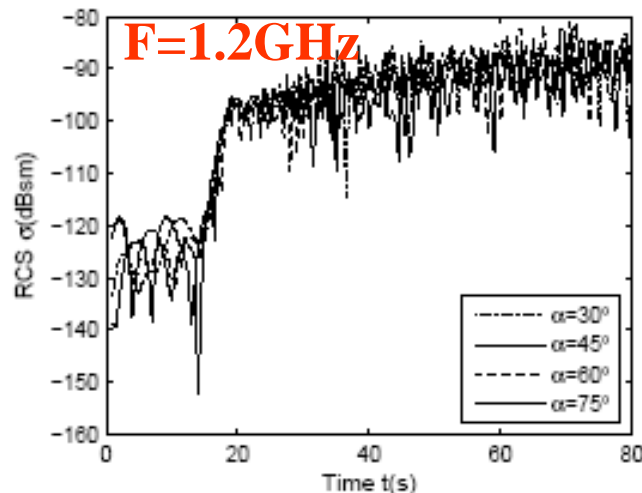
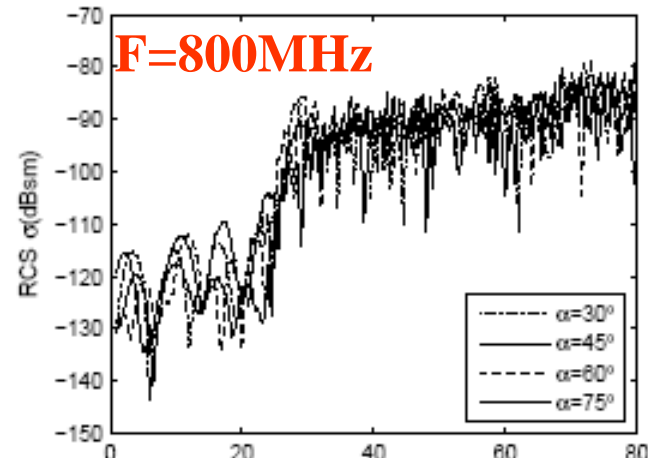
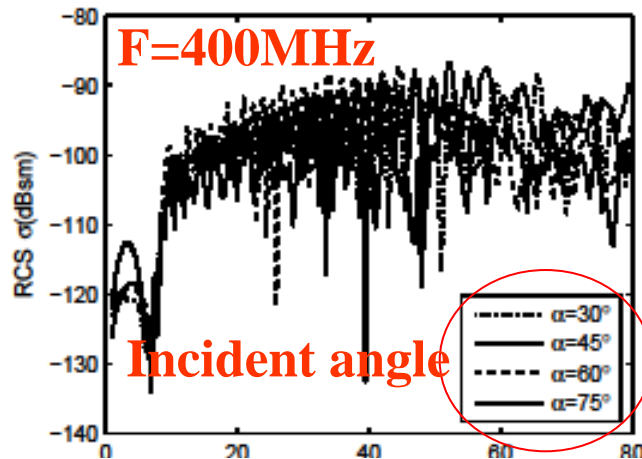
The RCS-frequency characteristic of wake vortex is studied based on the dielectric constant distribution. In the low frequency band, our result is in accordance with K. Shariff's prediction, and in the high frequency band, our result gradually approaches to Gilson's experimental result as the evolution time increases.



Wake Vortex EM Scattering Characteristics

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RCS-Time characteristic

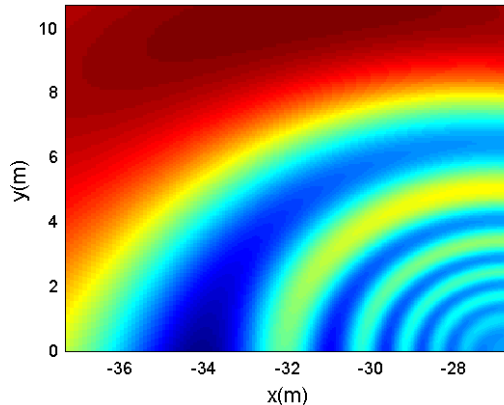


- ① Step is observed in the RCS-time curve
- ② The later the incident frequency, the later the RCS-step phenomenon occurs

