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This paper presents a system that provides a key element to computational electromagnetic modeling (CEM), that of creating the geometric model to be analyzed. The primary intent of the system is to automate the measurement and construction of accurate physical models of objects/platforms. The laser mapper produces CAD models in a fraction of the time that current methods involve, and with accuracy sufficient for a wide range of CEM analysis.

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System for Generating CAD Models of Full-Scale Objects

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Good afternoon,

I am Jim Thompson from the Naval Air Warfare Center. This morning Dave Benfey, and I will be describing a measurement tool for Generating CAD Models.

- The primary intent of the system is to automate the measurement and construction of accurate physical models of objects/platforms.

Outline

- Background
- Scanner Hardware
- Sample Data
- Summary

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- I will providing a brief background, that lead to the development of the scanner and describing my interest for Electromagnetic modeling.

- Dave will address the scanner hardware characteristics, operation and sample data collections

Background

- System developed to support Computational Electromagnetic (CEM) modeling
  - Optimize platform system performance
- Accurate models not available
  - Platforms extensively modified or unique (one of a kind)
  - Incompatible data bases
  - Model development requires a significant portion of time
  - Manual measurement too time consuming/error prone
    - Large platforms require large number of measurements
    - Error combines with relative measurements
- Laser scanner developed to automate geometry development
  - Significantly reduce data collection time
  - Improve measurement accuracy
  - Manage large models

The Laser scanner was developed in response to a Navy need for Computational Electromagnetic Modeling. Wanted to determine an optimum location for antenna placement on a platform.

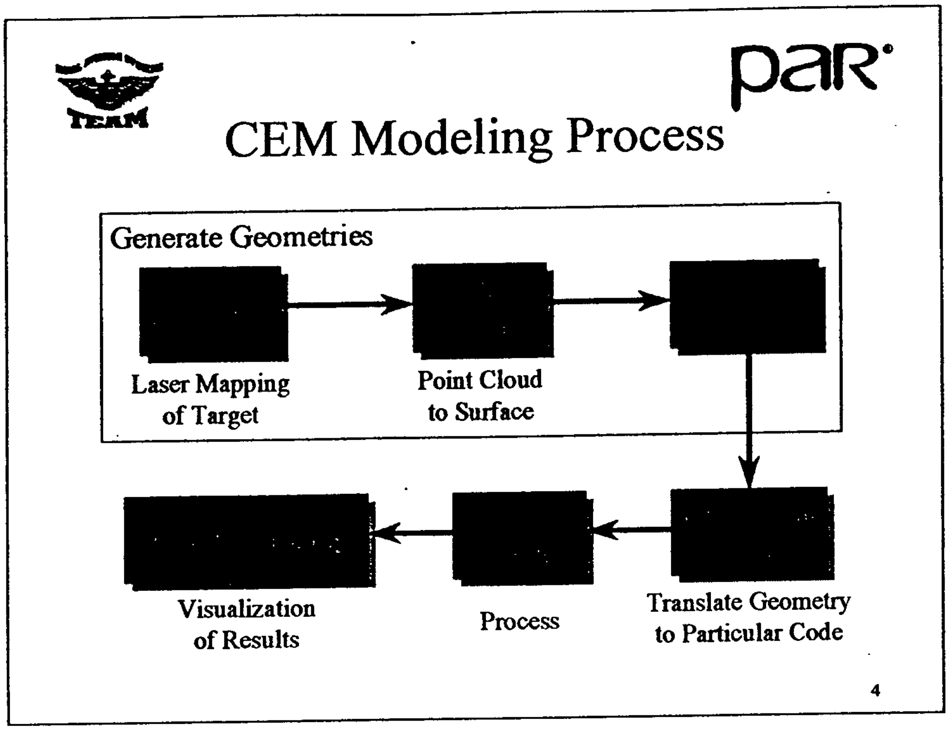
- A number of communication systems were being installed on various vehicle platforms, such as Chevy Surburbans, HUMVs and UAVs. Since many of these platforms were unique or one of a kind, antenna placement was usually a trial and error process. In an attempt to optimize antenna placement, electromagnetic modeling was employed.

