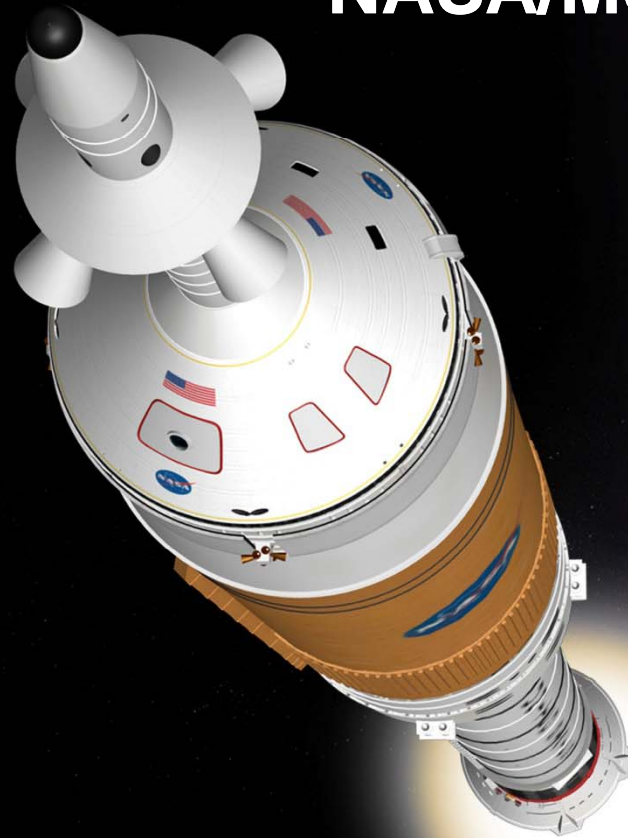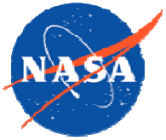National Aeronautics and Space Administration

Summary of Model-based Manufacturing Activities at NASA/MSFC

Steven Phillips

NASA – Marshall Space Flight Center
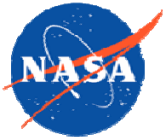
2/22/2011

MBE Status at MSFC

♦ **Current Status of MBE at MSFC**

- Level 0 to Level 1 up until the mid 2000s
  - Primary deliverable was 2D drawing
  - Models existed but no guarantee they were accurate; could not be used to cut chips
  - Manufacturing had to recreate models from drawings
- Reached Level 2 in the 2007-08 timeframe
  - CAD model and drawing provided and under configuration control
  - CAD model guaranteed accurate; can be used to cut chips
  - Notes and annotations on drawing, not model
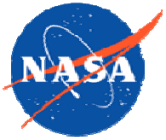 - No integration across the enterprise

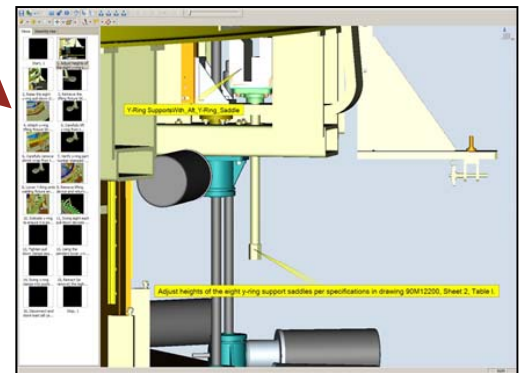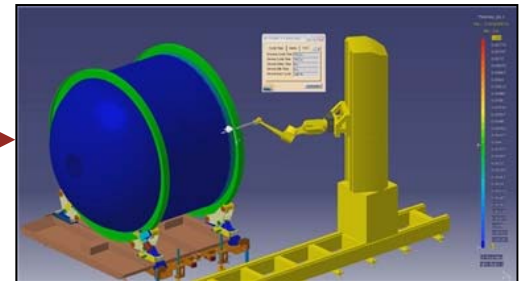| Level 0	• Drawing Centric • Disconnected Manufacturing - Disconnected Enterprise • Primary Deliverable: 2D Drawing
Level 1	• Model Centric • Neutral Model CAM - Disconnected Enterprise • Primary Deliverable: 2D Drawing and Neutral CAD Model
Level 2	• Model Centric • Native Model CAM - Disconnected Enterprise • Primary Deliverable: 2D drawing and Native CAD Model
Level 3	• Model Based Definition • Native Model CAM - Disconnected Enterprise • Primary Deliverable: 3D Annotated Model and Light Weight viewable
Level 4	• Model Based Definition • Integrated Manufacturing - Disconnected Enterprise • Primary Deliverable: 3D Annotated Model and Light Weight viewable via PLM
Level 5	• Model Based Enterprise • Integrated Manufacturing - Integrated Internal Enterprise • Primary Deliverable: Digital Product Definition Package and TDP
Level 6	• Model Based Enterprise • Integrated Manufacturing - Integrated Extended Enterprise • Primary Deliverable: Digital Product Definition Package and TDP via the web

