Visualization: Past, Present, and Future at The Boeing Company

Dave Kasik

Senior Technical Fellow

The Boeing Company

Christopher J Senesac

Senior Systems Architect

The Boeing Company

A Bit About Us

- **Dave**:
  - Involved in computer graphics since 1969
  - Boeing Senior Technical Fellow
  - ACM Fellow
  - Stand-in on starship bridges
  - Known around Boeing as
    - A curmudgeon about virtual reality in the immersive, stereo sense
    - An advocate for augmented reality
    - Leading proponent and expert for broad use of visualization for **geometric** and **non-geometric** data
- **Chris**:
  - Involved in computer graphics since 1990
  - Boeing Senior Architect
  - Specialty - being able to apply technology to real world problems
  - Passion is to simplify complex problems

Outline

- **Boeing's influence on visualization (Dave)**
- **Broadening applicability (Chris)**

The Past: Boeing and Computer Graphics

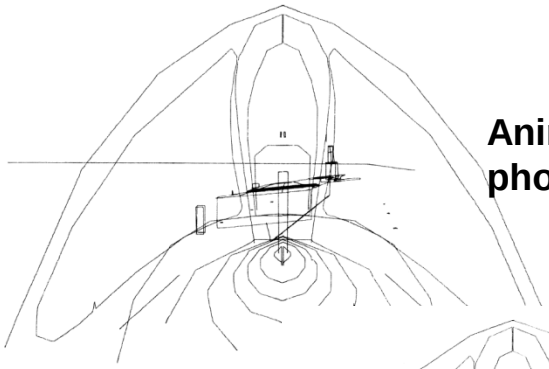
- **Computer graphics**
- **Human model**
- **B-spline surface rendering**
- **Fractals**
- **User interface management systems**
- **Industrial-strength NURBS Algorithms**
- **IGES**
- **Augmented reality**
- **FlyThru/IVT**
- **Voxmap PointShell (collision detection)**
- **Visual analytics**
- **Massive model visualization**

Computer Graphics

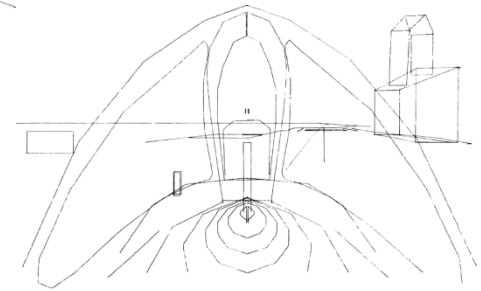
- **According to Wikipedia, computer graphics *has made computers easier to interact with, and better for understanding and interpreting many types of data. Developments in computer graphics have had a profound impact on many types of media...***
- **The term came from Boeing-Wichita's Verne Hudson in 1960. Bill Fetter popularized it.**

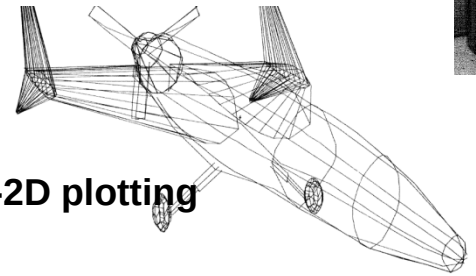

computer graphics
AIRCRAFT APPLICATIONS
A status report prepared by
the Engineering Graphics Unit,
ranch, Military
Systems Division,
The Boeing Company
D3-4124-1 March 15, 1962