- One of the most time consuming tasks in doing modeling is creating a suitable geometry file. The number of data points required in a geometry file is proportional to the size of the platform and the frequency of operation. Generally about 10 points per wavelength - also implies accuracy to 1/10th the wavelength.

- Since cad models were not available for the test platforms, measurements were made manually and translated into an acceptable form to support electromagnetic modeling. Manual attempts at measurement were found to be very time consuming and prone to errors. Measurement errors tended to accumulate.

- The time to generate a geometry file was too long and measurements not accurate, which motivated the development of a tool to automate the process.

The initial attempt was the Laser Mapper, which was to provide a means to scan a relatively large platform such as a vehicle. (The system is accurate to 1/4" at 30 feet) For larger models, a number of scan views can be integrated to create a single large model, such as an aircraft.



- In this view graph I have identified typical processes in EM modeling using the Laser Mapper.

- EM modeling starts with development of geometry data. The scanner is used to measure the physical characteristics of a test object at various scan positions.

- The measurement data is combined and filtered to form a point cloud and then generate a surface model.

- The surface is then gridded or meshed using components for the appropriate modeling code, such as a wire model for Method of Moments Code such as NEC, or patches for X-patch or GEMAC etc. The surface model is remeshed as a function of frequency. Generally you need 10 points/wavelength, so the higher the frequency the tighter the grid spacing.

- The components are then translated into a data file for insertion into the appropriate modeling code.