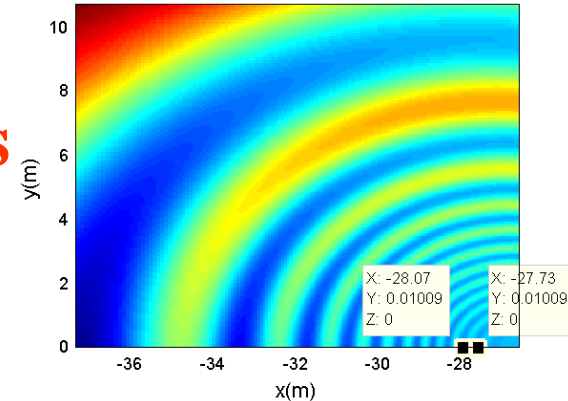
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- ① Laminating structures of the dielectric constant evolves from thick to thin; the moment the laminar structure with a characteristic scale of the incident frequency emerges, a step occurs in the RCS-time curve
- ② A higher incident frequency corresponds to a thinner laminar structure, which emerges later, so the RCS-step occurs later

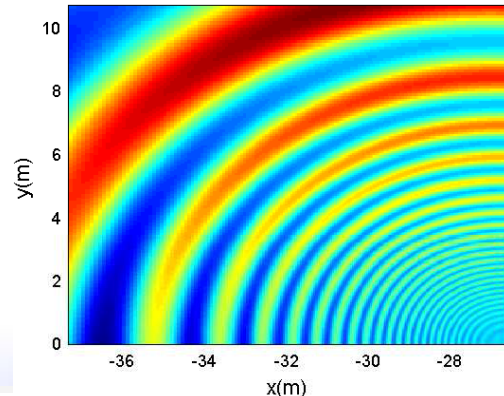
T= 5s



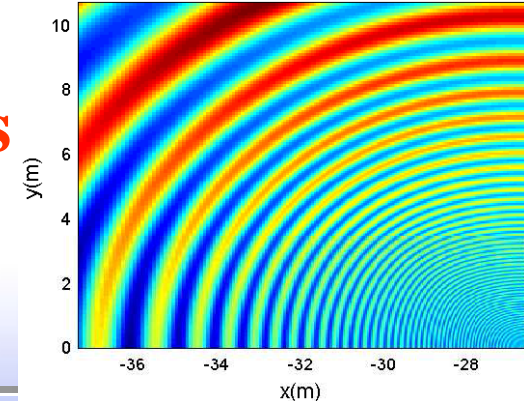
T=10s



T=20s



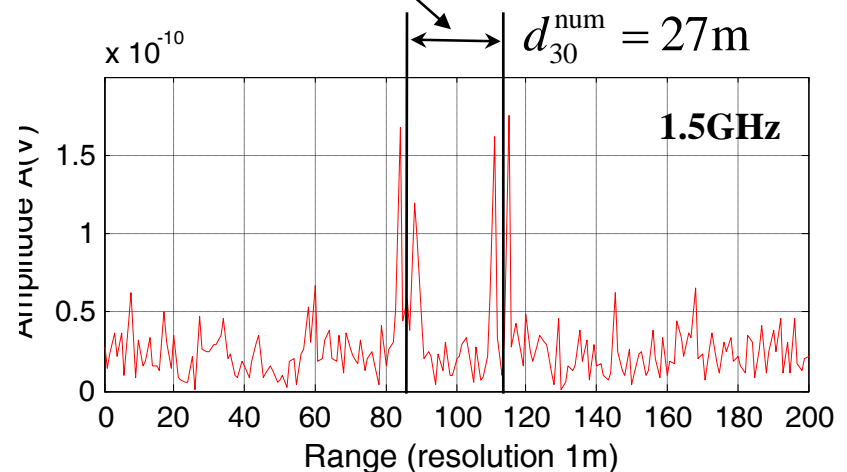
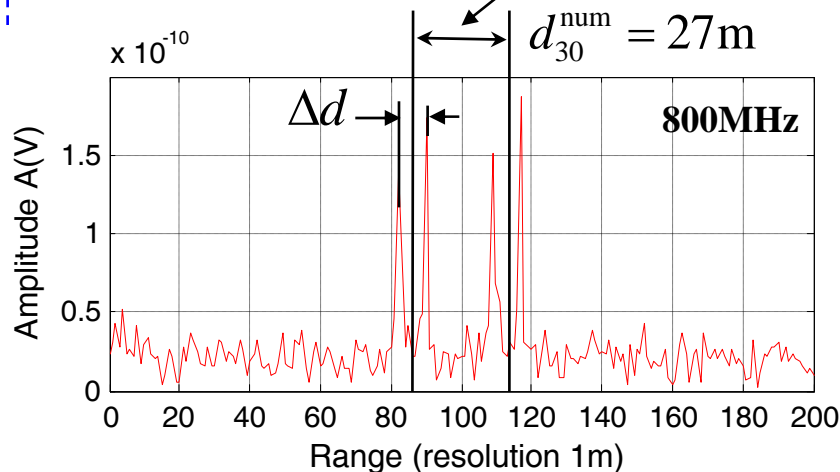
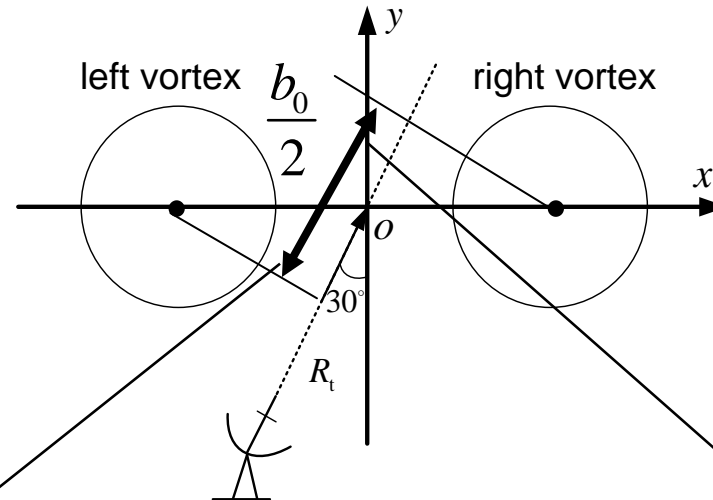
T=40s



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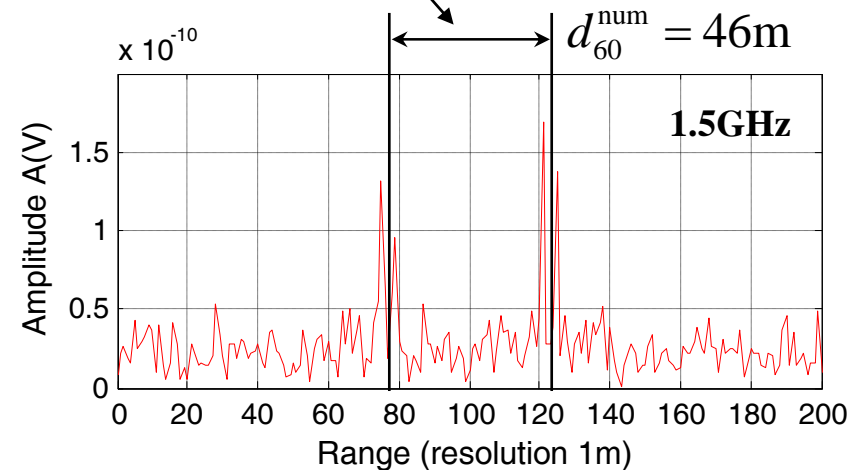
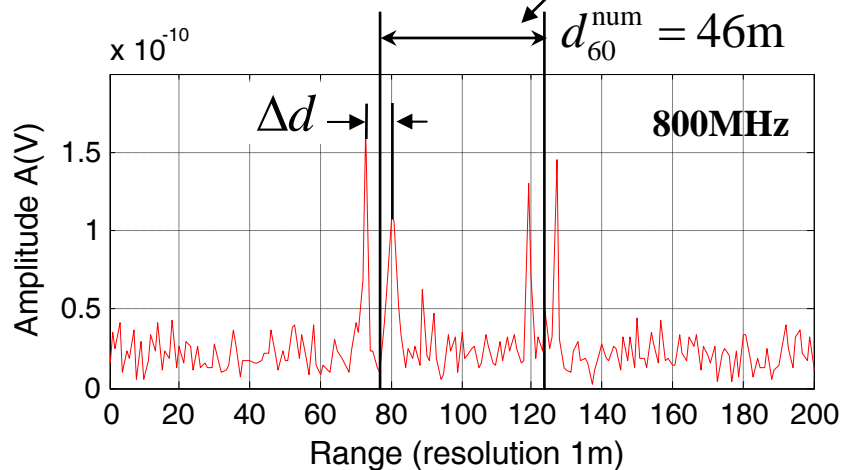
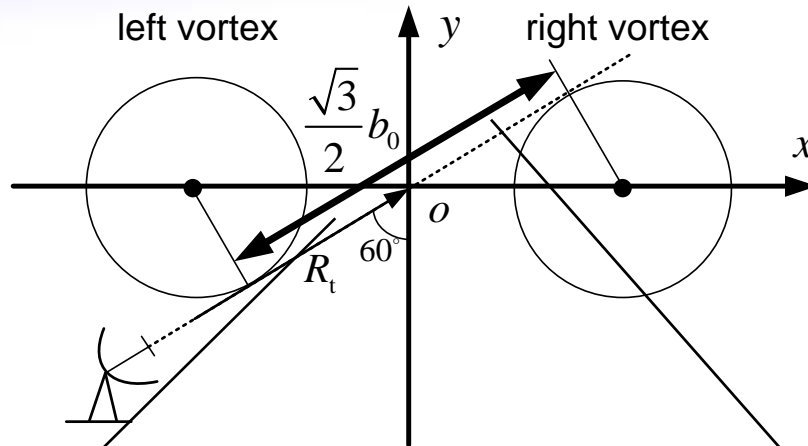
Radar HRRP of wake vortex

