Overview of Image-Based Near Field-to-Far Field Transformations (NFFFTs)

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NFFFT Outline

NFFFT Overview
- Background and formulation
- Collection geometries

Example CNFFFT Results
- RCS statistics
- Position error sensitivity
- Antenna pattern compensation
- Sub-360° processing

Summary

Not-So-Recent Overview of historical GD-AIS NFFFT work:

Rigorous Near Field Transformations

Near Field Antenna Measurements

Receive probe measures radiated field by scanning over entire surface

Near Field Scattering Measurements

Transmit and receive probes measure bistatic scattered field by scanning independently over entire surface

- Rigorous EM theory says that knowledge of a *radiated field* on a closed surface surrounding a source (antenna) implies knowledge everywhere in space (including the far field)
  - spheres and planes (and cylinders) allow wave function expansions for fast transformations
  - equivalent to synthesizing a plane wave
- Unfortunately, for *scattering* measurements (RCS), this theory applies *separately* to the incident and scattered fields – *bistatic* measurements are needed
  - must synthesize both the incident and scattered plane waves
  - provides full bistatic output (even if only monostatic is needed)
Image-Based NFFFT Background

- GDAIS MRDC has developed a collection of near field-to-far field transformation (NFFFT) algorithms for monostatic RCS measurements
  - Based upon scalar SAR imaging (single scattering) model
  - The term “image-based” in the name is a reference to the SAR scattering model, not an implicit requirement to form an image

- NFFFT has demonstrated very good far field prediction performance for both RCS patterns and RCS sector statistics (mean, median, $P_{\text{cum}}$) as a function of frequency, standoff distance, and target geometry
  - primary limitation is multiple scattering (interactions)
    - results in misalignment of peaks and nulls (overall level is less affected)
    - statistics of NFFFT predictions are often more accurate than patterns themselves
    - not an issue if interactions are locally in the far field
NFFFT Collection Geometries

Spherical / Circular Scanning

- 2-D (SNFFFT): azimuth cuts at multiple elevation angles
- 1-D (CNFFFT): single azimuth cut (typically at waterline)

Planar / Linear Scanning

- 2-D (PNFFFT): horizontal scans at multiple heights
- 1-D (LNFFFT): single horizontal scan (typically at waterline)

- **2-D scanning**: required for targets having NF effects in all three dimensions
  - treated as a full 3-D scattering problem
- **1-D scanning**: sufficient for FF waterline RCS of targets where "out-of-plane" NF effects are negligible
  - typically the vertical direction
  - treated as an equivalent 2-D scattering problem
- In all cases, wideband measurements are required
Generic NFFFT Fundamentals – 1 of 3

*How to Beat the “Bistatic” Dilemma…*

**The Model**
- Assume target satisfies scalar SAR “reflectivity density” model
  - implies multiple interactions are small or localized

**Near Field Measurement**

\[ u(r, k) = C \int_{V} \gamma(r') e^{i2kR} \frac{e}{(4\pi R)^2} dr \]

**Far Field Scattering Pattern**

\[ S_{FF}(\hat{r}, k) = \frac{1}{4\pi} \int_{V} \gamma(r') e^{-i2k\hat{r} \cdot r'} dr \]

**The Observation**
- Far field kernel is in the form of a propagating wave (a plane wave at twice the frequency)
  - but the near field kernel is not
- If only we could represent the near field kernel as a propagating wave…
  - we could then relate the near field to the far field
The "Trick"

- Apply a range-dependent weighting to the near field data

Actual Near Field Measurement

Modified Near Field Measurement

Near field kernel now satisfies the 3-D or 2-D propagating wave (spherical/cylindrical wave)
Preprocessed (Modified) NF Data

\[
U'(r,k) \begin{cases} 
= C' \int_V \gamma(r') \frac{e^{i2kR}}{4\pi R} \, dr' & \text{2-D scan (spherical, planar)} \\
\approx C' \int_V \gamma(r') H_0^{(1)}(2kR) \, dr' & \text{1-D scan (circular, linear)}
\end{cases}
\]

The Rest

- Expand near field kernel into a summation of 3-D or 2-D outward-traveling waves (exponentials) originating from the origin of coordinates
  - a Fourier transform can typically be used to efficiently compute this expansion
- Multiply each near field component wave by a factor to convert it to the corresponding far field component
- Sum up the far field components (exponentials) to get the far field data
  - can typically be done with inverse Fourier transforms
The Math* is obvious...