In June 1960,

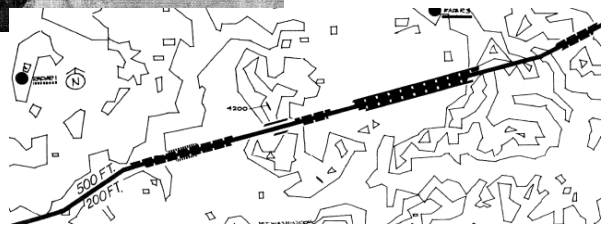


Animation by photography





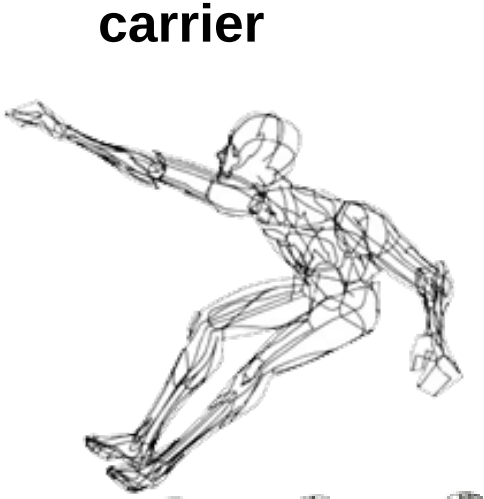
3D-2D plotting

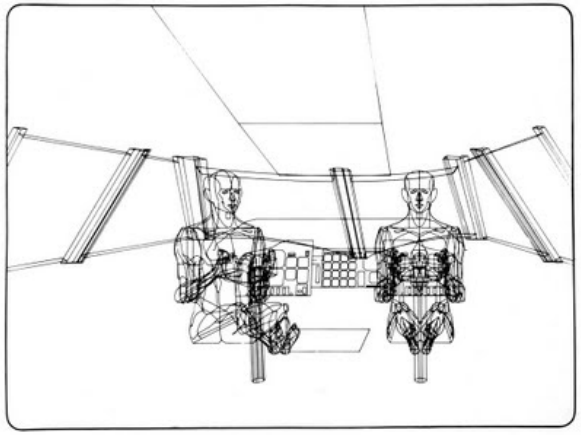


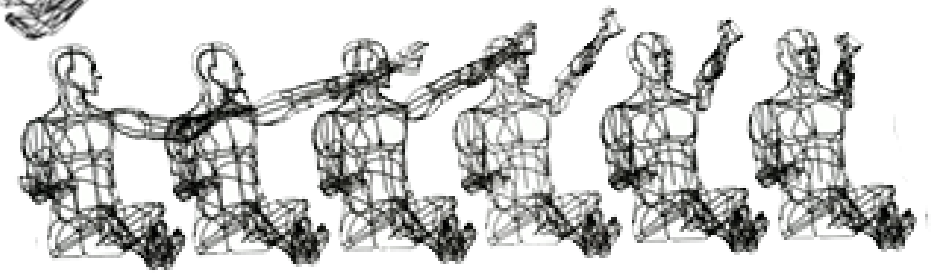
Contour plots

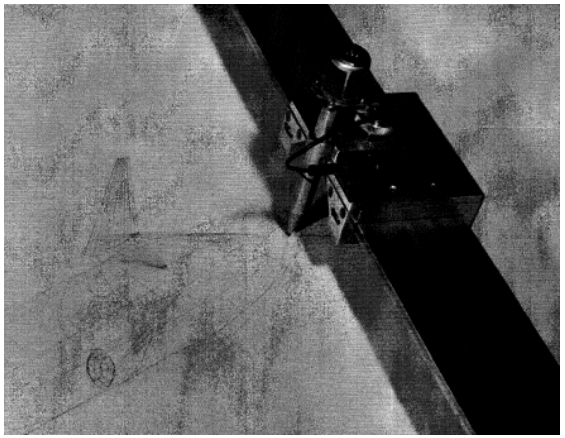
Human Model

- **Fetter developed BOEMAN, the first computer model of a human body in 1964**
- **Used a pen plotter to do reach studies for an aircraft carrier**









B-spline Surface Rendering

- **Jeff Lane and Loren Carpenter**
- **Cover article of Communications of the ACM, "Scan line methods for displaying parametrically defined surfaces", 1980**
- **Technique still in use in all CAD and visualization tools used in Boeing**
- **P.S.: Jeremy Jaech developed direct NURBS surface rendering in 1981**
  - **Left Boeing for dream job at a start-up**
  - **One of two developers of Aldus PageMaker**
  - **Left Aldus to found Visio**

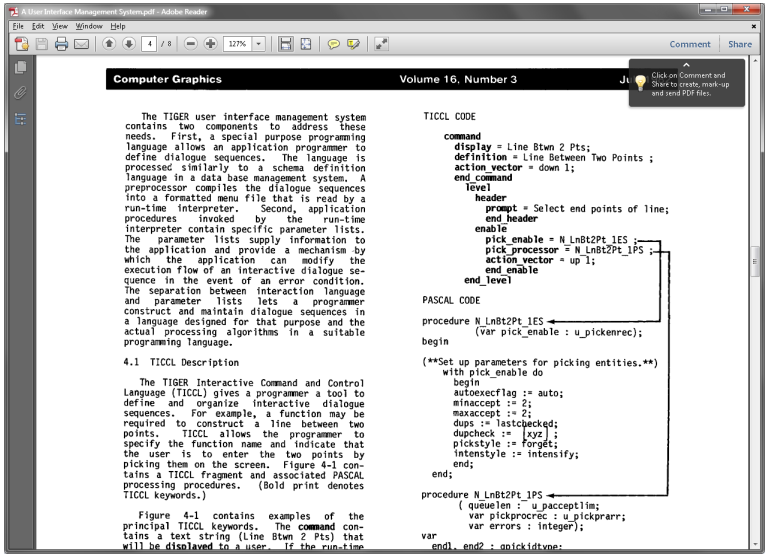
Fractal Animation

- **Loren Carpenter**
- **Produced, directed film called *Vol Libre***
- **Resulted in standing ovation at SIGGRAPH'80**

Courtesy: L. Carpenter

User Interface Management Systems

- **Started as part of the TIGER research project in 1980**
- **Designed by Dave Kasik and initially implemented by Loren Carpenter. Randy Houser, Hank Ramsey, and Steve Jensen handled UIMS evolution.**
- **The UIMS idea improved**
  - **The user experience with defaults, generic selection, etc.**
  - **The programmers' development of complex interactive sequences**
- **Originally published at SIGGRAPH'82**
- **Documented programmer productivity improvements (IEEE CG&A, 1988); COTS tools from Apollo and others**



Computer Graphics Volume 16, Number 3

The TIGER user interface management system contains two components to address these needs. First, a special purpose programming language allows an application programmer to define dialogue sequences. The language is processed similarly to a schema definition language in a data base management system. A preprocessor compiles the dialogue sequences into a formatted menu file that is read by a run-time interpreter. Second, application procedures invoked by the run-time interpreter contain specific parameter lists. The parameter lists supply information to the application and provide a mechanism by which the application can modify the execution flow of an interactive dialogue sequence in the event of an error condition. The separation between interaction language and parameter lists lets a programmer construct and maintain dialogue sequences in a language designed for that purpose and the actual processing algorithms in a suitable programming language.

4.1 TICCL Description

The TIGER Interactive Command and Control Language (TICCL) gives a programmer a tool to define and organize interactive dialogue sequences. For example, a function may be required to construct a line between two points. TICCL allows the programmer to specify the function name and indicate that the user is to enter the two points by picking them on the screen. Figure 4-1 contains a TICCL fragment and associated PASCAL processing procedures. (Bold print denotes TICCL keywords.)