Graph taken from http://model-based-enterprise.org
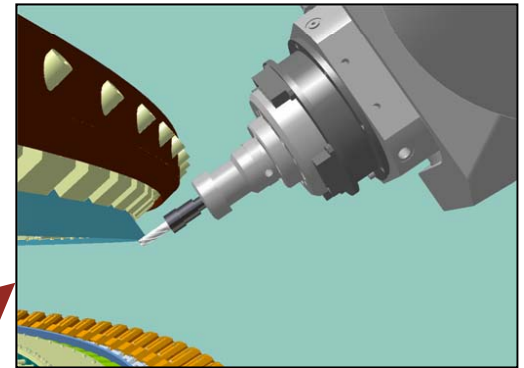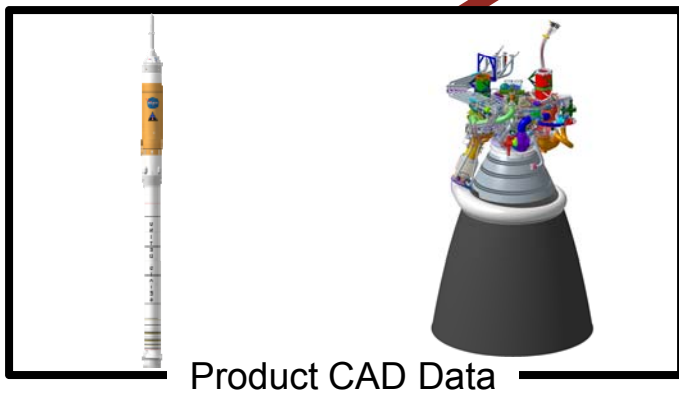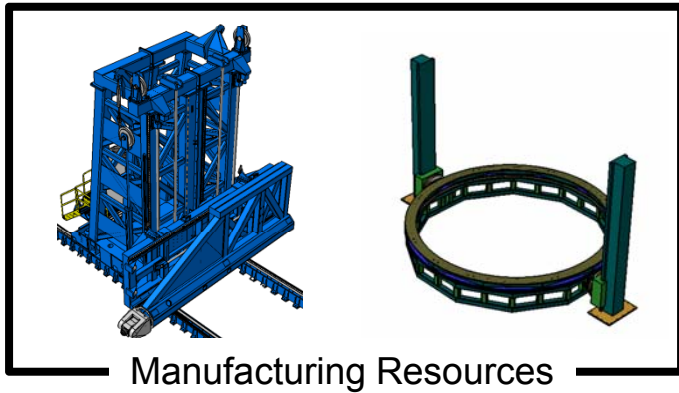
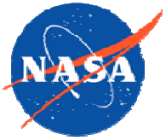# Recent Activities

♦ **Model-based Manufacturing Efforts**

- Expanded our simulation capabilities

- Implemented a Manufacturing Execution System

- Working to establish model-based instruction capability

- Established reverse engineering capability using scanning/photogrammetry

- Started integration between our PDM system and manufacturing systems; activity terminated due to funding being pulled.

Design → Verify through Simulation → Process Plan and Build → Verify As-Built to As-Designed

# Process Verification Through Simulation

Manufacturing Resources

Product CAD Data

Manufacturing Hub

Producibility Analyses

Off-line Programming

Model-Based Work Instructions
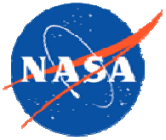
Producibility Analyses