Incident angle
30 degree



Wake Vortex EM Scattering Characteristics 12

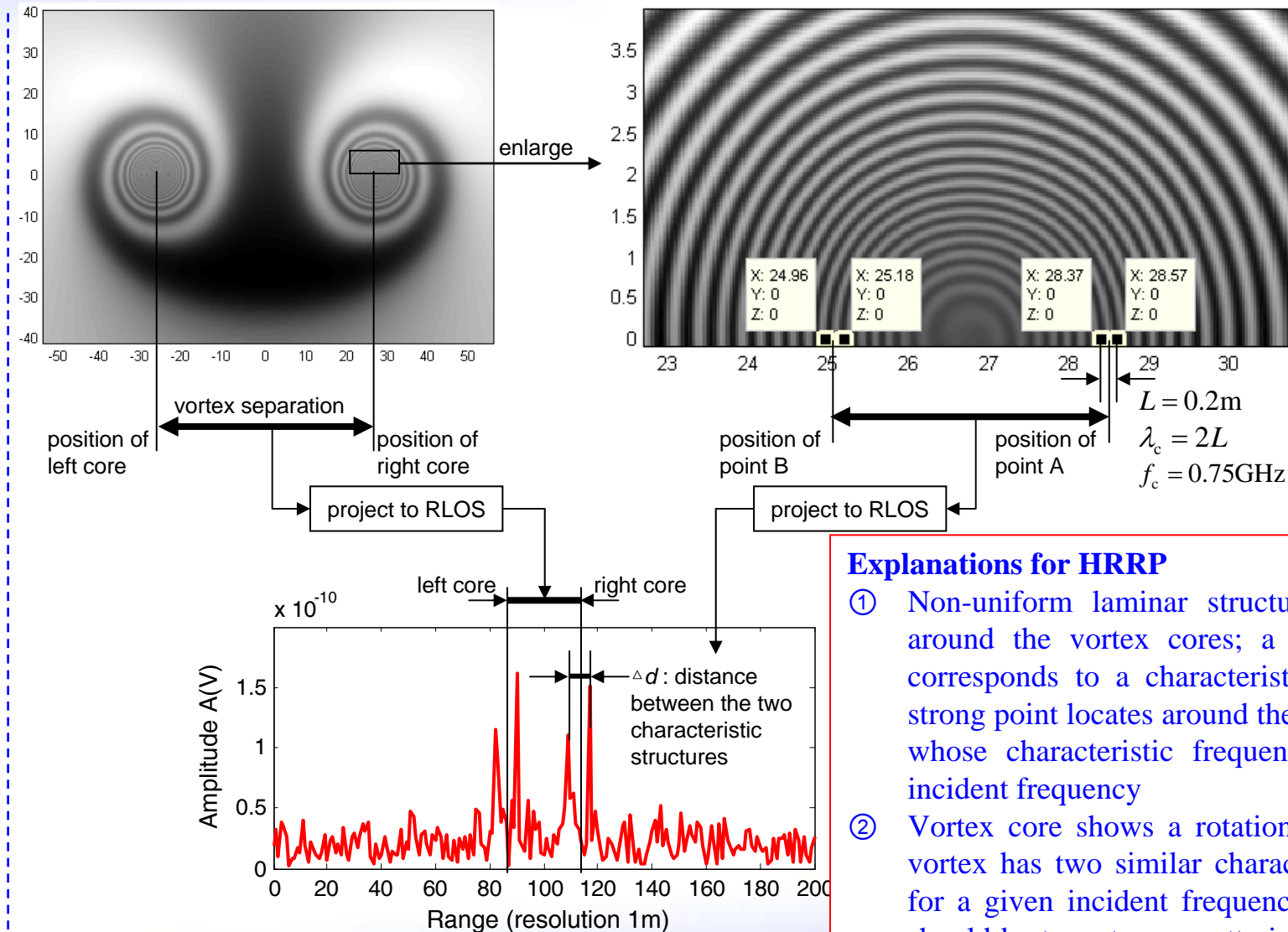
Incident angle
60 degree



- ① HRRP has two groups of relatively strong scattering points
- ② Each group is composed of two strong scattering points