Figure 4-1 contains examples of the principal TICCL keywords. The **command** contains a text string (Line Btwn 2 Pts) that will be displayed to a user. If the run-time

TICCL CODE

```
command
  display = Line Btwn 2 Pts;
  definition = Line Between Two Points ;
  action_vector = down 1;
  end_command
    level
      header
        prompt = Select end points of line;
        end_header
      enable
        pick_enable = N_LnBt2Pt_1ES ;
        pick_processor = N_LnBt2Pt_1PS ;
        action_vector = up 1;
        end_enable
    end_level

PASCAL CODE

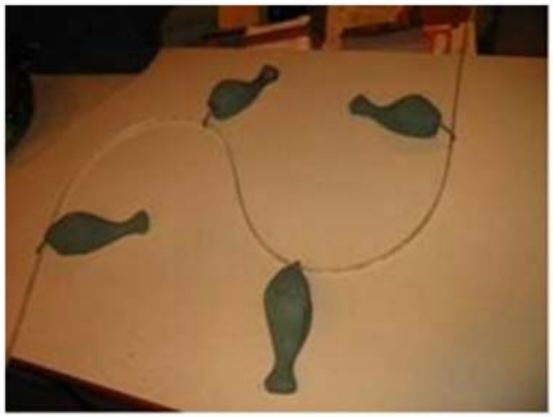
procedure N_LnBt2Pt_1ES
        (Var pick_enable : u_pickenrec);
begin

(**Set up parameters for picking entities.**)
    with pick_enable do
      begin
      autoexecflag := auto;
      minaccept := 2;
      maxaccept := 2;
      dups := lastchecked;
      dupcheck := [xyz] ;
      pickstyle := forget;
      intenstyle := intensify;
      end;
  end;

procedure N_LnBt2Pt_1PS
        ( queuelen : u_paccept1im;
          var pickprocrec : u_pickprarr;
          var errors : integer);
var
  end1, end2 : apickidtype;
```

Industrial Strength NURBS Algorithms

- **Extended academic math research (Cox-deBoor) to account for lofting use of splines.**
- **Implemented in the TIGER research system in 1980-1981**
- **Spearheaded by Bob Blomgren, Eugene Lee, Dick Fuhr, et al.**
- **Continued and expanded by Dave Ferguson, Tom Grandine, et al.**
- **Grandine and Fritz Klein developed first reliable surface-surface intersector in late 1990's**
- **Basis for CATIAV5, UG/NX, ProE. Still moving forward in Boeing as GEODUCK**



A physical spline

The historical evolution of airfoil sections, 1908-1944. The last two shapes (N.A.C.A. 66$_1$-212 and N.A.C.A. 747A315) are low-drag sections designed to have laminar flow over 60 to 70 percent of chord on both the upper and the lower surface. Note that the laminar flow sections are thickest near the center of their chords.

A physical spline

IGES

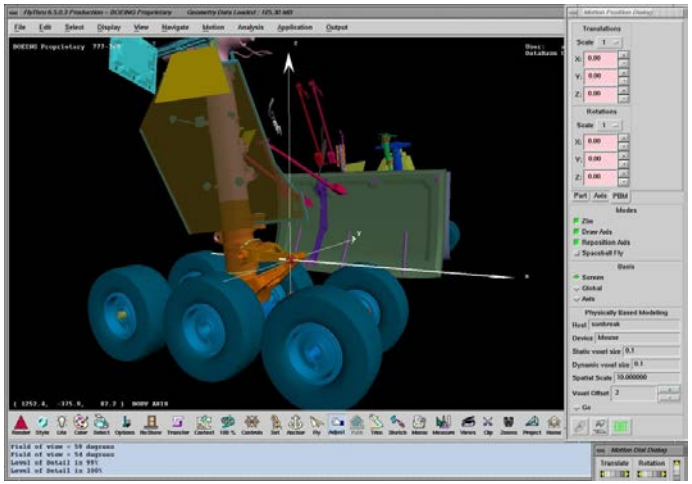
- **Outgrowth of the Boeing CIIN (CAD/CAM Integrated Information Network)**
  - **Exchange data between Computervision (757) and Gerber IDS (767) drafting systems**
  - **Extended to Applicon and others**
- **Walt Braithwaite and Mike Liewald proposed CIIN as a national data interchange format standard in the early 1980's**
- **CIIN became IGES (Initial Graphics Exchange Specification)**
  - **Boeing added non-uniform rational b-spline curves and surfaces in the mid-to-late 1980's**
- **Became standard interchange format across industry.**
- **Pre-cursor to STEP for interchange and archive.**

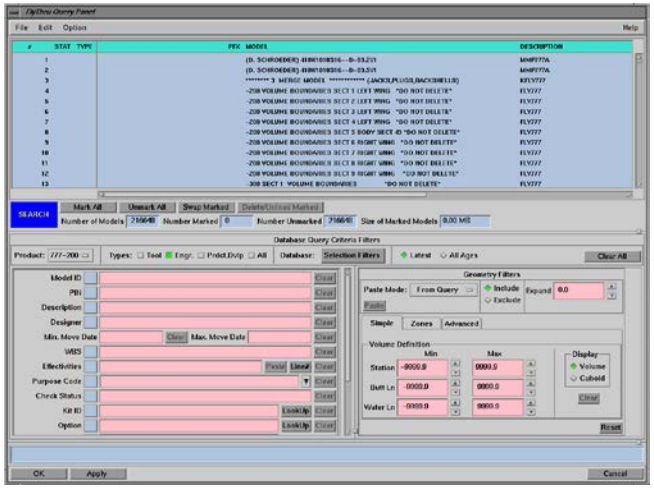
Augmented Reality

- **Term coined by Boeing's Tom Caudell in 1990**
- **Applications evaluated (Caudell, David Mizell) in Boeing proved impractical**
- **Boeing continues to invest in Augmented Reality.**
- **Little in production use.**