♦ **General Process Outline**
  • Assign the appropriate geometry and define the steps which are to be simulated
  • Conduct 3D producibility analyses in which manufacturing processes, large scale assemblies, and ground support equipment are checked for interferences, fit up, reachability, and accessibility
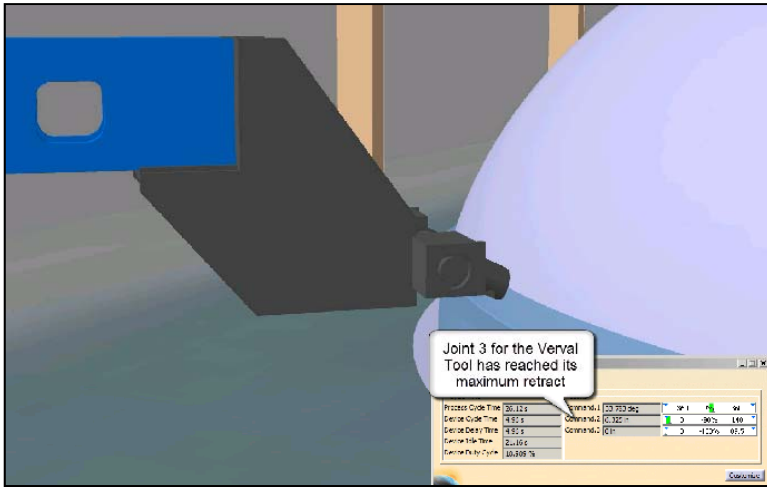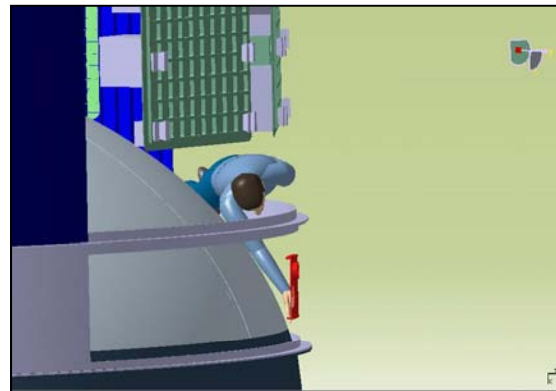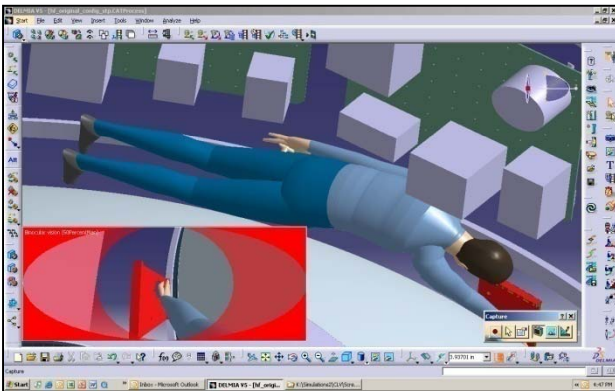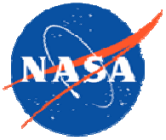