- ③ The distance from one group to another group is equal to the projection of vortex separation on the RLOS (radar line of sight)



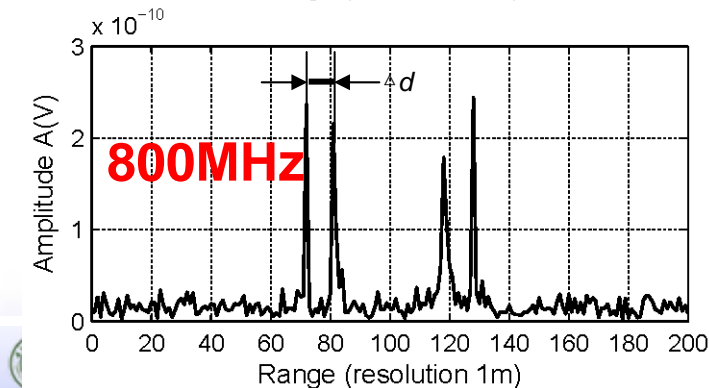
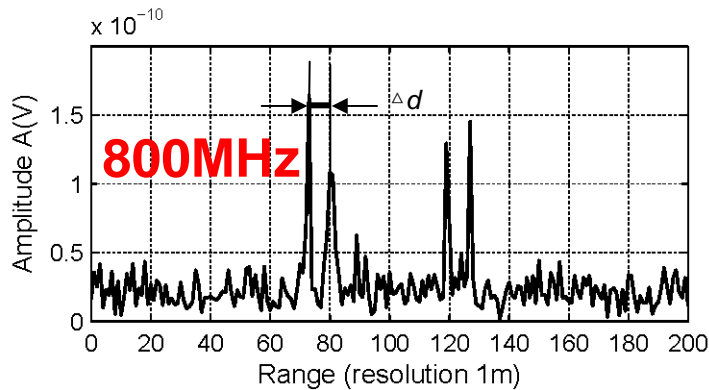
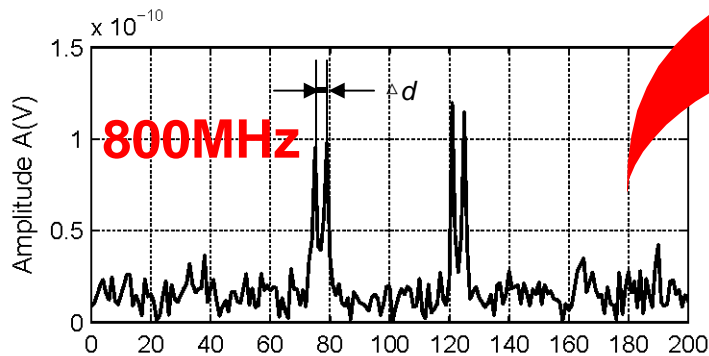
Wake Vortex EM Scattering Characteristics 13



