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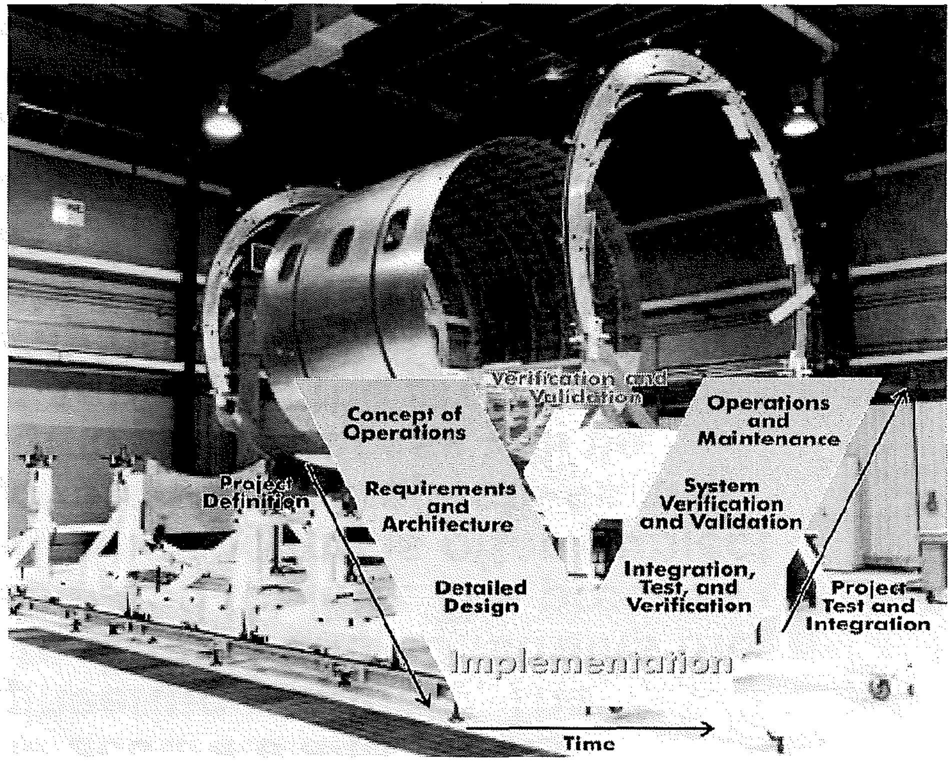
Systems Engineering Integrative Project
"A Systems Engineering Approach to Complex Tool Realization"



Jude Zils

December 4, 2009

Abstract

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- Tooling exists to assist in the accurate and precise performance of work on engineering products. The engineering product therefore defines and constrains the form and function of the associated tooling. The process of defining, fabricating, and verifying tooling is often subject to individual, business, or government perspectives and processes. The Systems Engineering process will be beneficial when adapted and applied to the process of defining, fabricating, and verifying tooling. The methodical processes and tools associated with Systems Engineering will embed the tooling process in the product requirement and design process and encourage increased interaction and concurrent engineering practices. A tooling process, based on System Engineering principles combined with best industry practices, that is ingrained in the product life cycle and which thoroughly documents associated technical and producibility requirements will reduce issues currently prevalent in complex tooling realization.

Problem Statement

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- Current tooling processes in industry are applied late in the product life cycle, loosely organized, insufficiently documented, and lack appropriate traceability for reference and future use or modification. This results in a loss of value to individual project stakeholders such as the customer, project management, the IPT, and the tooling fabrication team. The loss of project stakeholder value manifests itself in schedule delays, cost overruns, redesign, rework, underutilized tooling, excessive tooling, damaged product, and a lack of tooling producibility. The solution is a clearly defined tooling process based on established system engineering tools, project management tools, and best industry practices which encompasses the product life cycle from inception to verification. The tooling process must take into account the complexity, intended use, and size of the tooling as to not exceed the appropriate cost to benefit trade. The tooling process should be incorporated early in the project increasing the up front investment in documentation and engineering while reducing risk and avoiding future costs.

Project Approach

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- The author of this project paper is a Manufacturing Engineer at a major Aerospace company and a graduate student in Systems Engineering at Loyola Marymount University, L.A. This project paper is formulated as an application of Systems Engineering knowledge learned by the author in the graduate program to the tooling process issues experienced by the author in industry. Therefore a primary source for issues within the tooling process and the application of Systems Engineering principles are taken from the authors own experience. This paper will also utilize the knowledge and experience of other engineering disciplines and management close to the tooling process by means of personal interviews. Where applicable, literature related to tooling processes, lean methods, and System Engineering processes will be utilized. Included in reference literature will be government and industry standards for typical System Engineering tools; sources will include the DoD and INCOSE. The author will also utilize frequent interaction and review of materials with the project papers advisor, Dr. Galloway. The resulting mix of personnel, literary, industry, and government resources will aid in establishing the best solution in applying Systems Engineering principles and best industry practices to the tooling process.

Project Organization & Management

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- Complex tooling efforts, much like major projects, require effective management, planning, and organization.
- A project which commits early product development funding of management, organization, and planning for production and tooling efforts will see appreciable reduction of risk to late term schedules and cost. They will also realize a synergy within the Integrated Product Team which will smooth the transitions from product concept, to design, and production.