Preprocessed Nearfield Data:

\[ U' (\phi, k) = \frac{1}{(4\pi)^2} \sqrt{\frac{i\pi k}{\rho_c}} \int \gamma (\rho', \phi') \frac{e^{i2kR}}{\sqrt{i\pi kR}} \rho' d\rho' d\phi' \]

\[ \approx \frac{1}{(4\pi)^2} \sqrt{\frac{i\pi k}{\rho_c}} \int \gamma (\rho', \phi') H_0^{(1)} (2kR) \rho' d\rho' d\phi' \]

Far-Field Scattering Pattern:

\[ S_{FF} (\phi, k) = \frac{1}{4\pi} \int \gamma (\rho', \phi') e^{-i2kR' \cos (\phi - \phi')} \rho' d\rho' d\phi' \]

Cylindrical Wave Expansions:

\[ H_0^{(1)} (2kR) = \sum_{n=-\infty}^{\infty} H_n^{(1)} (2k\rho_c) J_n (2k\rho') e^{in(\phi - \phi')} \]

\[ e^{-i2kR' \cos (\phi - \phi')} = \sum_{n=-\infty}^{\infty} (-i)^n J_n (2k\rho') e^{-in(\phi - \phi')} \]

CNFFFT Far-Field Scattering Pattern Estimate:

\[ S_{FF} (\phi, k) = 2 \sqrt{\frac{\rho_c}{i\pi k}} \sum_{n=-N}^{N} \left( -i \right)^n e^{-i\phi} \frac{2\pi}{H_n^{(1)} (2k\rho_c)} \int_0^{2\pi} U' (\phi, k) e^{-i\phi} d\phi \]

NFFFT Measurement Requirements

Minimum Sample Region Concept

- **As a minimum**, NF measurements must span the projection of target onto scan surface/contour along desired FF directions for accurate RCS prediction
  - applies to both 2-D or 1-D scans
  - independent of NFFFT algorithm

1-D Circular Scan Example

- Target
- Measurement Surface / Contour
- Required Near Field Measurement Range
- Desired Far Field Estimate
Outline

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Example CNFFFT Results
- RCS statistics
- Position error sensitivity
- Antenna pattern compensation
- Sub-360° processing

Summary
**Configuration**

- 4 “wings”; 2 “edges” per wing
- 900 single scatterers per “edge”
- 2 multiple scatterer sets
  - 8 nose-to-tail (N-T)
  - 8 cross-body (X-B)
  - mean RCS (in sm) set equal to single scattering in nose sector
- 2 edge defects
  - placement: 10% from nose/tail
  - size: 3% and 20% of length
  - defect set to produce a 1-2 dB RCS growth in nose sector
- ~7200 total scatterers
- 10 : 4 : 1 (L : W : H) aspect ratio

**Simulation Parameter**

<table>
<thead>
<tr>
<th>Simulation Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standoff Distance (T = max target radius)</td>
<td>2.0T, 3.0T, 4.0T</td>
</tr>
<tr>
<td>Frequency (target electrical length)</td>
<td>10λ, 30λ, 50λ, 100λ, 300λ</td>
</tr>
</tbody>
</table>
Example CNFFFT RCS Statistics

- CNFFFT significantly reduces point-wise error
  - but error can still at times be non-trivial

- CNFFFT prediction error is instead assessed statistically using RCS $P_{\text{cum}}$ prediction errors within a sector of interest
  - Considering RCS as $P_{\text{cum}}$ distributions is common in RCS diagnostics

- Typical design/manufacturing specifications are defined for $P_{\text{cum}}$ values $\geq 50\%$

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Single Scattering Only

$T = 5\lambda$

Standoff = 2.0T

Legend:
- Far Field
- Near Field
- CNFFFT
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Position Error Compensation

Motivation and Approach

- Evaluate the impact of radial position errors on CNFFFT performance
  - ground-based mobile RCS diagnostic systems
  - static NF facilities using string supports
- Assess viability of motion compensation to mitigate error
- Performance is measured in terms of sector RCS $P_{cum}$ prediction error using simulated data
  - common in RCS diagnostics
Data Simulations – 1 of 2