NEC Geometry

```
CM SEA KING HELICOPTER - SKING98B.GW
CM
CM DATE:10-JUN-98
CM
CM NAME OF NEC INPUT FILE:sking98b.gw
CM
CM THE WIRE RADII IN THIS FILE WERE CALCULATED WITH
CM PROGRAM FNDRAD
CM
CM THIS VERSION HAS NO MULTI-SEGMENT WIRES EXCEPT ROTOR BLADES AND STRUTS
CM
CM
CM DERIVED FROM YOUSSEF BAHSOUN'S FILE TRANIC
CM SEA-KING MODEL FROM UK
CM SPOOLED FROM THE LSI ON MAY 3, 1990
CM NO ANTENNA
CM
CE
GW    1  1-.6860     .0000    1.745    -.8160     .5640    1.529    .3858E-01
GW    2  1-.6860     .0000    1.745    -.8160    -.5640    1.529    .3858E-01
GW    3  1-.6860     .0000    1.745    -.8160     .0000    1.327    .3346E-01
GW    4  1-.6860     .0000    1.745    -.8160     .5040    1.980    .4422E-01
GW    5  1-.6860     .0000    1.745    -.8160    -.5040    1.980    .4422E-01
GW    6  1-.6860     .0000    1.745    -.8160     .2280    2.206    .4307E-01
GW    7  1-.6860     .0000    1.745    -.8160    -.2280    2.206    .4307E-01
GW    8  1-.8160    -.5040    1.980    -.8160    -.2280    2.206    .6084E-01
GW    9  1-.8160    -.2280    2.206    -.8160     .2280    2.206    .7029E-01
GW   10  1-.8160     .2280    2.206    -.8160     .5040    1.980    .6083E-01
GW   11  1-.8160     .5640    1.529    -1.200     .8420    1.142    .5908E-01
GW   12  1-.8160    -.5640    1.529    -1.200    -.8420    1.142    .5908E-01
GW   13  1-.8160     .0000    1.327    -1.200     .0000    .9720    .6844E-01
GW   14  1-.8160     .5040    1.980    -1.200     .8280    2.196    .7882E-01
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GW   17  1-.8160    -.2280    2.206    -1.200    -.4150    2.640    .8805E-01
GW   18  1-1.200    -.4150    2.640    -1.200     .4150    2.640    .7410E-01
GW   19  1-1.200    -.8280    2.196    -1.200    -.4150    2.640    .7479E-01
GW   20  1-1.200     .4150    2.640    -1.200     .8280    2.196    .7470E-01
GW   21  1-1.200     .8420    1.142    -1.440     .9240    .9650    .5632E-01
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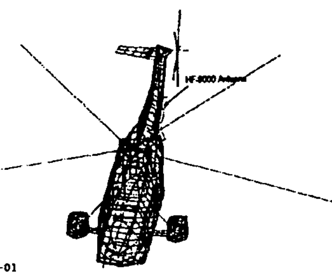

Wire-Grid Model

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-This slide shows a small portion of a NEC input file used for modeling the Sea King Helicopter.

- NEC is a Method of Moments (MOM) code which uses wires as the primary element for modeling.

- The Wire-Grid Model used for this file is shown to the right.

- Notice the large number of wires used to construct this model.