Project Organization & Management

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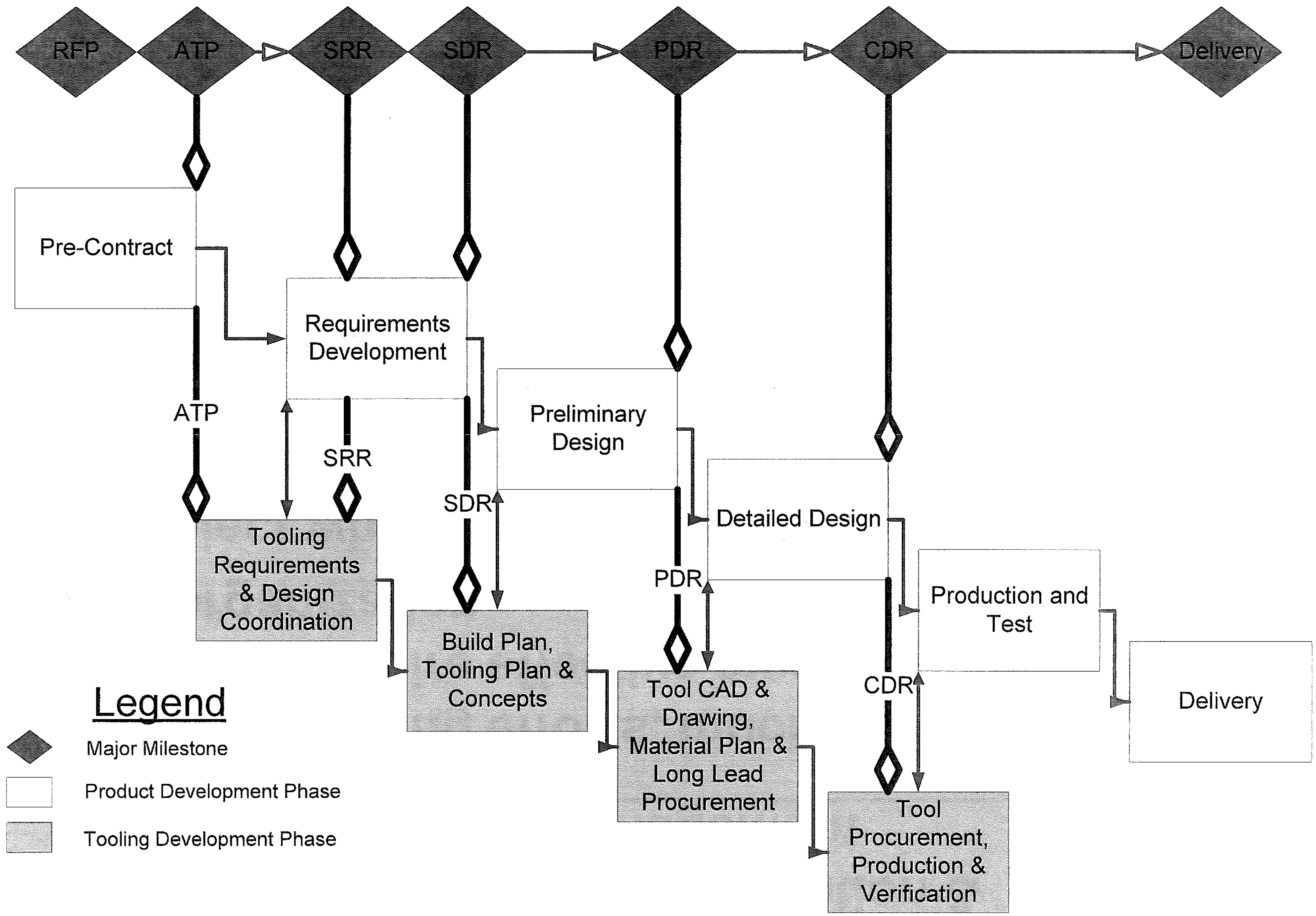
System & Tooling Development Timeline