X-Wing Generalized Point Scatterer Target

- 4 “wings”; 2 “spokes” per wing
- Dense arrays of single scatterers provide specular flashes from "spokes"
- Multiple scatterer added to produce 1.5 dB RCS growth in nose sector (off-specular "well")
  - along-body (A-B)
  - cross-body (X-B)
- Single & multiple scatterer "defects" can be switched on & off to produce 1.5 dB RCS growth in nose sector (off-specular "well")
  - used to simulate damage/repair
  - left "on" for this study
- ~7200 total scatterers
- 10 : 4 : 1 (L : W : H) aspect ratio

<table>
<thead>
<tr>
<th>Simulation Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standoff Distance (T = max target radius)</td>
<td>3.0T, 4.8T</td>
</tr>
<tr>
<td>Target length at center frequency</td>
<td>300(\lambda)</td>
</tr>
</tbody>
</table>
Data Simulations – 2 of 2

Simulation Geometries

Slowly-Varying Error ("Wobble")

- Modeled as $A \cdot (\sin(\theta) + \cos(3.3 \cdot \theta))$
  - where $A$ sets the maximum error level
- Represents drift in position control system

Rapidly-Varying Error ("Noise")

- Modeled as uniformly distributed and over $[-B, B]$ and uncorrelated angle-to-angle
- Represents vibration in antenna pedestal

* Wobble and noise exaggerated for illustration
# Simulation Error Parameters

## Three Cases Considered

<table>
<thead>
<tr>
<th>Case</th>
<th>Wobble (A)</th>
<th>Noise (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slowly-Varying Error (Wobble)</td>
<td>$2.0\lambda$</td>
<td>0.0</td>
</tr>
<tr>
<td>Rapidly-Varying Error (Mild Noise)</td>
<td>0.0</td>
<td>$0.06\lambda$</td>
</tr>
<tr>
<td>Rapidly-Varying Error (Severe Noise)</td>
<td>0.0</td>
<td>$0.2\lambda$</td>
</tr>
</tbody>
</table>

- CNFFFT performance was evaluated with and without a first-order phase compensation

$$S_{\text{comp}}^{NF}(\theta) = S^{NF}(\theta)e^{-i2k\Delta r(\theta)}, \quad \Delta r(\theta) = \text{radial offset}$$

- provides perfect compensation at center of measurement circle
- assumes that the radial offset from the ideal circle is known at each aspect angle
Example CNFFFT Results

**RCS vs Aspect**

**Error-Free Case**
- Far field, CNFFFT
- Near field

**Mild Noise Case**
- Far field, comp. CNFFFT
- Near field
- Uncomp. CNFFFT

- Even small amount of rapidly-varying error can severely degrade CNFFFT performance (w/o compensation)

**Standoff: 3.0T**

- Nose Region: 0-60 degrees
- Specular Region: 75-105 degrees
- Tail Region: 120-180 degrees
**CNFFFT Prediction Error – 1 of 3**

### Unprocessed Near Field Data

<table>
<thead>
<tr>
<th>NEAR FIELD</th>
<th>Region →</th>
<th>Nose</th>
<th>Tail</th>
<th>Specular</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pcum % →</td>
<td>50</td>
<td>80</td>
</tr>
<tr>
<td>No error</td>
<td></td>
<td>R = 3T</td>
<td>4.3</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R = 4.8T</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Slowly-varying error</td>
<td></td>
<td>R = 3T</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R = 4.8T</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Rapidly-varying error:</td>
<td></td>
<td>R = 3T</td>
<td>4.3</td>
<td>4.4</td>
</tr>
<tr>
<td>mild</td>
<td></td>
<td>R = 4.8T</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Rapidly-varying error:</td>
<td></td>
<td>R = 3T</td>
<td>4.3</td>
<td>4.4</td>
</tr>
<tr>
<td>severe</td>
<td></td>
<td>R = 4.8T</td>
<td>2.0</td>
<td>1.9</td>
</tr>
</tbody>
</table>