- Generally the wire definitions are entered manually in a text file. The lines starting with GW are used to define the wire geometry. The first column is an identifier for the wire number or tag. The next column defines the number of segments in the wire, for this model only one segment. The next three columns define the x,y, and z coordinates for one end of a wire. The next three columns define the x,y, and z coordinates for the other end of a wire. The last column is used to define the diameter of the wire.

- As you can see, it can be very tedious and time consuming to construct a model.

- The Laser Mapper provides a tool for rapidly determining the physical characteristics of an object in cartesian coordinates, which can be translated into a format acceptable to modeling code being used.

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Typical Timelines for Model Development

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Process	Current	With Scanner/ Modeling Tools
Construct Object Geometries	12 Weeks	1 Day
Translate Geometries into Format for Modeling Code	4 Weeks	1 Day
Totals	16 Weeks	2 Days

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This slides shows the potential time savings in generating a model to support Electromagnetic Modeling.

- Typically it can take about 4 months to manually generate an appropriate model of a platform to support EM modeling.

- With the laser scanner, the time to develop a model can be reduced to a few days, which can significantly reduce overall analysis cost and provide timely predictions.

- This time reduction makes a big difference in responding to the needs of our sponsors. Results can now be produced in weeks rather than nearly a half a year.

- At this time I would like to turn it over to Dave, who will be defining the specific technical performance parameters of the system.

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Laser Mapper LM-100a

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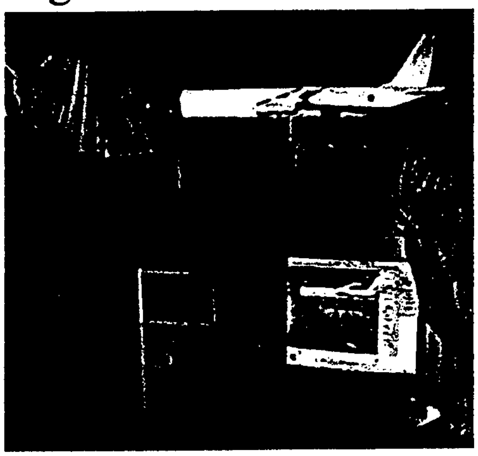
High Precision Surface Measurement System



- System Concept
- Position System Design
- Laser Radar Design
- Surface Mapping Algorithms
  - Single Scan
  - Multi-Scan Combination
- Data Acquisition, Editing, Processing
- Data Reduction Processing, Automation

The Most Advanced Full-Scale Measurement Device Available

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PAR Government / RRC recently developed the Laser Mapper system, the LM-100, for rapidly generating 3D CAD files of external surfaces of large objects, ex. vehicles, airframes, etc.

- Intended use for Computational Electromagnetic (CEM) modeling applications