Explanations for HRRP

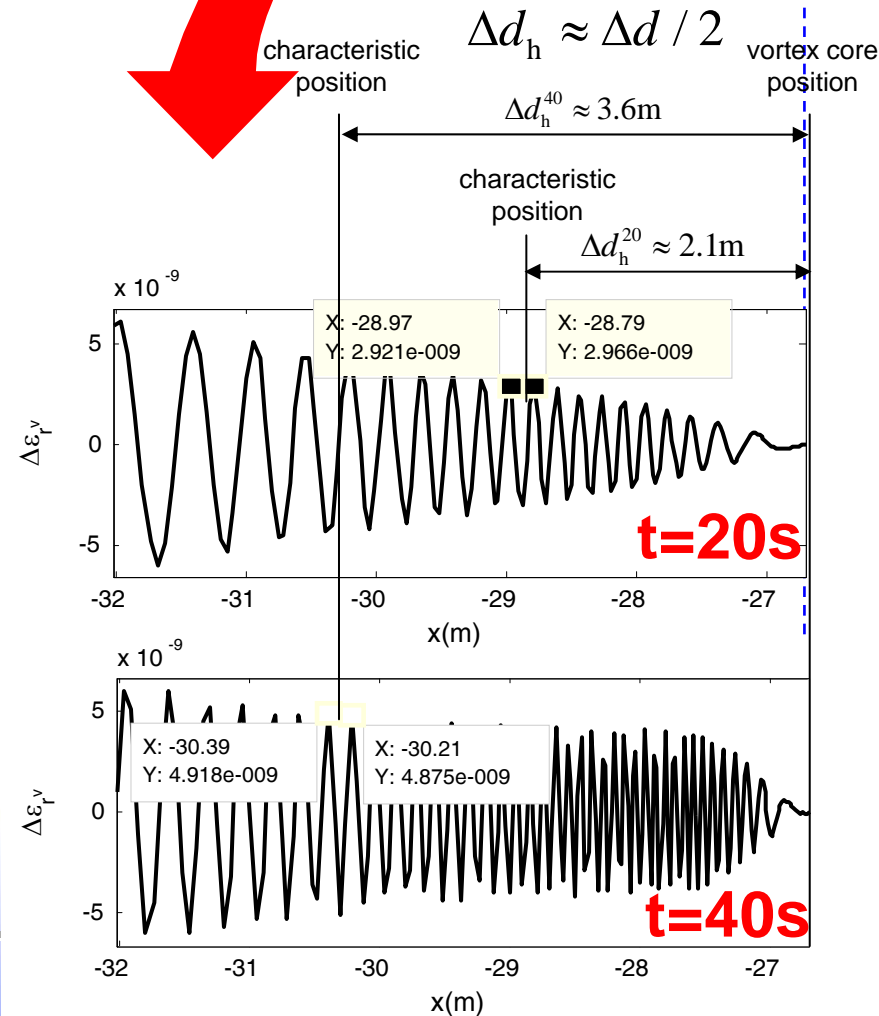
- ① Non-uniform laminar structures exist in and around the vortex cores; a laminar structure corresponds to a characteristic frequency; the strong point locates around the laminar structure whose characteristic frequency equals to the incident frequency
- ② Vortex core shows a rotational structure, so a vortex has two similar characteristic structures for a given incident frequency, and then there should be two strong scattering points around a core. Two vortex cores result in four strong scattering points.