Project Organization & Management

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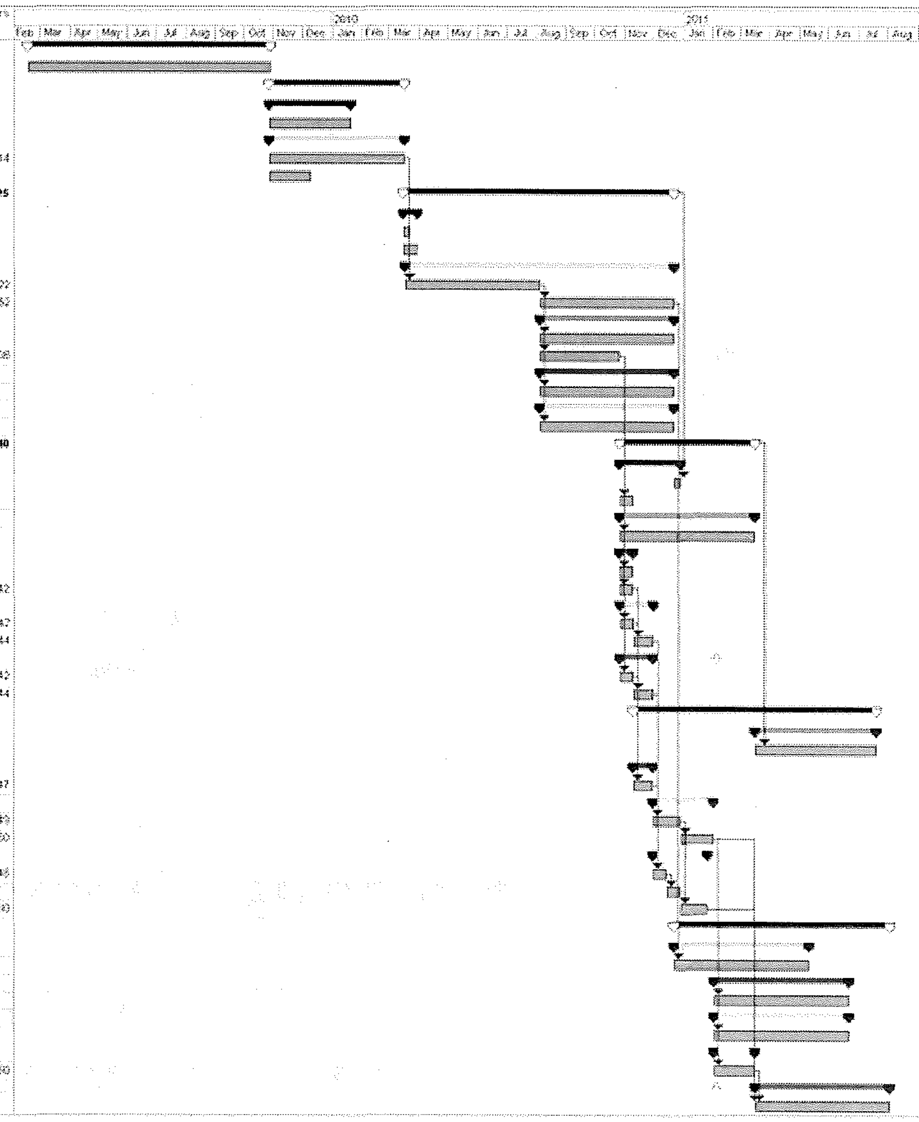
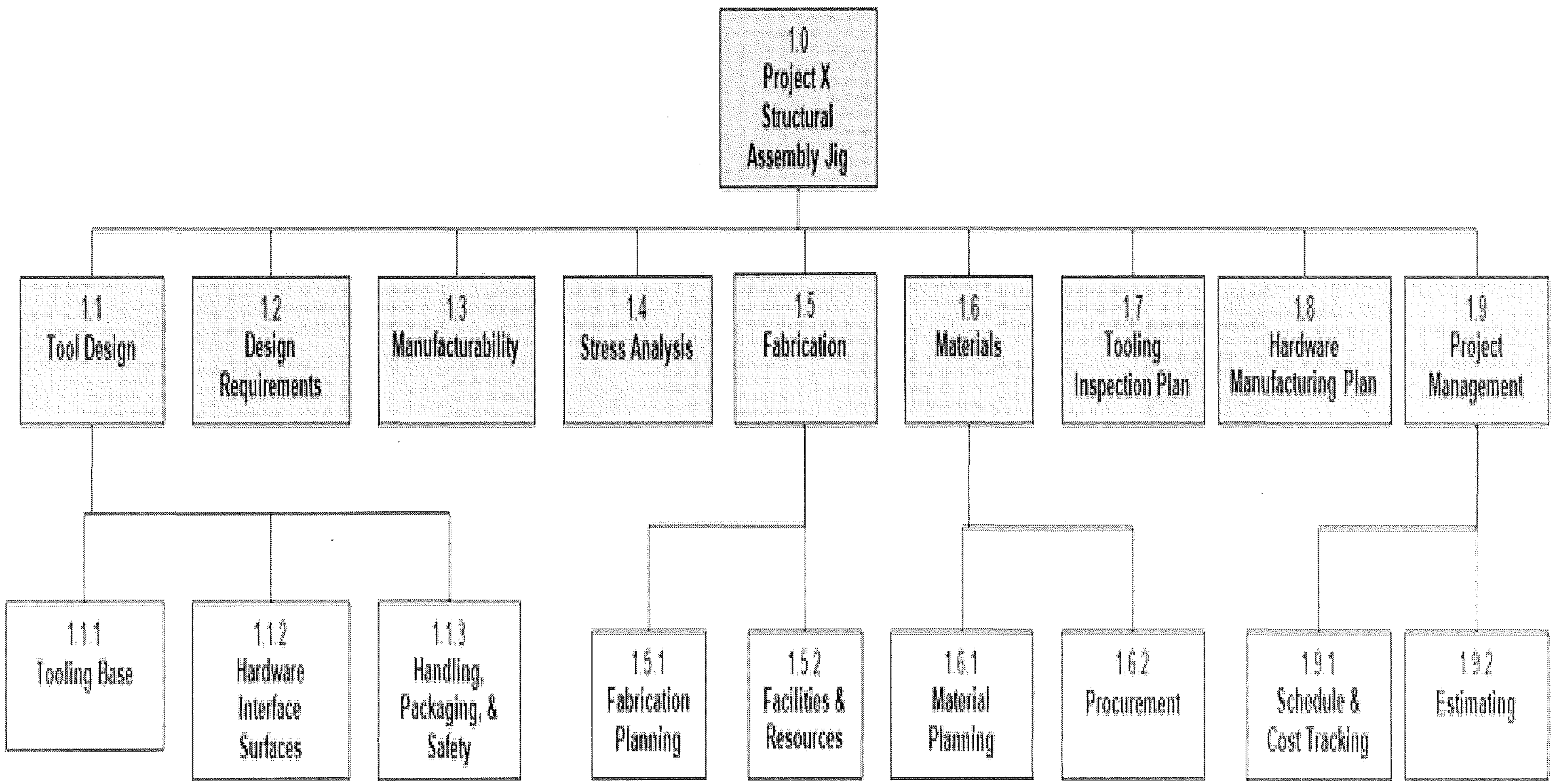
Integrated Scheduling