Simulation Setup

Interference Analysis
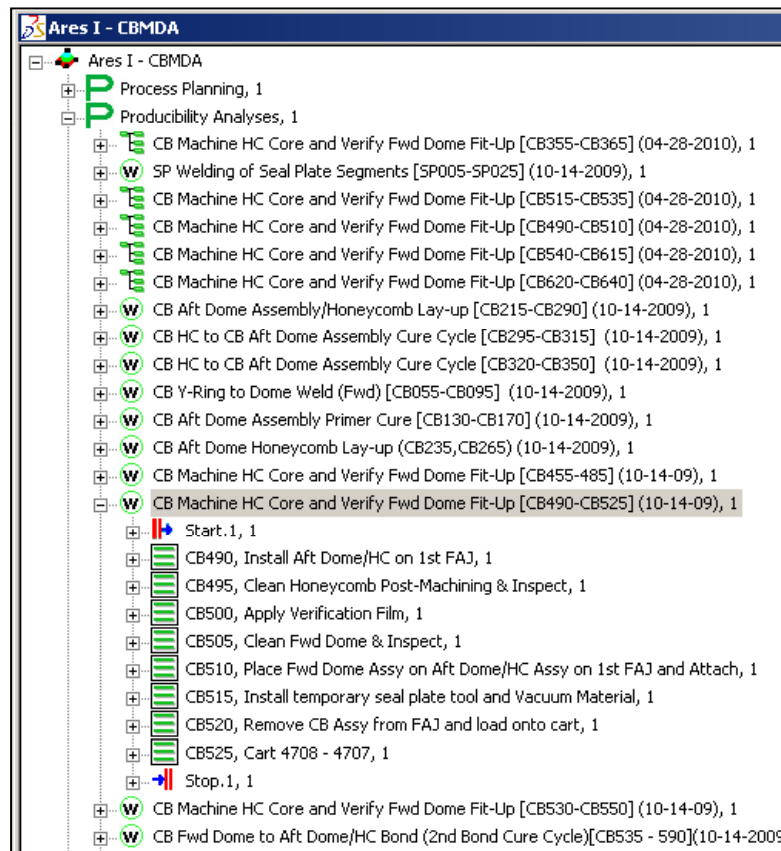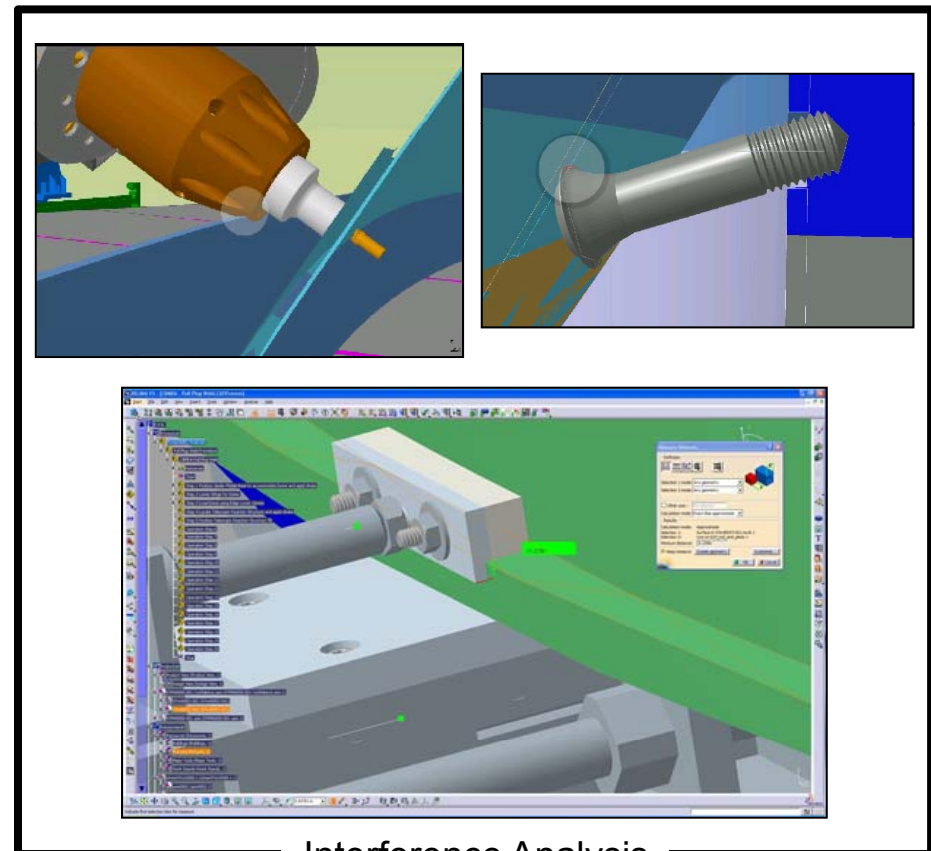
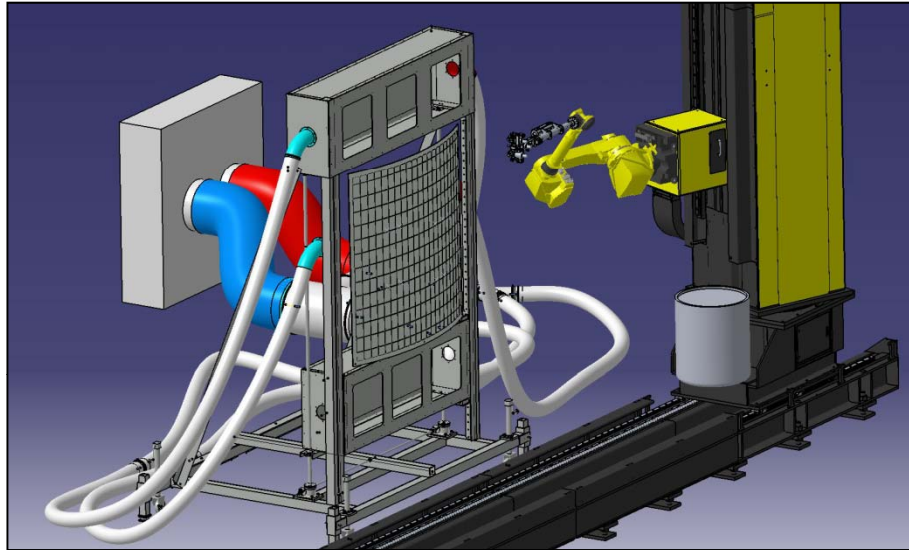# Producibility Analyses