FlyThru

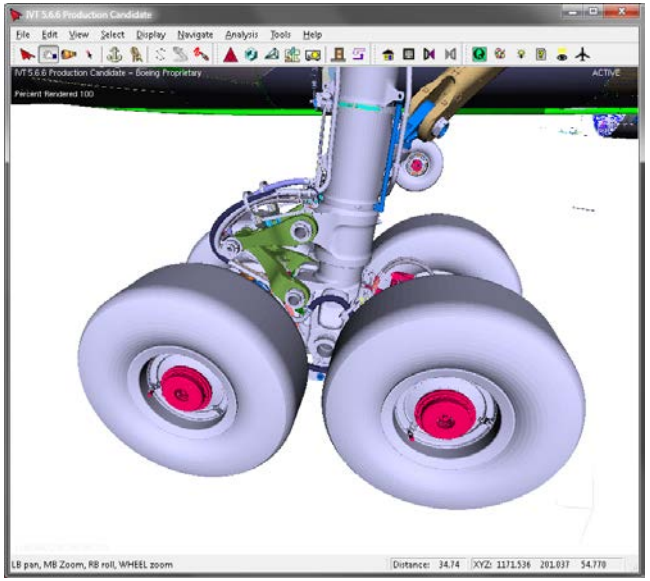
- **Implemented in early 1990's to support design reviews for the 777 (Bob Abarbanel, Eric Brechner, Bill McNeely, et al.)**
- **Published by Abarbanel at SIGGRAPH'96**
- **Sucked all possible performance from SGI hardware**
- **Linked to geometry configuration management systems (EPIC/DIRRECT)**
- **Eventually implemented on IBM RS6000s**
- **Preferred visualization tool in BCA and some BDS.**

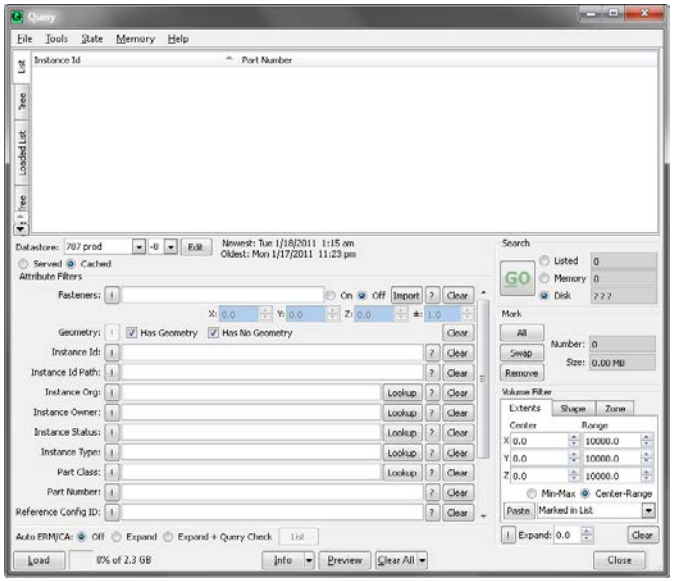




IVT

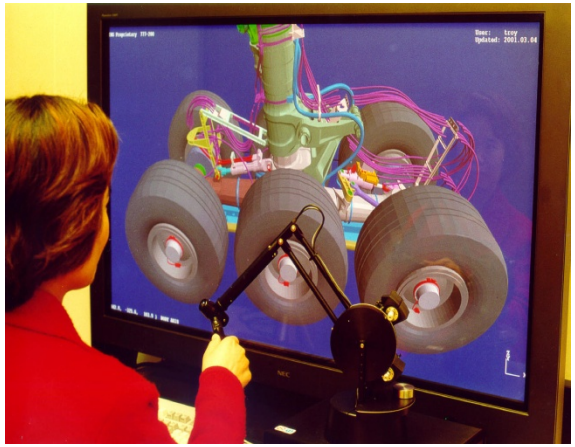
- **FlyThru transitioned to IVT (Interim -> Integration Visualization Tool) and PCs for the 787 in early 2000's (John Gass, Bill McGarry, Nik Prazak, Richard Clark, et al.)**
- **Linked to geometry configuration management systems (EPIC/DIRRECT, Enovia)**
- **20,000 registered users across BCA/BDS programs**

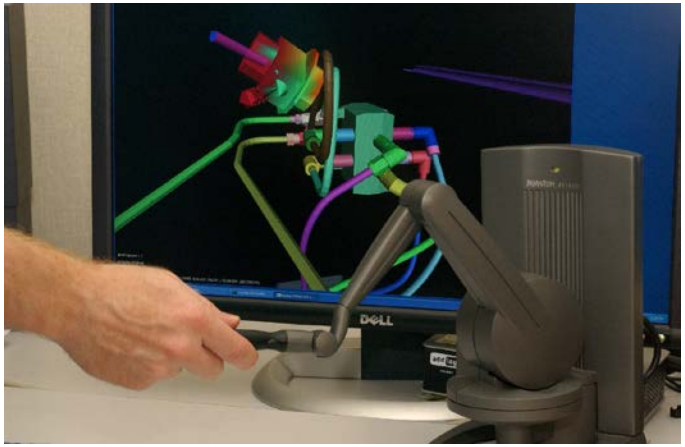




Voxmap PointShell (VPS)