ID	Task Name	Duration	Start	Finish	Predecessors	Successors
1	**Authority to Proceed (ATP)**	183 days	Mon 2/16/09	Wed 10/28/09		
2	Business Development & Mission Engineering	183 days	Mon 2/16/09	Wed 10/28/09		
3	**Systems Requirements Review (SRR)**	100 days	Wed 10/28/09	Tue 3/16/10		
4	**Project Management**	60 days	Wed 10/28/09	Tue 1/19/10		
5	Schedule Definition	60 days	Wed 10/28/09	Tue 1/19/10		
6	**System Engineering**	100 days	Wed 10/28/09	Tue 3/16/10		
7	Requirements Definition	100 days	Wed 10/28/09	Tue 3/16/10		14
8	CONOPS	30 days	Wed 10/28/09	Tue 12/8/09		
9	**System Design Reviews (SDR)**	201 days	Tue 3/16/10	Tue 12/21/10		25
10	**Project Management**	10 days	Tue 3/16/10	Mon 3/29/10		
11	Core Production Team Formation	5 days	Tue 3/16/10	Mon 3/22/10		
12	Material & Labor Estimating	10 days	Tue 3/16/10	Mon 3/29/10		
13	**System Engineering**	200 days	Wed 3/17/10	Tue 12/21/10		
14	Requirements Allocation	100 days	Wed 3/17/10	Tue 8/3/10	7	17,18,20,22
15	Design Synthesis	100 days	Wed 8/4/10	Tue 12/21/10	14	52
16	**Design Engineering**	100 days	Wed 8/4/10	Tue 12/21/10		
17	Design Synthesis	100 days	Wed 8/4/10	Tue 12/21/10	14	
18	Conceptual Design	60 days	Wed 8/4/10	Tue 10/26/10	14	28,31,33,36
19	**Production Engineer**	100 days	Wed 8/4/10	Tue 12/21/10		
20	Tooling Requirements & Design Coordination	100 days	Wed 8/4/10	Tue 12/21/10	14	
21	**Tool Design**	100 days	Wed 8/4/10	Tue 12/21/10		
22	Tooling Requirements & Design Coordination	100 days	Wed 8/4/10	Tue 12/21/10	14	
23	**Preliminary Design Review (PDR)**	100 days	Wed 10/27/10	Tue 3/15/11		40
24	**Project Management**	45 days	Wed 10/27/10	Tue 12/28/10		
25	Production Support Team Formation	5 days	Wed 12/22/10	Tue 12/28/10	9	
26	Material & Labor Estimating	10 days	Wed 10/27/10	Tue 11/9/10	18	
27	**Design Engineering**	100 days	Wed 10/27/10	Tue 3/15/11		
28	Detail Design	100 days	Wed 10/27/10	Tue 3/15/11	18	
29	**Production Engineer**	10 days	Wed 10/27/10	Tue 11/9/10		
30	Manufacturing Plan & Flow	10 days	Wed 10/27/10	Tue 11/9/10	18	
31	Tooling Plan	10 days	Wed 10/27/10	Tue 11/9/10	18	34,37,42
32	**Tool Design**	25 days	Wed 10/27/10	Tue 11/30/10		
33	Tooling Plan	10 days	Wed 10/27/10	Tue 11/9/10	18	34,37,42
34	Concept Tooling	15 days	Wed 11/10/10	Tue 11/30/10	31,33	44
35	**Production**	25 days	Wed 10/27/10	Tue 11/30/10		
36	Tooling Plan	10 days	Wed 10/27/10	Tue 11/9/10	18	42
37	Concept Tooling	15 days	Wed 11/10/10	Tue 11/30/10	31,33	44
38	**Critical Design Review (CDR)**	180 days	Wed 11/10/10	Tue 7/19/11		
39	**Design Engineering**	90 days	Wed 3/16/11	Tue 7/19/11		
40	Drawing Release	90 days	Wed 3/16/11	Tue 7/19/11	23	
41	**Production Engineer**	15 days	Wed 11/10/10	Tue 11/30/10		
42	Material & Labor Estimating	15 days	Wed 11/10/10	Tue 11/30/10	31,33,36	47
43	**Tool Design**	45 days	Wed 12/1/10	Tue 2/1/11		
44	CAD Model	20 days	Wed 12/1/10	Tue 12/28/10	34,37	45,49
45	Tooling Drawing	25 days	Wed 12/29/10	Tue 2/1/11	44	54,56,58,60
46	**Material**	40 days	Wed 12/1/10	Tue 1/25/11		
47	Material Planning	10 days	Wed 12/1/10	Tue 12/14/10	42	48
48	Material Estimating	10 days	Wed 12/15/10	Tue 12/28/10	47	
49	Long Lead Procurement	20 days	Wed 12/29/10	Tue 1/25/11	44	60
50	**Tool Production, Test, & Delivery**	160 days	Wed 12/22/10	Tue 8/2/11		
51	**System Engineering**	100 days	Wed 12/22/10	Tue 5/10/11		
52	Verification & Validation	100 days	Wed 12/22/10	Tue 5/10/11	15	
53	**Production Engineer**	100 days	Wed 2/2/11	Tue 6/21/11		
54	Production Support	100 days	Wed 2/2/11	Tue 6/21/11	45	
55	**Tool Design**	100 days	Wed 2/2/11	Tue 6/21/11		
56	Tooling Support & Modification	100 days	Wed 2/2/11	Tue 6/21/11	45	
57	**Material**	30 days	Wed 2/2/11	Tue 3/15/11		
58	Procurement	30 days	Wed 2/2/11	Tue 3/15/11	45	60
59	**Production**	100 days	Wed 3/16/11	Tue 8/2/11		
60	Tool Production	100 days	Wed 3/16/11	Tue 8/2/11	45,49,58	



Project Organization & Management

Work Breakdown Structure



Project Organization & Management

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Work Breakdown Structure

Work ID	Work Name	Description	Include (Completion Criteria)	Customer	Asset Type	Complexity	Estimated Effort	Skill Required	Dependency	Hand Off To	Storage/Location
1.0	Project X Structural Assembly Jig	Jig to Assemble Main Structure	Complete Fabrication & Inspection	Project X	Project Specific Tooling	High	5000 Hrs	N/A	Project Schedule	Mechanical Production	
1.1	Tool Design	CAD Model & Drawing	Completed Drawing	Proj. Mgt.	N/A	High	1000 Hrs	CAD	Requriements	Procurement & Mfg.	Main Server
1.2	Design Requriements	System & Hardware Requirements	RequirementS preadsheet	Tool Design	N/A	High	200 Hrs	Design	System Design	Mfg. & Tool Design	Main Server
1.6	Materials	Build Materials	BOM	Mfg.	Material	Moderate	750 Hrs	Material	Tool Concept	Mfg.	Stores
1.6.1	Material Planning	Material Planning	BOM	Mfg.	N/A	Moderate	250 Hrs	Planning	Tool Concept	Proj. Mgt.	Main Server
1.6.2	Procurement	Material & Labor Procurement	Material Delivery	Proj. Mgt. & Mfg.	N/A	Low	500 Hrs	Procuremen t	BOM	Mfg. & Proj. Mgt.	N/A
1.9	Project Management	Project Management	Complete Fabrication	Project X	N/A	Moderate	500 Hrs	Proj. Mgt.	Project Kickoff	Project X	N/A
1.9.1	Cost & Schedule Tracking	Cost & Schedule Tracking	Complete Fabrication	Proj. Mgt. & Project X	N/A	Moderate	300 Hrs	Proj. Mgt.	Project Kickoff	Project X	Main Server
1.9.2	Estimating	Material & Labor Estimating	Production	Proj. Mgt. & Project X	N/A	Moderate	200 Hrs	Proj. Mgt.	Project Kickoff	Project X	Main Server