Kinematic Analysis

Human Factors Analysis

Off-line Programming

Development of Robotic Process Parameters



```
AD01Try2.ls - Notepad
File  Edit  Format  View  Help
/PROG  AD01Try2
/ATTR
OWNER          = MNEDITOR;
COMMENT        = "DELMIA OFFLINE PROGRAM -  Resource Id ";
PROG_SIZE      = 0;
CREATE         = DATE 10- 05- 18 TIME  02:00:59;
MODIFIED       = DATE 10- 05- 18 TIME  02:00:59;
FILE_NAME      = ;
VERSION        = 0;
LINE_COUNT     = 0;
MEMORY_SIZE    = 0;
PROTECT        = READ_WRITE;
TCD:  STACK_SIZE        = 0,
      TASK_PRIORITY     = 50,
      TIME_SLICE        = 0,
      BUSY_LAMP_OFF     = 0,
      ABORT_REQUEST     = 0,
      PAUSE_REQUEST     = 0;
DEFAULT_GROUP  = 1,*,*,*,*;
CONTROL_CODE   = 00000000 00000000;
/MN
   1:  UTOOL_NUM  = 2 ;
   2:  UFRAME_NUM = 1 ;
   3:J P[1] 40% CNT100  ;
   4:L P[2] 800mm/sec CNT100  ;
   5:L P[3] 800mm/sec CNT100  ;
   6:L P[4] 800mm/sec CNT100  ;
   7:L P[5] 800mm/sec CNT100  ;
   8:L P[6] 800mm/sec CNT100  ;
   9:L P[7] 800mm/sec CNT100  ;
  10:L P[8] 800mm/sec CNT100  ;
  11:L P[9] 800mm/sec CNT100  ;

/POS
P[1]{
   GP1:
   UF : F, UT : F,          CONFIG : 'F U T, 0, 0, 0',
   X = 3696.365  mm,  Y = -983.978  mm,  Z = 2123.848  mm,
   W = 179.185 deg,   P =  -0.001 deg,   R =  0.000 deg,
   E1 =      0.000 deg, E2 =    0.000 mm,  E3 =    0.000 mm
};
P[2]{
   GP1:
   UF : F, UT : F,          CONFIG : 'F U T, 0, 0, 0',
```