- Near field (unprocessed) RCS error is greatest in specular region
- Near field (unprocessed) RCS error is relatively insensitive to position errors
  - errors affect primarily the near field phase

![Error Scale](Error.png)
Uncompensated CNFFFT is extremely sensitive to rapidly-varying position errors. Sensitivity to slowly-varying errors is limited to the specular region — although all regions show improvement relative to unprocessed near field data.
Compensated CNFFFT

<table>
<thead>
<tr>
<th>COMPENSATED CNFFFT</th>
<th>Region →</th>
<th>Nose</th>
<th>Tail</th>
<th>Specular</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pcum % →</td>
<td>50</td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td>No error</td>
<td>R = 3T</td>
<td>0.9</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>R = 4.8T</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Slowly-varying error</td>
<td>R = 3T</td>
<td>0.9</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>R = 4.8T</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Rapidly-varying error: mild</td>
<td>R = 3T</td>
<td>0.9</td>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>R = 4.8T</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Rapidly-varying error: severe</td>
<td>R = 3T</td>
<td>1.3</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>R = 4.8T</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

- Error ≤ 1 dB
- 1 dB < Error ≤ 2 dB
- Error > 2 dB

- Compensated CNFFFT performance is very good over all sectors for all three error cases
  - exception is specular region for slowly-varying errors
Outline

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Example CNFFFT Results
- RCS patterns
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- Sub-360° processing

Summary
CNFFFT Antenna Pattern Compensation

Assumptions

- Target is in the far field of the antenna
  - but antenna is still in the near field of the target
- Amplitude (and phase) of far-field antenna pattern are known (in waterline plane)
  - one-way or two-way
- Antenna is boresighted on the center of rotation
CNFFFT APC Implementation Summary*

\[ U'(\phi, k) = \frac{1}{\pi \sqrt{\rho_0}} \int R_0^{3/2} e^{i2kR_0} \int u(\phi, k')e^{-i2k'R_0} dk'dR_0 \]

\[ S_{FF}(\phi, k) = 2 \sqrt{\frac{\rho_0}{i\pi k}} \sum_{n=-N}^{N} (-i)^n e^{in\phi} \int_{0}^{2\pi} U'(\phi_0, k) e^{-in\phi_0} d\phi_0 \]

where

\[ P_n(2k\rho_0) = \sum_{m=-M}^{M} i^m a_m H^{(1)}_{n+m}(2k\rho_0) \]

\[ a_m = \text{antenna pattern Fourier coefficients} \]

CNFFFT with APC Performance – 1 of 4

RCS Vs Azimuth (3 GHz)

One-Way Pattern = \( \cos^4(\psi) \)

One-Way Pattern = \( \cos^8(\psi) \)

- CNFFFT with APC reduces pattern errors to essentially zero

Single point scatterer
Freq band: 2.75 - 3.25 GHz
Measurement radius: 45 m
APC is excellent across the entire band
— neglecting band edge effects
Pattern errors are most significant near broadside.

Residual error after APC is primarily due to out-of-plane NF effects.
CNFFFT with APC Performance – 4 of 4

RCS Error Vs Frequency (Azimuth = 90°)

- APC is excellent across the entire band
  - neglecting band edge effects

One-Way Pattern = \( \cos^4(\psi) \)

One-Way Pattern = \( \cos^8(\psi) \)

X-wing target
Freq band: 2.75 - 3.25 GHz
Measurement radius: 45 m

Far Field
CNFFFT error w/o APC
CNFFFT error w/ APC

30 m
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Summary
360° CNFFFT Formulation

- Note that the CNFFFT can be discretized and implemented as a pair of appropriately weighted angular FFTs
  - Recall CNFFFT formulation for an isotropic antenna:

\[
S_{FF}(\phi, k) = 4\pi \sqrt{\frac{\rho_c}{i\pi k}} \sum_{n=-N}^{N} \frac{(-i)^n e^{i\phi}}{H_n^{(1)}(2k\rho_c)} \int_{0}^{2\pi} U'(\phi, k)e^{-i\phi} d\phi
\]

Far field scattering pattern estimate \(S_{FF}(\phi, k)\) computed from preprocessed near field \(U'(\phi, k)\):