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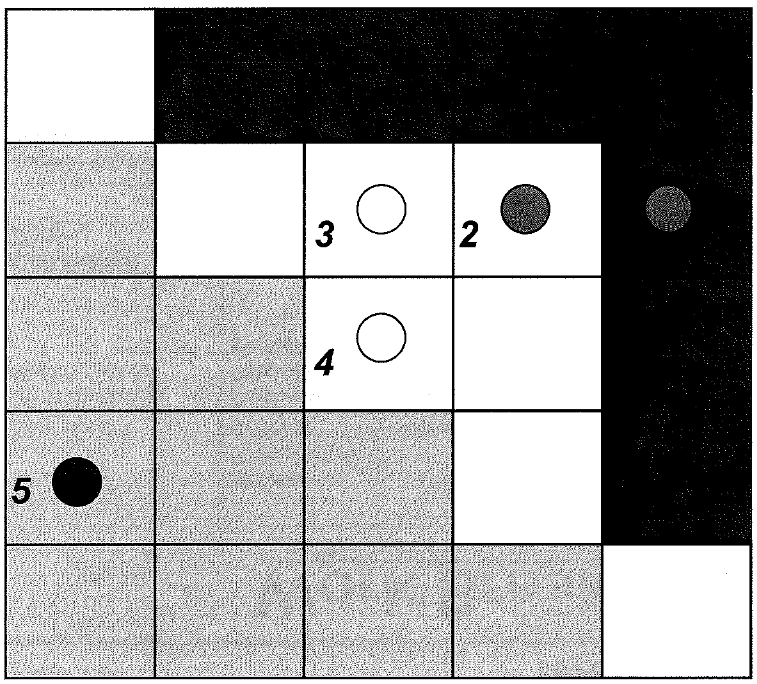
Project Organization & Management

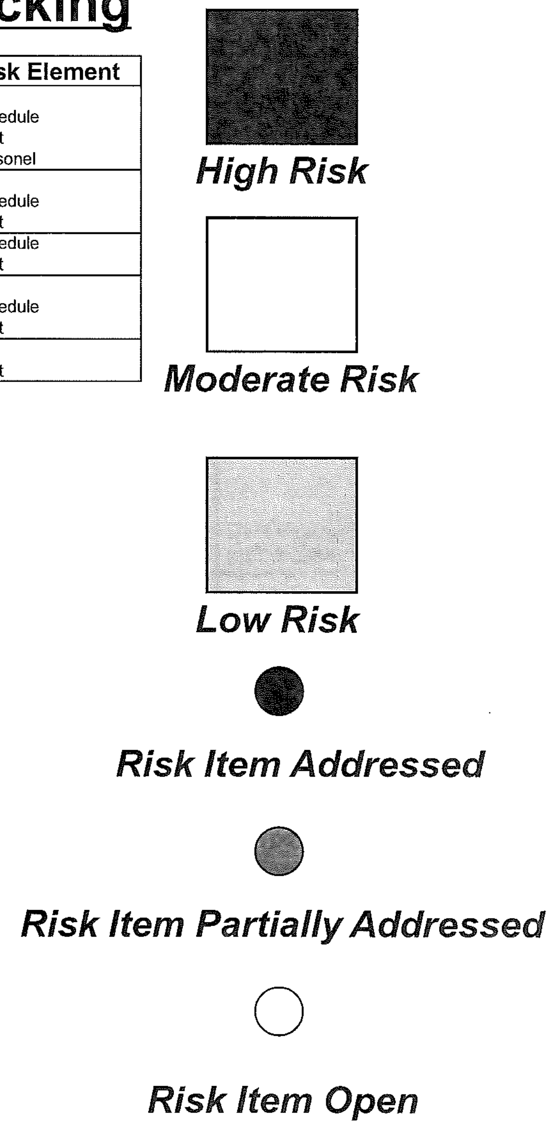
Risk Identification, Management, Planning, & Tracking

Risk ID	Description	Milestone	Risk Level	Action	Risk Element
1	Phase Funding Restrictions	System Requirements Review (SRR) System Definition Review (SDR) Preliminary Design Review (PDR) Critical Design Review (CDR)	High	Request Increased Funding Focus on Long Lead Tooling Elements Schedule Alterations to Push Tooling Intesive Products	Schedule Cost Personel
2	Long Lead Procurement Items	Critical Design Review (CDR)	Moderate	Early Procurement Aggressive Procurement Action Increased Procurement Funding	Schedule Cost
3	Product Design Change	Critical Design Review (CDR)	Moderate	Tooling Design Change to match Product Design	Schedule Cost
4	Tooling to Design Requirements Verification	Production Kickoff	Moderate	Early Verification Plan Definition Engagement with Measurements & Quality Group Tool Design to Match Product Design	Schedule Cost
5	System Requirements Change	System Requirements Review (SRR)	Low	Tooling Requirements Change Tooling Plan Alteration	Cost

Likelihood



Consequences



Integrated Product Team Interaction

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- The Systems Engineering discipline uses architectural tools to describe the operational interaction and function of a complex system; these tools can be used in a similar fashion to describe the interaction within an Tooling Project IPT.
- Operational Views as described by the DoDAF can be used to describe more than hardware interactions.
- A select number of Operation Views from the DoDAF have been chosen to describe the IPT interaction, informational exchange, organizational structure, and functional activity.