- RRC engineers developed the LM-100:
  - System concept - non-contact laser scanner integrated with real-time data acquisition computer, and remote user interface PC (via Ethernet)
  - Electrical/optical/mechanical/servo design for scanner/rangefinder
  - Mapping/data acq. and processing algorithms
  - User interface and post-processing software for editing/evaluation
- Primarily COTS components with some custom enhancements/ modifications to meet requirements

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LM-100a System Specifications

Parameter	Specification
Maximum Range	30 Feet
Accuracy Range Elevation Azimuth	0.25 Inch Maximum 0.13 Inch 150 µrad 150 µrad
Field of Regard Elevation Azimuth	 ± 40 Deg ± 45 Deg
Data Acquisition Rate	5,000 Points/Sec (Typ.)
Typical Measurement Time	11 Minutes (10' x 20' Surface Sampled at 1/8" Steps)
Scanner System Enclosure	30 x 32 x 16 Inches
Power Requirement	1,800 Watt (110 VAC, 60 Hz)
User Interface	Windows 95/NT
Remote PC Interface	Ethernet

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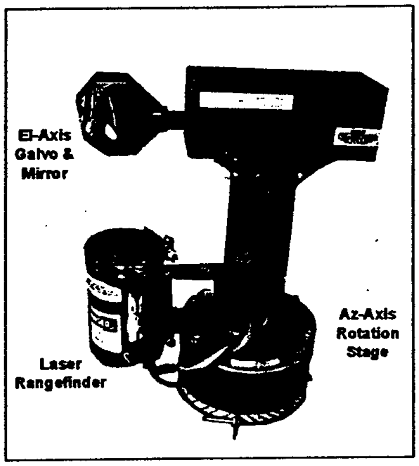
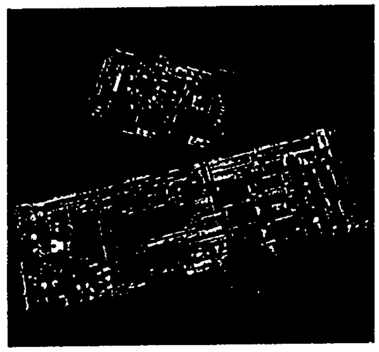
Performance specs for LM-100

- Max range of 30 feet refers to tested operating range (calibrated/verified)
  - Longer ranges (to 40+ ft) appear to be attainable
- Accuracy of 1/4" refers to combined (transformed) scans from multiple aspect angles
  - Single-scan accuracy is appx. 0.15"
  - Directly applicable to CEM modeling up to single-digit GHz ($\lambda/10$ accuracy); possibly extendible to higher frequencies
- Combined field of regard plus max range allows objects on the order of 30+ feet on a side to be scanned
  - Larger objects can be scanned by propagating measurements, however at some small degradation to accuracy
- Typically, 6-10 scans of an object are required to obtain enough "views" to capture entire external surface
  - Tag points on surface are used to align (transform) scans into a single 3D point-cloud model (during post-processing)
  - Either scanner and/or object can be moved to obtain individual scans
  - Depending on setup time and time required to reposition object/scanner, typical full scans take less than one day

Laser Rangefinder and 2-Axis Scanner





Custom Circuit Cards for Motion Control and Synchronization

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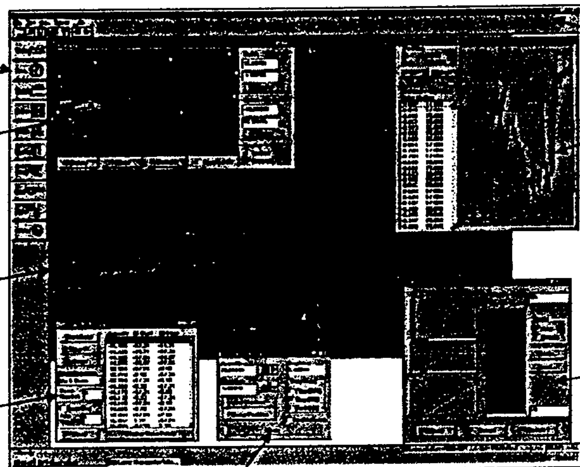
Key component of LM-100 is the scanner/rangefinder shown on left

- Rangefinder is rigidly attached to Az stage of two axis scanner