- This summation is DFT #2
- Once discretized, this integral becomes DFT #1

- For a non-isotropic antenna, the Hankel functions are replaced by a set of probe compensation factors as discussed previously
  - but the CNFFFT is still computed using a pair of DFT's
Sub-360º CNFFFT Formulation – 1 of 2

- Define the $n^{th}$ azimuthal harmonic of the preprocessed near-field (NF) data at wavenumber $k$:

$$U'_n(k) = \frac{1}{2\pi} \int_0^{2\pi} U'(\phi, k)e^{-in\phi} d\phi$$

- Define the $n^{th}$ azimuthal harmonic of the far-field (FF) data at wavenumber $k$:

$$S_{n,FF}(k) = 2\pi \left[ 2\sqrt{\frac{\rho_c}{i\pi k}} \frac{(-i)^n}{H_n^{(1)}(2k\rho_c)} \right] U'_n(k)$$

- Note that the far-field harmonics are the product of the sequence in brackets and the modified near-field harmonics.

- The inverse DFT of the above sequence in brackets thus defines a convolution kernel in the azimuth domain.

- Yields far-field data when convolved with the modified near-field data (and scaled by $2\pi$).
Sub-360° CNFFFT Formulation – 2 of 2

CNFFFT Equation in Azimuthal Harmonic Domain

\[ S_{n,FF}(k) = 2\pi \left[ 2 \sqrt{\frac{\rho_c}{i\pi k}} \frac{(-i)^n}{H_n^{(1)}(2k\phi_c)} \right] U'_n(k) \]

Since the CNFFFT kernel has a finite width in azimuth (to a very good approximation), we can determine \textit{a priori} how much NF data must be collected to support a given FF angular sector.
CNFFFT Convolution Kernel Parameterization

Kernel is a function of two parameters:
- Lumped parameter $2k\rho_c$
- Number of azimuthal harmonics $2N+1$ computed
  - $N$ is selected to capture all significant target azimuthal harmonics*
  - $N = 2k\rho_t + n_1$
  - $n_1$ is relatively small compared to $2k\rho_t$ (typically 3 orders of magnitude smaller)

*(Jensen, F. and Frandsen, A., Proc. AMTA ’04)

These parameters can be expressed in terms of two other (normalized) parameters:
- Maximum target radius in wavelengths ($\rho_t / \lambda$)
- Standoff distance relative to maximum target radii ($\rho_c / \rho_t$)

$$2k\rho_c = \left(\frac{4\pi}{\lambda}\right)(\rho_c / \rho_t)\rho_t = \left(4\pi\right)(\rho_c / \rho_t)(\rho_t / \lambda)$$
$$N = 2k\rho_t + n_1 = \left(4\pi\right)(\rho_t / \lambda) + n_1$$
Geometric Approximation of CNFFFT Kernel Width

- Project the target's maximum radius circle onto the measurement circle.
- The angle $\beta$ subtended by this projection is approximately equal to the width of the CNFFFT kernel.
- Next slide illustrates accuracy of approximation.

$$\beta = 2 \sin^{-1}(\rho_t / \rho_c)$$
Accuracy of Geometric Approximation

The geometrical approximation is a reasonable “first cut” to estimate the CNFFFT kernel width, especially for higher $\rho_t/\lambda$ values.
Sub-360° CNFFFT Numerical Tests

X-Wing Generalized Point Scatterer Target

- 4 “wings”; 2 “spokes” per wing
- Dense arrays of single scatterers provide specular flashes from "spokes“
  - scatterer spacing determined by simulation frequency to avoid grating lobes
- 10 : 4 : 1 (L : W : H) aspect ratio
- X-wing target can include multi-bounce scatterers and defects which violate the assumptions upon which the CNFFFT is based
  - these were set to zero because we are only concerned with demonstrating relative error between the full-360° and sub-360° CNFFFTs
Simulation Geometry and Parameters