Integrated Product Team Interaction

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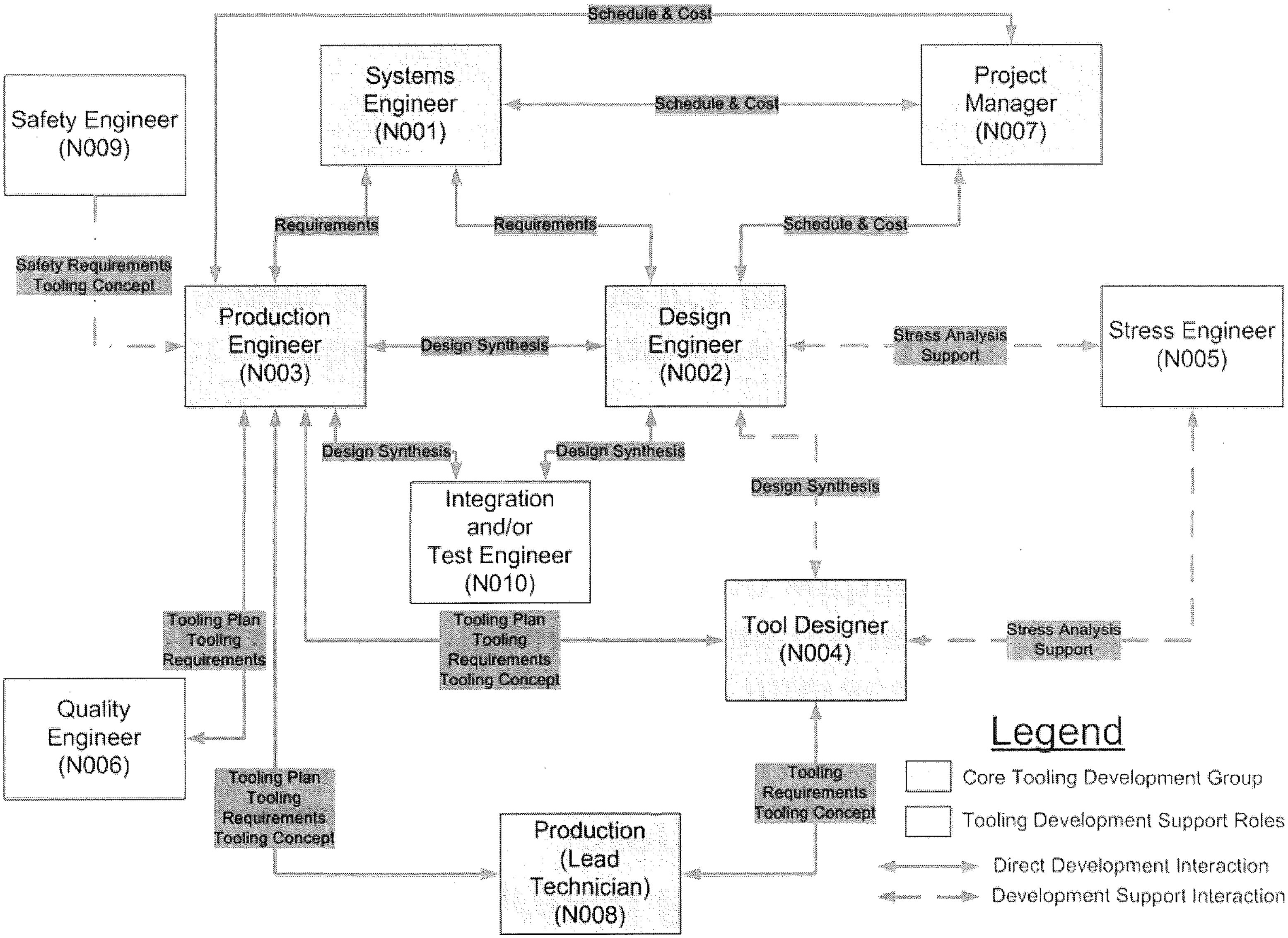
OV-2 Operational Node Connectivity



Integrated Product Team Interaction

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OV-3 Operational Information Exchange Matrix

Information Description	Node	Information Source	Information Destination	Information Exchange Attribute
Schedule	N007	Project Manager	Systems Engineer (N001) Design Engineer (N002) Production Engineer (N003)	Goals, Milestones, and Progress.
Cost	N007	Project Manager	Systems Engineer (N001) Design Engineer (N002) Production Engineer (N003)	Cost Reporting
System Requirements	N001	Systems Engineer	Design Engineer (N002) Production Engineer (N003)	Requirements Allocation & Negotiation
Design Synthesis	N002	Design Engineer	Design Engineer (N002) Production Engineer (N003) Tool Designer (N004) Integration/Test Engineer (N010)	Drawings, Reviews, Producibility, Testability
Tooling Plan	N003	Production Engineer	Tool Designer (N004) Quality Engineer (N006) Production (N008)	Build & Tooling Plan, Need Dates, Long Lead Items
Tooling Requirements	N003	Production Engineer	Tool Designer (N004) Quality Engineer (N006) Production (N008)	Production Requirements, Access, Materials, Envelope
Tooling Concept	N004	Tool Designer	Production Engineer (N003) Production (N008) Safety Engineer (N009)	Tooling Concepts & Feedback
Stress Analysis Support	N005	Stress Engineer	Design Engineer (N002) Production (N008)	Analysis support for flight and non-flight structures, Analysis Proofing of Tooling
Safety Requirements	N009	Safety Engineer	Production Engineer (N003)	Personnel and Hardware Safety Requirements