- Az-axis is provided by (motorized) rotation stage
- El-axis is provided by mirror attached to galvanometer motor

All components are COTS with exception of the opto-mechanical mount for the scanner/rangefinder, plus two custom circuit cards for motion control and synchronization - these were required to improve performance of the system

Data Acquisition and Processing



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User interface is provided on remote PC which controls data acquisition system and provide viewing/editing/processing of data

- Win 95/NT user-friendly interface - requires minimal training
  - Point & click menus/toolbars
  - Graphical cues - from setup through post-processing
  - On-screen video
- Data evaluation tools
  - Razor-edge range plots; direct read-out of range/angle
  - False-color topographic imaging for visualization
  - Reflectivity image - highlights regions of possibly insufficient signal
  - Range gating to remove background surfaces
  - Data editing/erasure of extraneous data
  - Filtering
- Combine scans using built-in transformation routine to obtain full 3D surface model in single coordinate system
- Data output
  - 3D surface model in raw (point cloud) or processed (filtered) formats
  - Drawing interchange format (DXF/DXB) export

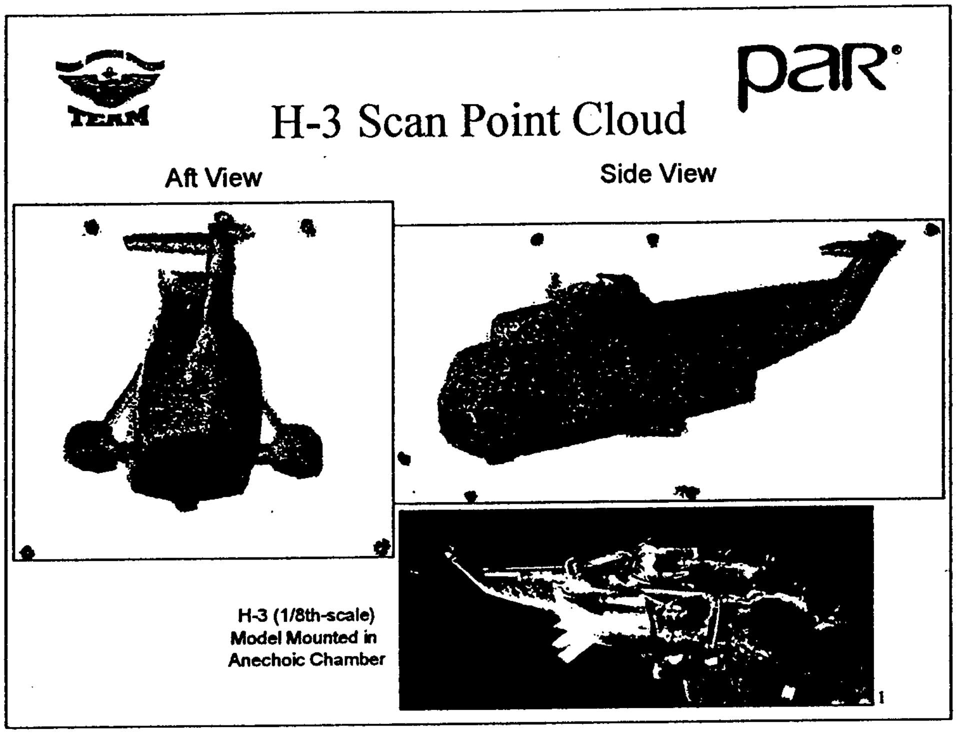
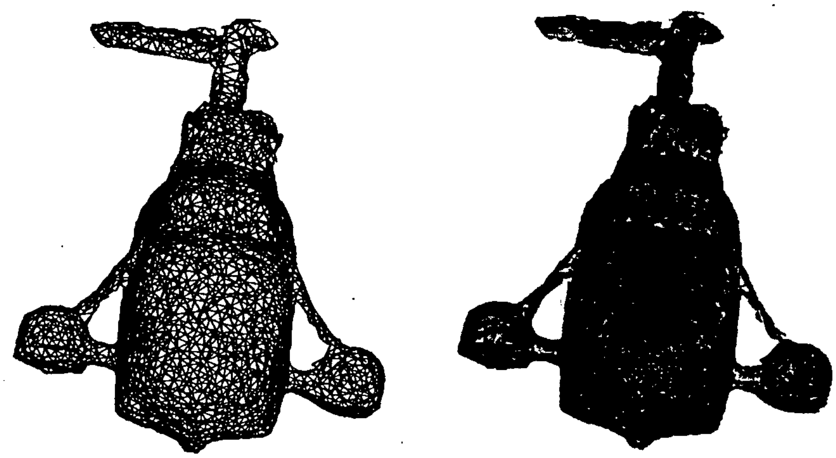


Diagram shows results from recent scan of an 1/8th-scale H-3 helicopter (shown in lower right) - appx. 8 ft long

- Top views (aft/side) show filtered point-cloud data output
  - 9 scans were taken to capture entire surface - different colors represent data from each scan
  - Total of appx. 1/2-million points were taken in combined data set (filtered to remove background/extraneous points)
  - Resulting accuracy of combined model was appx. 0.13"
  - Total time for scans and post-processing to point cloud was appx. 8 hrs - incl. setup, scans, repositioning, post-processing, and tear-down
- Tag points are visible in images [balls shown around model]
  - 7 tag points used for this model
  - Most of the tag points are visible in each scan
  - Post-processing alignment SW uses tag point locations to transform each scan into a common base coordinate system

H-3 Helo Scan
Front View - 0.5" Mesh



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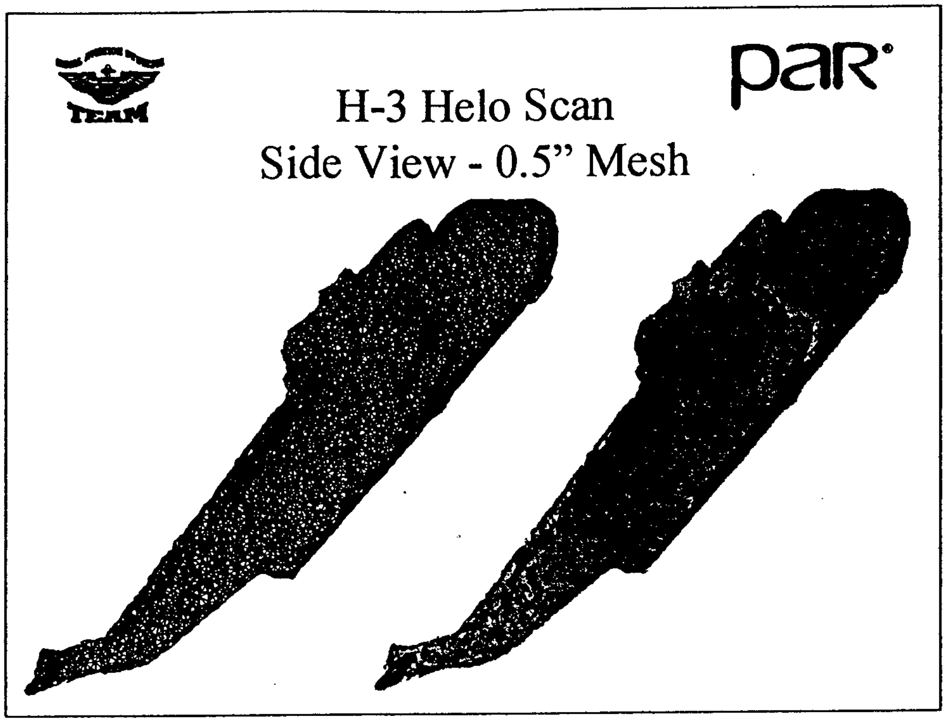
As part of ongoing research, we are currently working on converting point cloud data to surfaces using COTS SW (Metris)

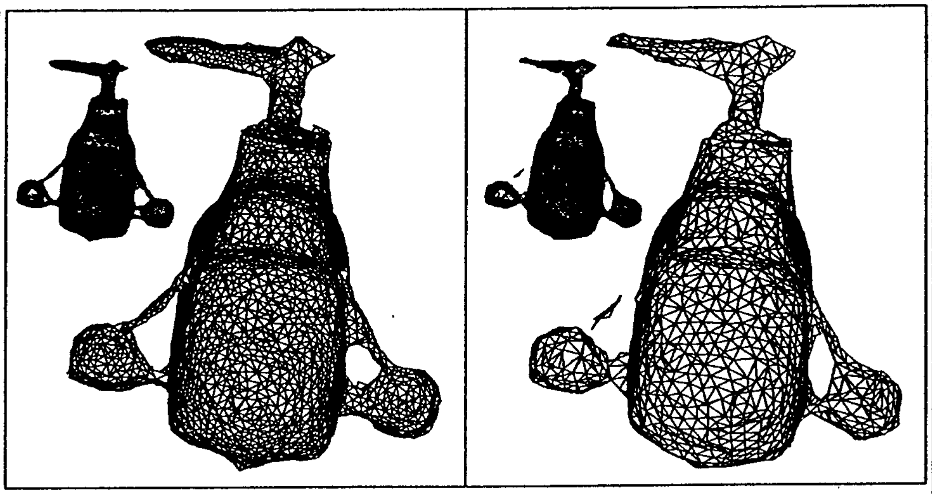