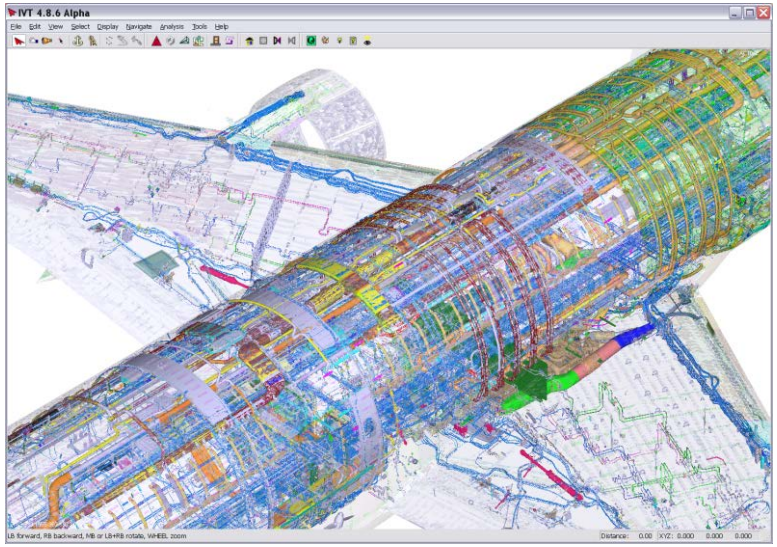
- **VPS supports real-time collision detection for haptics**
- **Speed is essential**
  - **Visualization requires at least 10Hz**
  - **Touch requires at least 1000 Hz**
- **Developed in 1997, by Bill McNeely, Jim Troy, Jeff Heisserman, Kevin Puterbaugh, Karel Zikan, et al.**
- **VPS met speed and accuracy requirements for Boeing maintenance removal tasks and interference checking**
- **Published at SIGGRAPH'99**

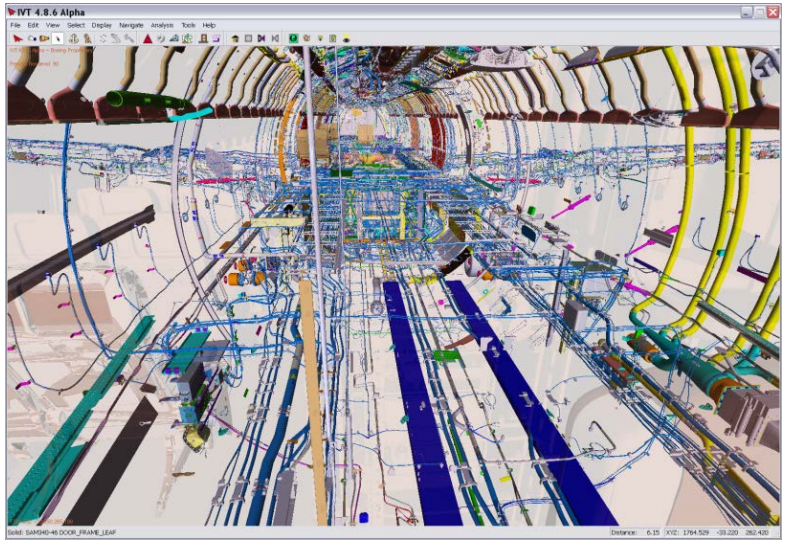




Massive Model Visualization

- **Dave Kasik started investigating ways to visualize entire aerospace products in 2004 in collaboration with organizations around the world**
- **Monograph ‘Real-Time Massive Model Rendering’ (Yoon, et al.) 2008**





Observations

- **Boeing has a long tradition in computer graphics and interactive techniques**
- **Visualization has specific value for**
  - **Highly complex products**
  - **Processing huge amounts of data**
  - **Widest path into brain**
  - **Complex system integration**
  - **Complex non-geometric data exploration and analysis tasks**
- **Boeing pushed the state-of-the-art to understand state-of-the-art products**
- **It takes a long time for state-of-the-art in aerospace and computing technology to become widespread**

Moving Forward

Technology	Boeing start	Evolution
Computer graphics	1960	CAD (1980's) -> entertainment (late 1990's). Now everywhere.
Man-model	1964	2 internal systems until late 1990's. Mostly COTS today
B-spline surface rendering	1980	NURBS started dominating CAD geometry in mid-to-late 1990's
Fractals & animation	1980	Fractals became commonplace in mid-1990s
User interface management systems	1981	Precursor published in 1976. Became COTS in 1980's and fizzled in mid-1990's
NURBS Algorithms	1981-1982	NURBS started dominating CAD geometry in mid-to-late 1990's
IGES	1982	Dominant interchange format until late 1990's. Gradually giving way to STEP.
Augmented Reality	1990	Lots of academic research through late 2000's. Finally becoming 'real' with mobile maps.
FlyThru/IVT	1992	CAD vendors built/acquired similar systems in the early 2000's
VoxMap PointShell	1997	Collision detection embedded in many electronic games, surgical trainers, etc. Boeing has sold a few VPS licenses.
Massive model visualization	2004	Full production in Superviewer. One COTS package (Right Hemisphere), no CAD vendors.
Visual analytics	2004	Primary use in intelligence community. Early experimental use in Boeing.