## Weld / Trim Schedule Generation
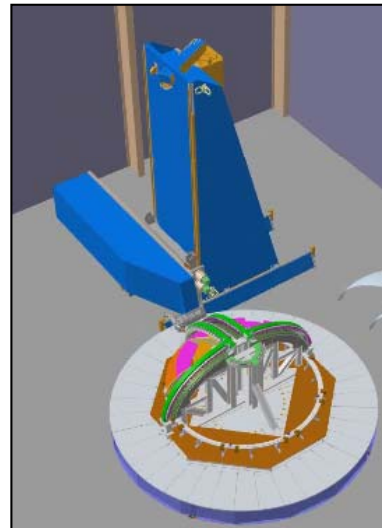

```
WELD_tab144full.wld - Notepad
File  Edit  Format  View  Help
DELAY/SEC,2.0
FORGECONTROL/FORCE,150.0,RATE,100.0,ACCEL,150.0
PINCONTROL/FORCE,-3000.0,RATE,200.0,ACCEL,200.0
DELAY/SEC,15.0

#line36:start travel
PINCONTROL/FORCE,-3000.0,RATE,200.0,ACCEL,200.0
FEEDRATE/IPM,10.0,ACCEL,1.3
GOTO/20.505 ,   6.962 ,  -6.422  ,0.0000  ,0.139292,0.990251

#line41:transition to main schedule
PINCONTROL/FORCE,-3850.0,RATE,200.0,ACCEL,200.0
FEEDRATE/IPM,11.5,ACCEL,1.0
SPINDLE/RPM,130.0,ACCEL,25.0
GOTO/20.50530,  8.36752,  -6.61788,0.00000,0.139292,0.990251
GOTO/20.50549,  9.24835,  -6.74617,0.000001,0.148570,0.988902
#begin taper to 0.360 schedule 1.5 in above 148" gore panel start
FEEDRATE/IPM,10.8,ACCEL,0.00163
SPINDLE/RPM,140.0,ACCEL,0.02323
GOTO/20.50569, 10.08503,  -6.87571,0.000002,0.157383,0.987538
GOTO/20.50590, 10.92053,  -7.01270,0.000004,0.166183,0.986095
GOTO/20.50609, 11.65740,  -7.13988,0.000005,0.173944,0.984756
GOTO/20.50633, 12.54506,  -7.30060,0.000007,0.182665,0.983175
GOTO/20.50655, 13.30684,  -7.44505,0.000010,0.190149,0.981755
GOTO/20.50681, 14.14249,  -7.61125,0.000012,0.198360,0.980129
GOTO/20.50707, 14.97662,  -7.78487,0.000015,0.206557,0.978435
GOTO/20.50734, 15.80918,  -7.96588,0.000017,0.214740,0.976671
GOTO/20.50763, 16.64011,  -8.15425,0.000020,0.222907,0.974840
GOTO/20.50793, 17.46934,  -8.34993,0.000023,0.231059,0.972940
GOTO/20.50823, 18.29682,  -8.55290,0.000025,0.239195,0.970972
GOTO/20.50855, 19.12248,  -8.76312,0.000028,0.247314,0.96893|5
```
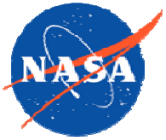
Process Planning and Shop Floor Execution

♦ **Current Look of Work Instructions**
  • References drawings
  • Static view of data
  • Limited information can be discerned about the entire part/assembly

Process Planning and Shop Floor Execution

♦ **MBE Impacts on Work Instructions**
  - Realizing MBE will help deliver less ambiguous work instructions
  - Rich, model-based, work instructions can be written which take advantage of model-based notes and annotations

Comparison of As-Designed to As-Built

◆ **Use white light scanning and photogrammetry to create as-built CAD models**
  - Comparison of as-built models to as-designed models reveals deviations, trending.
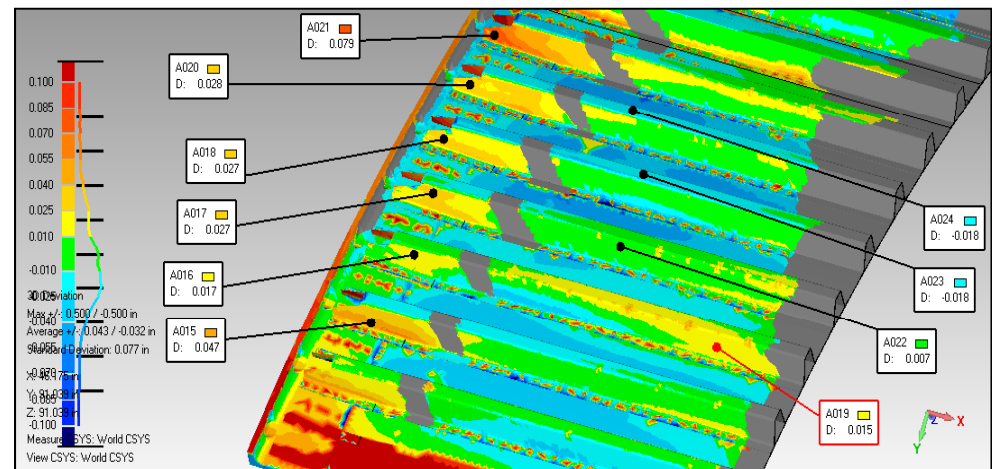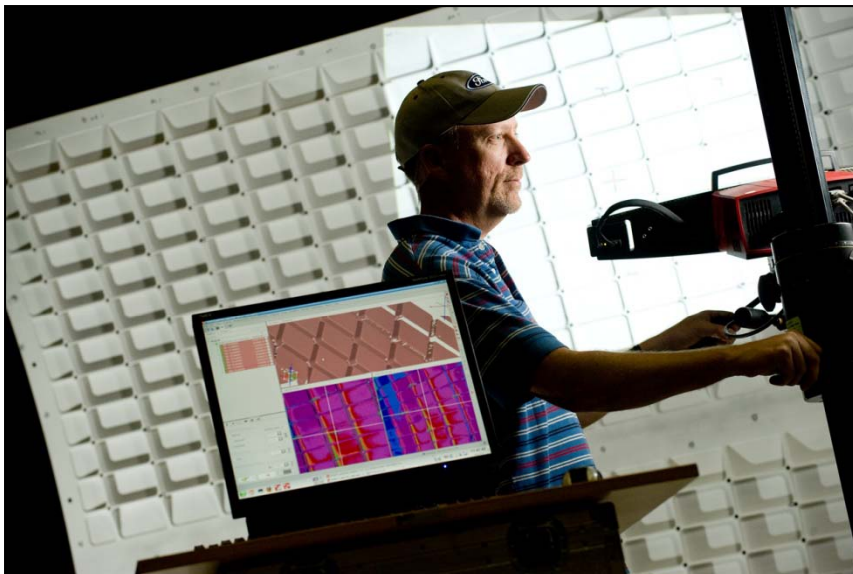
Cost Avoidance