- Diagram shows initial results using the H-3 point cloud data
  - Triangulated mesh and rendered image (using AutoCAD)
- As shown, surfacing SW adequately converted points to surfaces
  - Filtering settings allow control of nominal triangle size
  - Degree of filtering (triangle size) can be varied around object; ex. adaptive filtering where mesh is coarser around flat areas, while more refined at high curvatures



Same data set as previous slide.

Again, mesh appears to be quite good.

H-3 Helo Scan
1.0” & 1.5” Meshes



1.0" Mesh 1.5" Mesh

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Two additional meshes created from H-3 point cloud data for different mesh sizes.

Here we can see that there are some anomalies present as evident looking at the outrigger struts.

- E.g. in the 1.5” mesh, the one strut is disconnected from the body of the helo.
- This could arise from a number of areas
  - Inadequate filtering ⇒ investigate adaptive filter (based on curvature) and/or refine filtering steps
  - Inadequate data from original scan ⇒ rescan
  - Or, combination of above

Note, the struts are relatively small structures and are thus more difficult to treat from a surfacing standpoint.

We believe that tuning the filtering processes associated with post-processing the acquired data set will result in consistent accurate meshes. However, since the time to scan the object is minimal, and post-processing is likewise quite rapid, activities such as rescanning are practical so as to obtain a good data set.

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Summary

- System developed to support CEM modeling
- Proven hardware/software
- System availability
  - Modeling services available at NAWC/Pax
  - Technical support by developer
- Many potential applications

In summary, we have presented a system which provides a key element to CEM modeling, that of creating the geometric model to be analyzed. The Laser Mapper produces CAD models in a fraction of the time that current methods involve, and with accuracy sufficient for a wide range of CEM analyses.

The Laser Mapper hardware and software have been proven in the field. The system is currently available at NAWC/Pax, where additional CEM services are available. Technical support is also available from PAR/RRC for operational use, HW/SW upgrades, and other enhancements.

There are certainly many potential applications beyond that of CEM modeling. These include virtually any application requiring digitization of an object's geometry.