Technology Transition Duration

Technology	Boeing start	Evolution
Computer gra	20 yrs to CAD, 10 to games, 20 to commonplace	entertainment (late 1990's). Now
Man-model	45 yrs to reasonable use 1964	2 internal systems until late 1990's. Mostly COTS today
B-spline surfac	20 yrs to commonplace 1980	NURBS started dominating CAD geometry in mid-to-late 1990's
Fractals & anir	15 yrs to commonplace 1980	Fractals became commonplace in mid-1990s
User interface	15 yrs to reasonable use, little use in 2011	sor published in 1976. Became COTS in and fizzled in mid-1990's
NURBS Algori	20 yrs to commonplace 1981-1982	NURBS started dominating CAD geometry in mid-to-late 1990's
IGES	5 yrs to reasonable use, some use in 2011	ant interchange format until late 1990's. ally giving way to STEP.
Augmented Re	20 yrs to some use 1990	Lots of academic research through late 2000's. Finally becoming 'real' with mobile maps.
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Outline

- Boeing's influence on visualization (Dave)
- **Broadening applicability (Chris)**

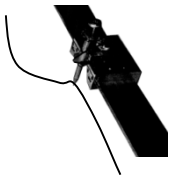
Paradigm Shift for Visualization – Massive Model Viewer

Paradigm Shift for Visualization – Massive Model Viewer

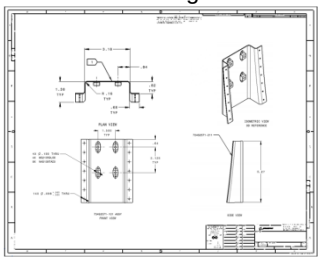
Deliverable's

Paper, Velum

2D Plot

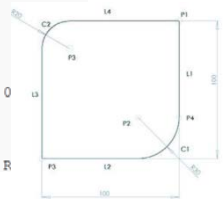


2D Drawings



CAM - APT

```
PARTNO / APT-1
CLPRNT
UNITS / MM
NOPOST
CUTTER / 10.0
$$GEOMETRY DEFINITION
SETPT = POINT / 0.0, 0.0, 0
STRTPT = POINT / 70,70,0
P1 = POINT / 50, 50, 0
P2 = POINT / 20, -20, 0
C1 = CIRCLE / CENTER, P2, R
```



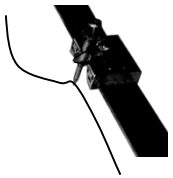
60's

Paradigm Shift for Visualization – Massive Model Viewer

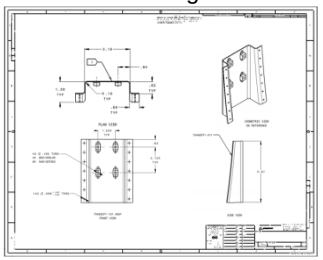
Deliverable's

Paper, Velum

2D Plot



2D Drawings



CAD model

IGES

CAM - APT

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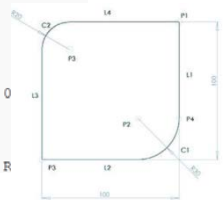
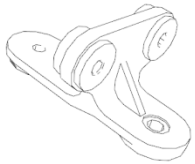




CAD/CAM – **3D Wireframe Surfacing**

70's

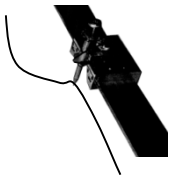
60's

Paradigm Shift for Visualization – Massive Model Viewer

Deliverable's

Paper, Velum

2D Plot



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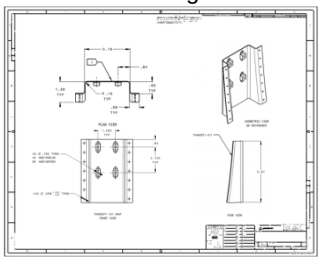

CAD model

IGES

STEP

CAM - APT

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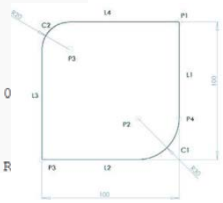
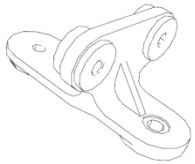
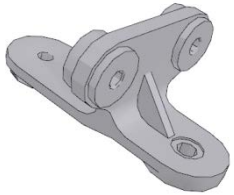