♦ **Conservative estimate of $3.62M in cost avoidance for the first two items alone.**

- These two items represent tooling and processes used to build just 0.25% of the Ares I Upper Stage.
- Cost avoidance total is greater than the amount invested in this technology/capability.
- Image the value provided when used across the entire vehicle!

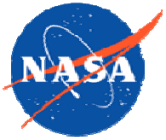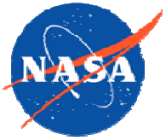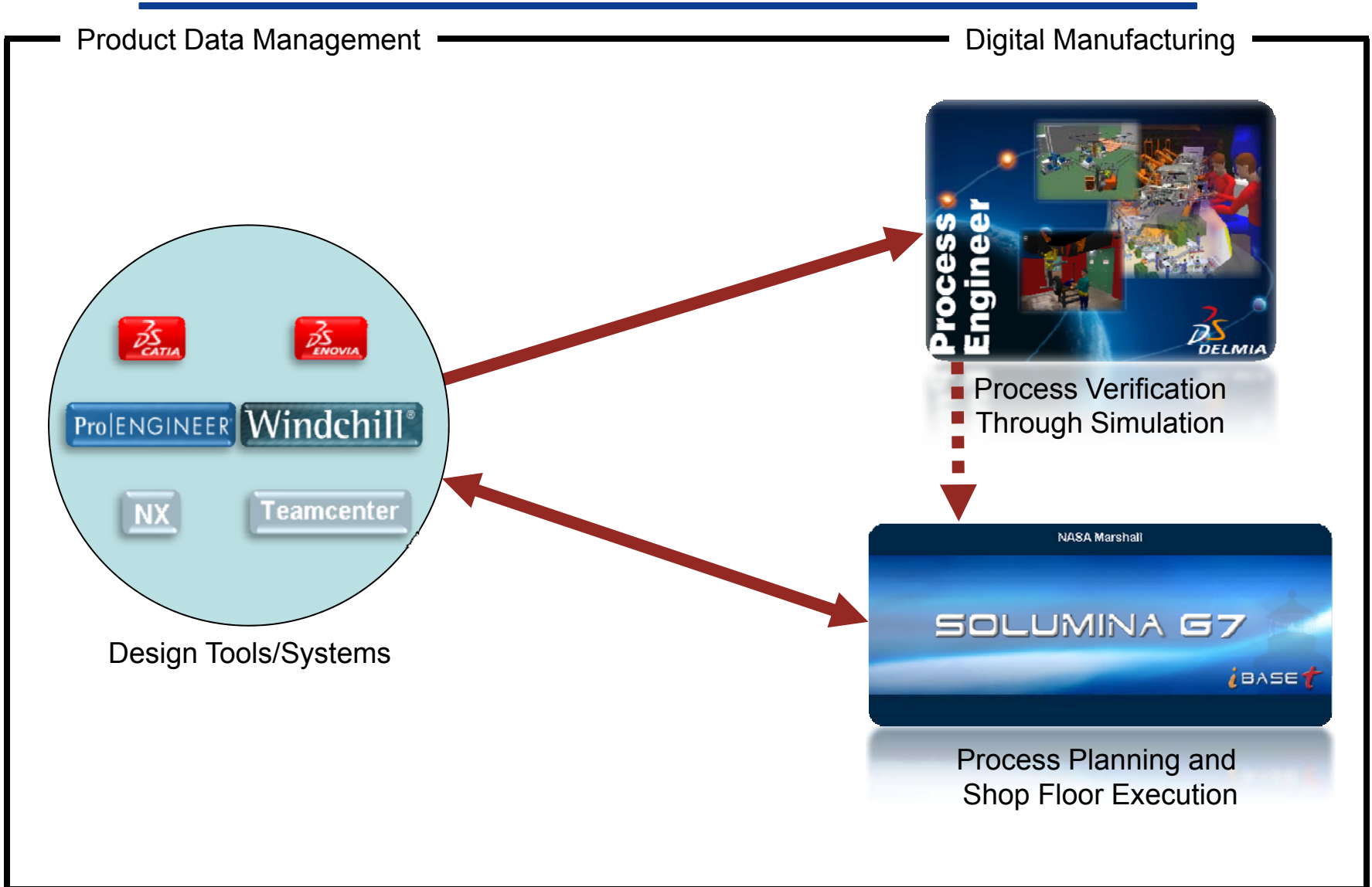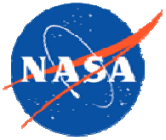| Problem Found	Result / Impact
Robotic Weld Tool (RWT) Spindle / CB Y-Ring Interference M5 Pull Plug (Ares Manufacturing Development) / Common Bulkhead Fwd Dome Interference	Common Bulkhead Y-Ring Resized; Major impact to Critical Path if not found.
Verval Tool (Tooling for Upper Stage Friction Stir Welding) - Kinematic Limitations	Tool Redesigned; Caught early, otherwise a 3 month critical path impact.
RWT Hydraulic Hose / Fixture Interference	Hoses Rerouted on Weld Head
Pull Plug Internal Spider Assembly (Upper Stage Manufacturing Development) - Kinematic and Interference Problems	Design Changes
Common Bulkhead Tooling / Despatch Oven Floor Interference	Change in Allowable Dimensions in the Boeing Tooling RFP
J2X / Thrust Cone Mate to LOX Tank	Interference between Thrust Cone and LOX Feedline. Problem still being worked.
Common Bulkhead Manufacturing Development Article (CBMDA) Forward Dome / Clamp Support Beam Interference	Fixture Modified