<table>
<thead>
<tr>
<th>Two Frequency Bands</th>
<th>Low Band</th>
<th>High Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standoff Distance ($\rho_c$)</td>
<td>$3\rho_t$</td>
<td></td>
</tr>
<tr>
<td>Geometric Kernel Width ($\beta$)</td>
<td>38.9°</td>
<td></td>
</tr>
<tr>
<td>Max Target Radius ($\rho_t$)</td>
<td>$150\lambda$</td>
<td>$750\lambda$</td>
</tr>
<tr>
<td>Fractional Bandwidth</td>
<td>16.7%</td>
<td>1.67%</td>
</tr>
<tr>
<td>Frequency Sample Spacing</td>
<td>for unaliased range interval = $4\rho_t$</td>
<td></td>
</tr>
<tr>
<td>Azimuth Sample Spacing</td>
<td>1.5X Nyquist*</td>
<td></td>
</tr>
</tbody>
</table>

*Based on two-way -50 dB truncation of near-field azimuthal harmonics (Jensen, F. and Frandsen, A., Proc. AMTA ’04)

- NF data were simulated over a full-360°
- NF data were processed with both the full-360° and sub-360° CNFFFTs
  - sub-360° CNFFT can be applied to any collection larger than the kernel width
- The results were evaluated in terms of coherent residual error for various truncated kernel widths

$$\text{coherent error} = \left| S^{full\ 360}_{FF} - S^{sub\ 360}_{FF} \right|^2$$
The coherent error metric allows us to better see the differences between the overlapping full-360° and sub-360° CNFFT predictions.
For a 30º kernel, the results are unacceptable.
For a 45º kernel, the residual error is typically 10dB below the full-360º CNFFFT.
For the 60º and 75º kernels, the residuals error is typically 12-18 dB below the full-360º CNFFFT.

From the above (and additional observations), a kernel width about 15% greater than the geometric kernel width $\beta$ (38.9º for this case) will produce respectable sub-360º CNFFFT results.
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Summary
The IB-NFFFT has been shown to provide robust and accurate far field predictions for a wide range of targets, frequencies, and collection geometries — both RCS patterns and sector statistics.

The algorithm has been formulated for many of the common measurement geometries — 2-D scans: spherical, planar — extension to cylindrical is straightforward — 1-D scans: circular and sub-circular, linear.

In this presentation, we have focused on the IB-NFFFT formulation for circular and sub-circular measurement geometries.

Methods for mitigating IB-NFFFT measurement errors have been developed — position errors: circular — antenna pattern: circular & linear — extensions to other scan geometries are planned.

IB-NFFFT algorithms have been demonstrated and/or implemented on operational systems with our customers — both indoor and outdoor measurement facilities.
Appendix 1:
CNFFFT with MoM and measured data
CNFFFT Example - MoM Simulations – 1 of 2

Conesphere Target

- NF data differ significantly from far field throughout entire pattern

Simulated Near Field Data

- HH
- VV

Far Field
NF (R = 1.0D)
NF (R = 1.5D)
NF (R = 2.0D)
NFFFT has substantially improved agreement with FF RCS—especially at VV pol.
CNFFFT Example – Measured Data – 1 of 3

AFRL ACR Measurements

AFRL “Delta Dart” (D2) test body
Circular (1-D) near field data
AFRL “Delta Dart” (D2) test body
1-D CNFFFT (waterline cut)
Frequency = 1.48 GHz
Target size (D) = 6.67 ft. (10\(\lambda\))
NF standoff (R) = 15, 16.5 ft. (2.25D, 2.5D)
AFRL “Delta Dart” (D2) test body
1-D CNFFFT (waterline cut)
Frequency = 2.95 GHz
Target size (D) = 6.67 ft. (20\lambda)
NF standoff (R) = 15, 16.5 ft. (2.25D, 2.5D)
Appendix 2: CNFFFT Numerical Improvement* (2005)

Recent improvements to CNFFFT reduce algorithm error to essentially zero for targets satisfying the reflectivity model.

Ringing at edges of band are due to finite bandwidth effects of range compensation.

Freq band: 2.75 - 3.25 GHz
Measurement radius: 45 m
Improved CNFFFT Example Results – 2 of 2

Numerical Simulations: X-Wing Target

- Improvements are less noticeable for a complex target
  - but they can still make a difference when performing RCS diagnostics
- Residual error is ~35 dB below target

RCS Vs Azimuth (3 GHz)  
RCS Vs Frequency (0°)

Freq band: 2.75 - 3.25 GHz  
Measurement radius: 45 m