60's



CAD/CAM – **3D Wireframe**
Surfacing

70's



CAD/CAM –
Shaded Wireframe
Hidden Line Removal
Primitive Solids

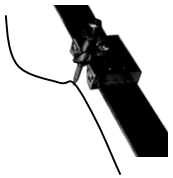
80's

Paradigm Shift for Visualization – Massive Model Viewer

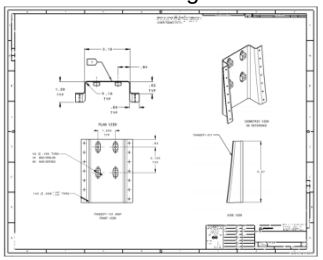
Deliverable's

Paper, Velum

2D Plot



2D Drawings



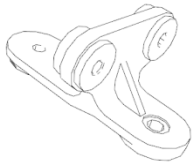
CAD model

IGES

STEP

CAD/CAM –
Solids Modeling

80-90's



CAD/CAM – **Shaded Wireframe**
Hidden Line Removal
Primitive Solids

80's

CAM - APT

```
PARTNO / APT-1
CLPRNT
UNITS / MM
NOPOST
CUTTER / 10.0
$$GEOMETRY DEFINITION
SETPT = POINT / 0.0, 0.0, 0
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P2 = POINT / 20, -20, 0
C1 = CIRCLE / CENTER, P2, R
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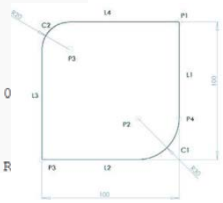


CAD/CAM – **3D Wireframe**
Surfacing

70's

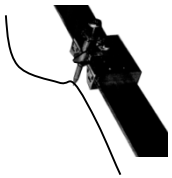
60's

Paradigm Shift for Visualization – Massive Model Viewer

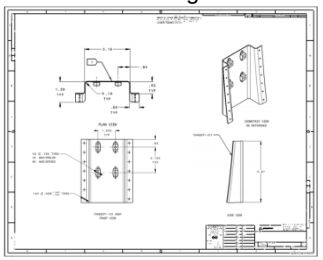
Deliverable's

Paper, Velum

2D Plot



2D Drawings

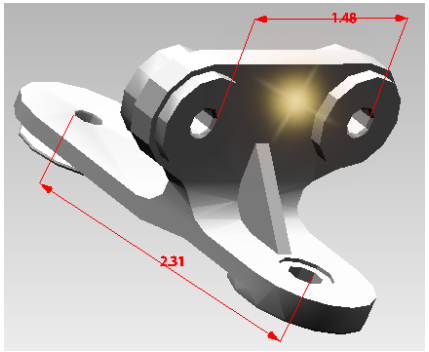


CAD model

IGES

STEP

3D PDF

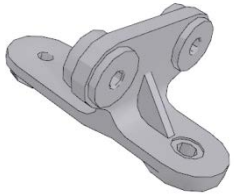


CAD/CAM –
Solids Modeling Model Based Design (**MBD**)

90-00's

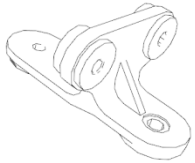
CAD/CAM –
Solids Modeling

80-90's



CAD/CAM –
Shaded Wireframe
Hidden Line Removal
Primitive Solids

80's



CAD/CAM – **3D Wireframe**
Surfacing

70's

CAM - APT

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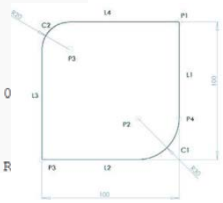


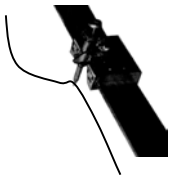
60's

Paradigm Shift for Visualization – Massive Model Viewer

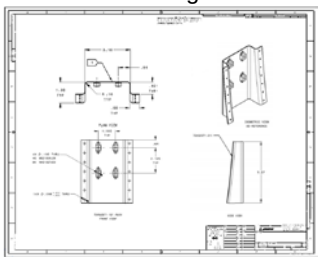
Deliverable's

Paper, Velum

2D Plot



2D Drawings

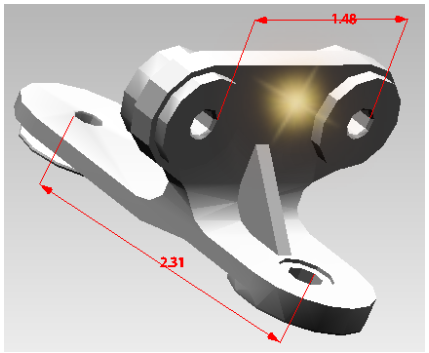


CAD model

IGES

STEP

3D PDF

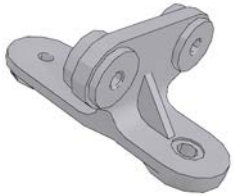


CAD/CAM –
Solids Modeling
Model Based Design (**MBD**)

90-00's

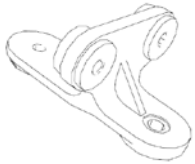
CAD/CAM –