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The longer t

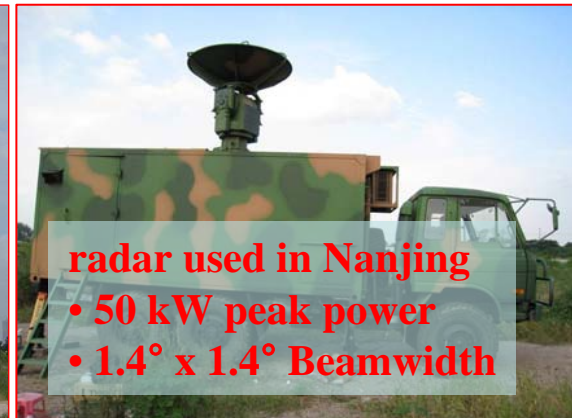
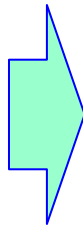
The larger Δd



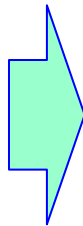
✈ Wake Vortex Radar Detection Trials

In Oct. 2008, National University of Defense Technology started radar detection trials of aircraft wake vortices in China. The first trial was executed in Nanjing, with a vehicle X-band Doppler weather radar deployed, and the second was in Changsha, in Mar. 2009, with the use of a X-band experimental radar, whose waveform and bandwidth can be easily changed.

Nanjing trial



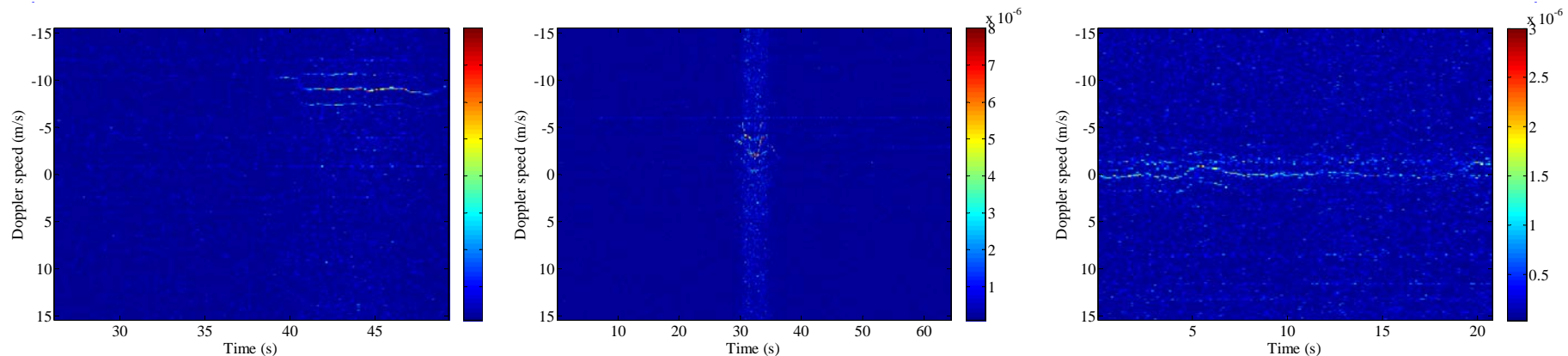
Changsha trial



✈ Wake Vortex Radar Detection Trials

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In both of the trials, some of the echoes from aircraft wake vortices are detected, and the results show that, aircraft wake vortices usually have several time-varying spectral lines, whose positions and intensities are approximately symmetrically distributed. At 1.4km away from the radar, the radar cross section (RCS) of the wake vortices of a small transport plane is about between -90dBsm and -80dBsm.



Time-Doppler spectra of the wake vortices

Further trials using a more powerful experimental radar are expected to be started in the near future.

→ Conclusions and Outlooks

- ❑ Based on the study of several preliminary problems including the dielectric constant distribution model and the oscillatory integral evaluation methods, some electromagnetic scattering characteristics of wake vortex are analyzed by computational simulation.
- ❑ Subjected to the Radar equipments, the electromagnetic scattering characteristics of wake vortex under different weather conditions still remains difficult to be effectively validated.
- ❑ A concept for establishing the Next Generation of Civil Aviation Transportation System in China has also been proposed in recent years, the advanced wind & wake vortex sensors are coming into view, wider and deeper research shall be in great necessity.

✈ Acknowledgement

We would like to show our appreciation of the advices from Radar experts in:

- Nanjing Institute of Electronic Technology., China**
- THALES, France**
- ONERA, France**
-**

Further collaboration and deeper research on Wake Vortex are expected

Thank you for your attention!



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