Integrated Product Team Interaction

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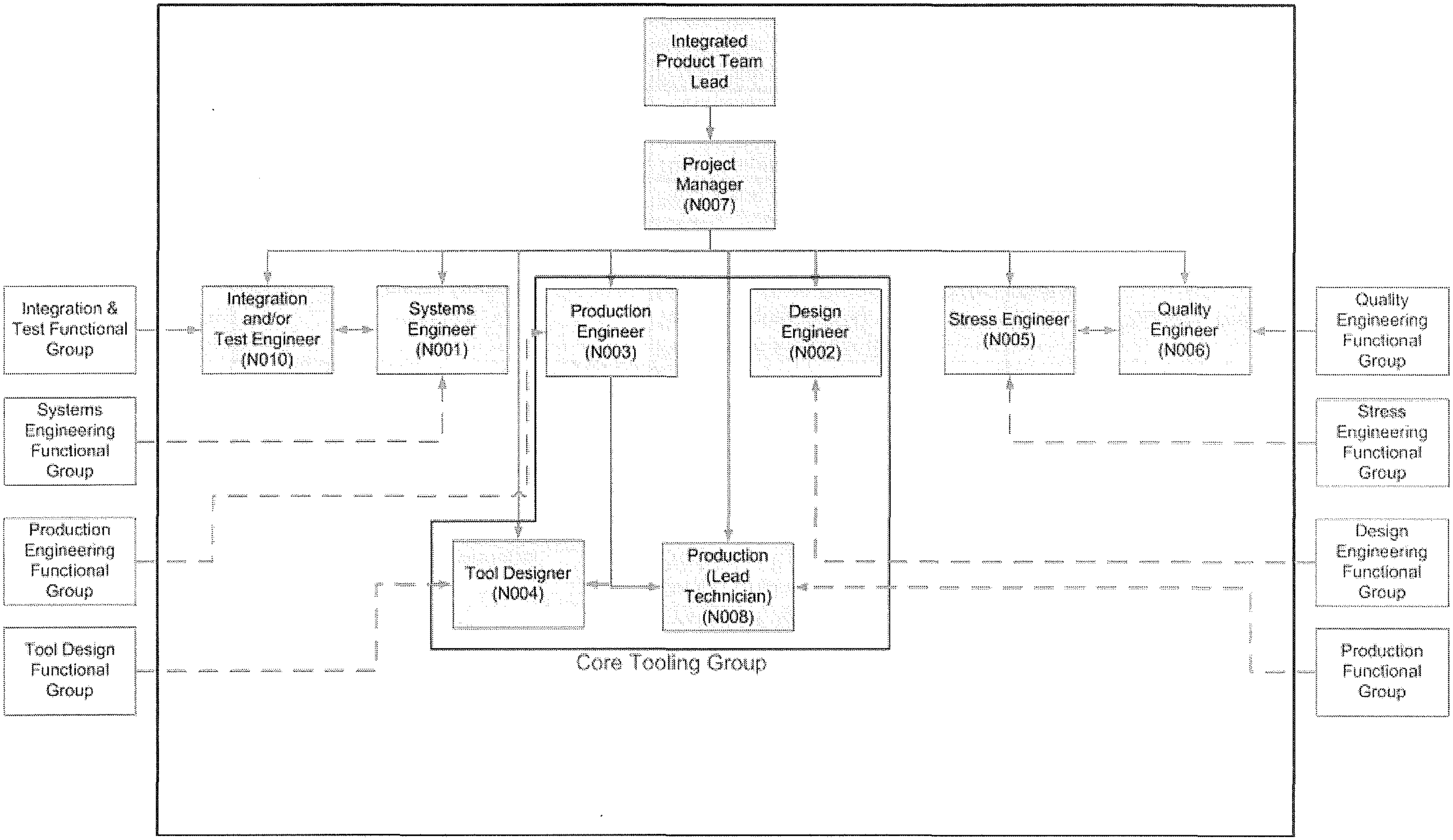
OV-4 Organizational Relationship Chart



Core Project Group

Integrated Product Team Interaction

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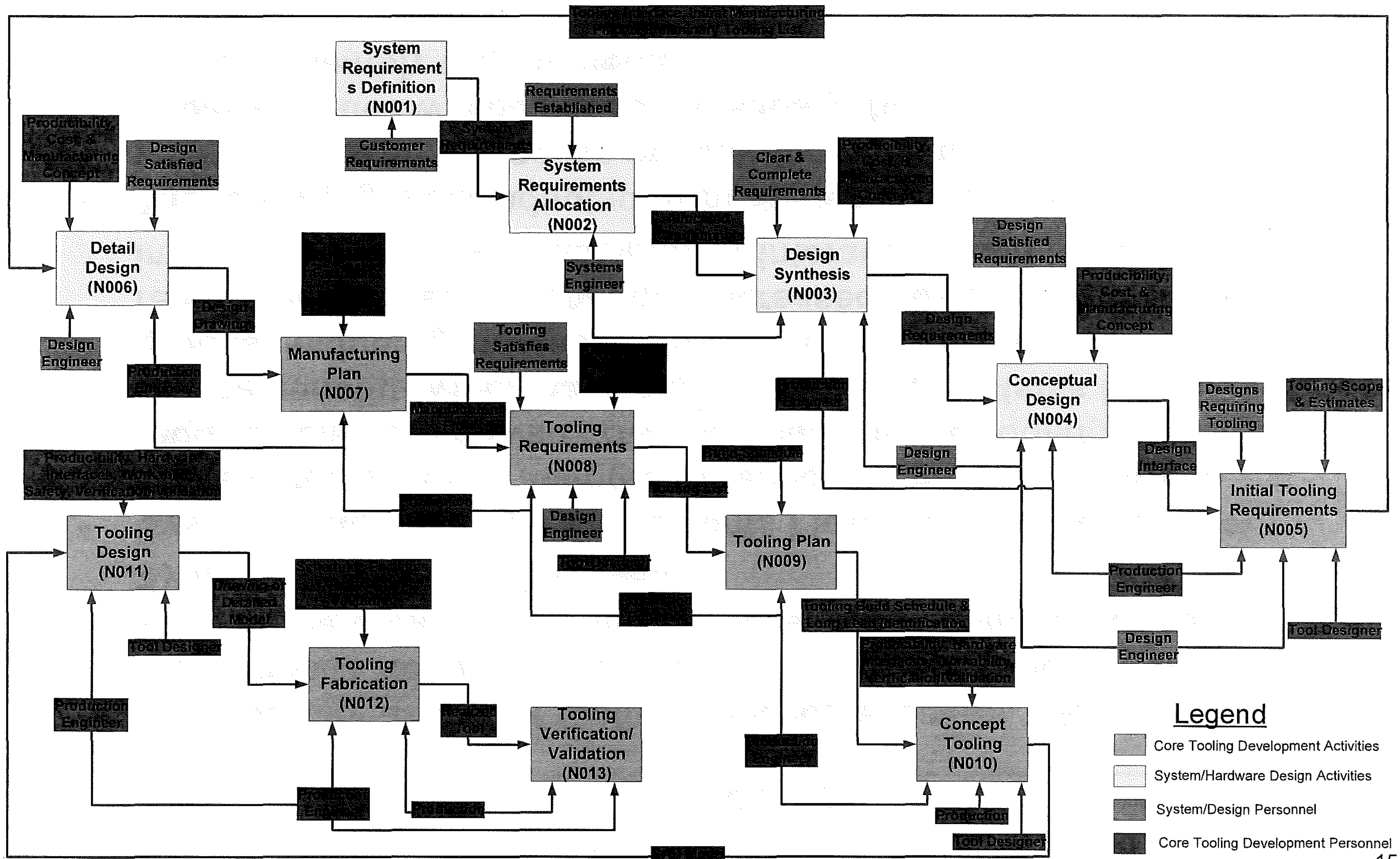
OV-5 Functional Activity Model