Backup Charts

Backup

Digital Manufacturing
Architecture

Product Data Management — Digital Manufacturing

Process Verification
Through Simulation

Design Tools/Systems

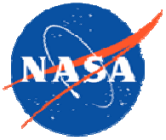Process Planning and
Shop Floor Execution

Digital Manufacturing
Summary of Capabilities

◆ **Process Planning and Shop Floor Execution (Solumina Software)**

- Process Planning
  - Full configuration control of process plans
  - Routing and approval of plans before they can be released to the shop floor
  - eBOM to mBOM planning and reconciliation (Did we account for all parts during planning?)
  - Allows planners to include rich instruction content such as CAD models, drawings, movies, documents, etc.
  - Effectivity assigned to plans (serial, lot, and date effectivity types)
  - Inclusion of model-based instructions (MBIs)

- Process Execution
  - Enforces that work is performed in the order / sequence defined by planning
  - Captures as-built data generated on the shop floor
  - Captures the serial number or lot number of all parts consumed into an assembly
  - Allows for redlining of plans on the floor
  - Provides method of superceding a work order with a later revision of a process plan
  - Electronic buyoffs from technicians from engineers

- Process Quality
  - Discrepancy initiation, MRB reviews, corrective actions, etc.
  - Allows for liens to be placed on parts
  - Electronic quality buyoffs
  - Captures quality information from parts vendors

Digital Manufacturing
Summary of Capabilities

♦ **Process Verification Through Simulation (DELMIA Software)**
- Verification of Facilities
  – Identification of process flow and assembly problems due to facilities limitations
- Interference Analysis
  – Gain understanding of all the interactions between tooling, fixtures, GSE, etc.
  – Simulate assembly processes and identify problems (interferences, violation of keep out zones, pinch points, etc.)
- Kinematic Verification
  – Definition of complex kinematic mechanisms, up to 9 degrees of freedom
  – Determine through process simulations whether planned operations are kinematically feasible
- Off-line Robotic Programming
  – Optimization of robotic systems in an offline, 3D environment
  – Deliver programs to the manufacturing floor for execution