Solids Modeling

80-90's



CAD/CAM –
Shaded Wireframe
Hidden Line Removal
Primitive Solids

80's



CAD/CAM – **3D Wireframe**
Surfacing

70's

CAM - APT

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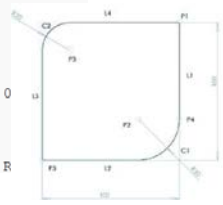
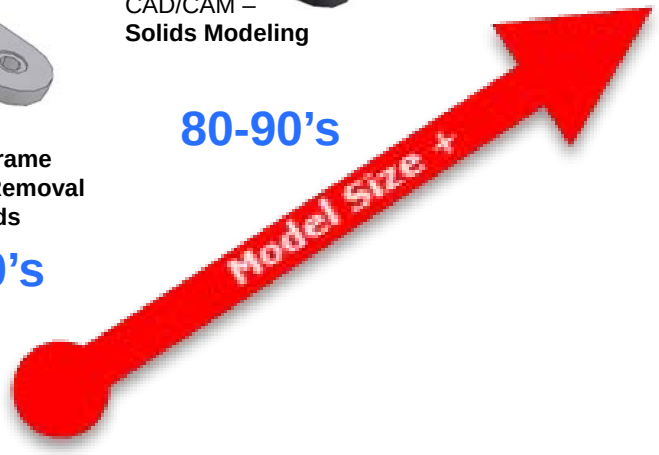


60's

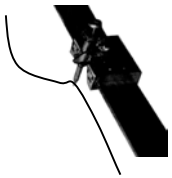


Paradigm Shift for Visualization – Massive Model Viewer

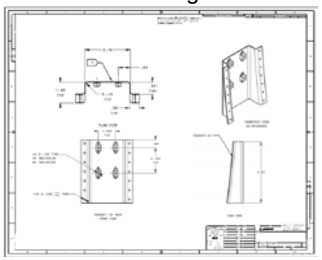
Deliverable's

Paper, Velum

2D Plot



2D Drawings

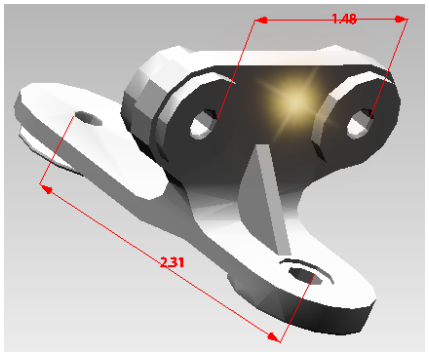


CAD model

IGES

STEP

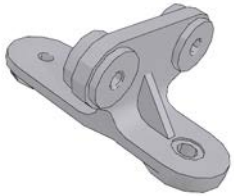
3D PDF



CAD/CAM –
Solids Modeling
Model Based Design (**MBD**)

90-00's

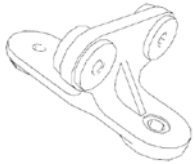
CAD/CAM –
Solids Modeling



CAD/CAM –
Shaded Wireframe
Hidden Line Removal
Primitive Solids

80-90's

CAM - APT



CAD/CAM – **3D Wireframe**
Surfacing

80's

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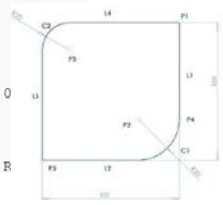


70's

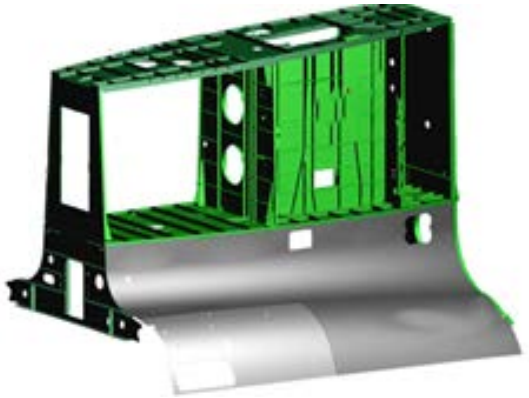
60's

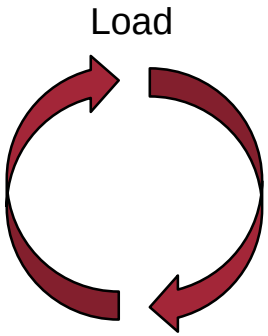
Model Size +

Visualization

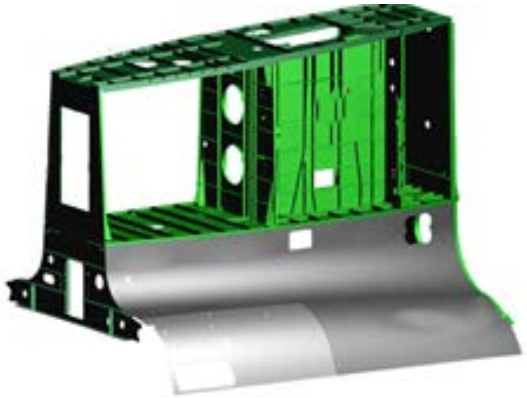
Massive Model Visualization

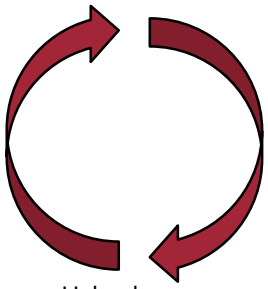
Legacy Visualization

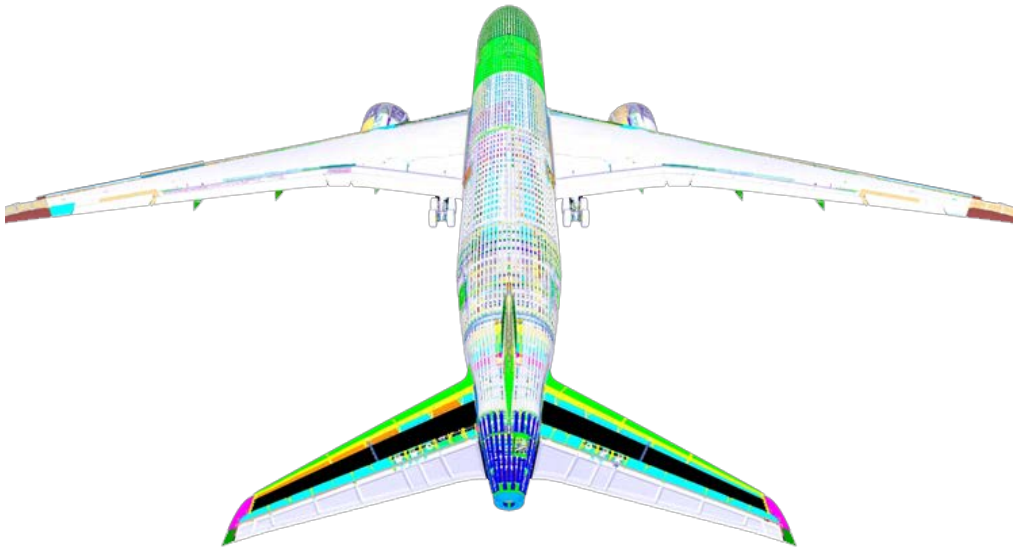




Massive Model Visualization







Load Once

Massive Model Visualization Use Cases

- **Dozens of use cases, including**
  - **Visualize entire BCA AC – gain insight into complex relationships**
  - **Non-conformances - Quickly identify part meta data and coordinates on AC for reporting of issues**
  - **Visualize installations in context**
  - **Provide Condition of Assembly – right amount of data, right time**
  - **Visualize incoming out-of-sequence work**
  - **Visual analytics for non-geometric data - Heat maps of issues**
  - **Serialized Controlled parts**
  - **As-designed to Current build comparison (Shake)**
  - **Customer comparison of two AC**
  - **……..**

Demonstration