Requirements Flowdown & Allocation

- An important aspect of tooling conceptualization, design, and realization is Requirements Flowdown and Allocation. In this manner the tooling realization process is very similar to the Systems Engineering process.
- Systems Engineering Requirements Flowdown and Allocation process tools can be adapted to reflect the process by which requirements are flowed down and allocated to tooling. In doing so the benefits which have been realized by Systems Engineering groups, including increased organization, reduction of requirements creep or change, decreased cost, reduced schedule impact, and increased disciplinary interaction, can be realized.
- The following tools, adapted from Systems Engineering tools, are intended to spur a process of determining what functions and subassemblies will be needed to satisfy the hardware fabrication and/or assembly requirements.

Requirements Flowdown & Allocation

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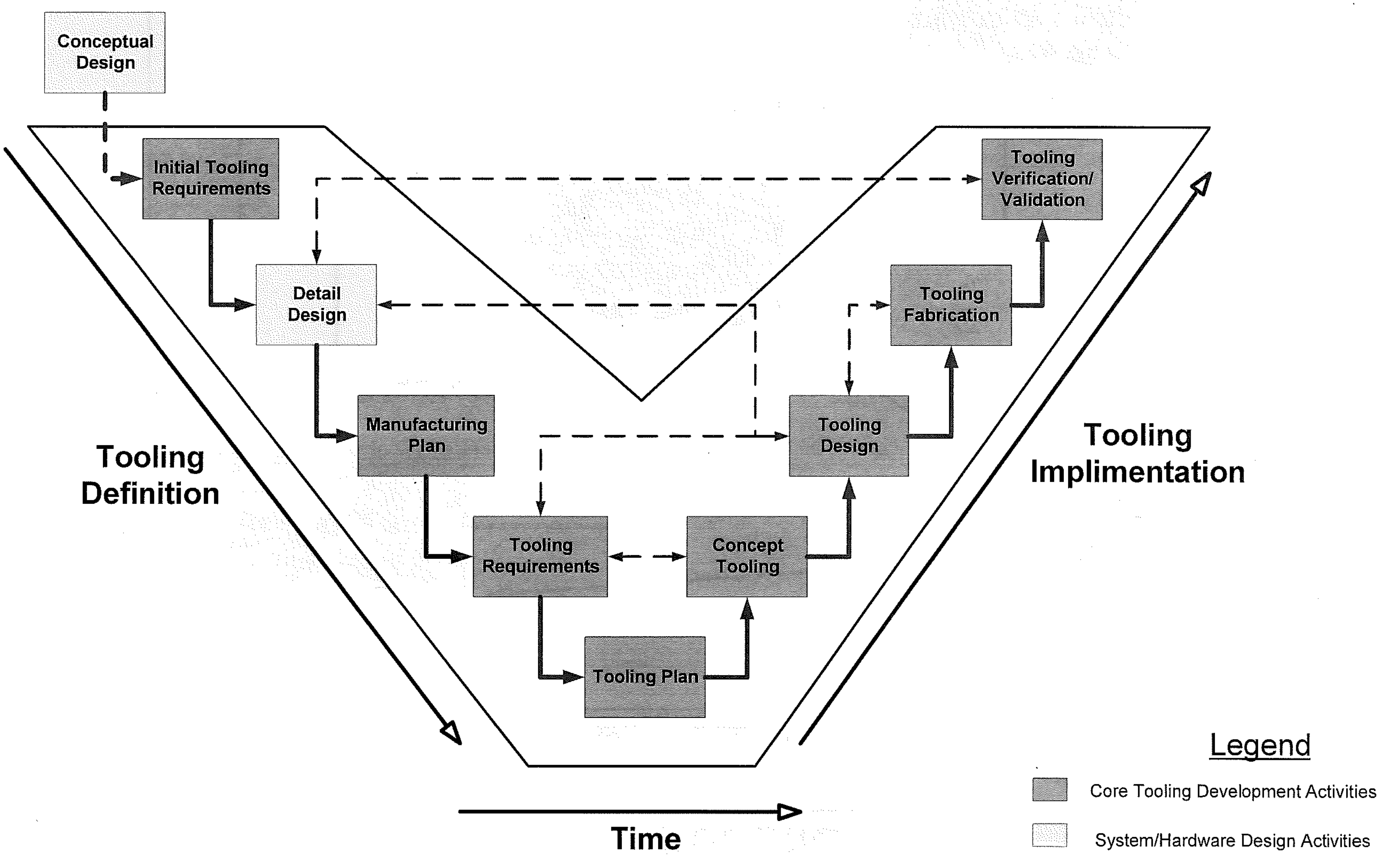
Tooling Development Adapted Vee-Model



Requirements Flowdown & Allocation

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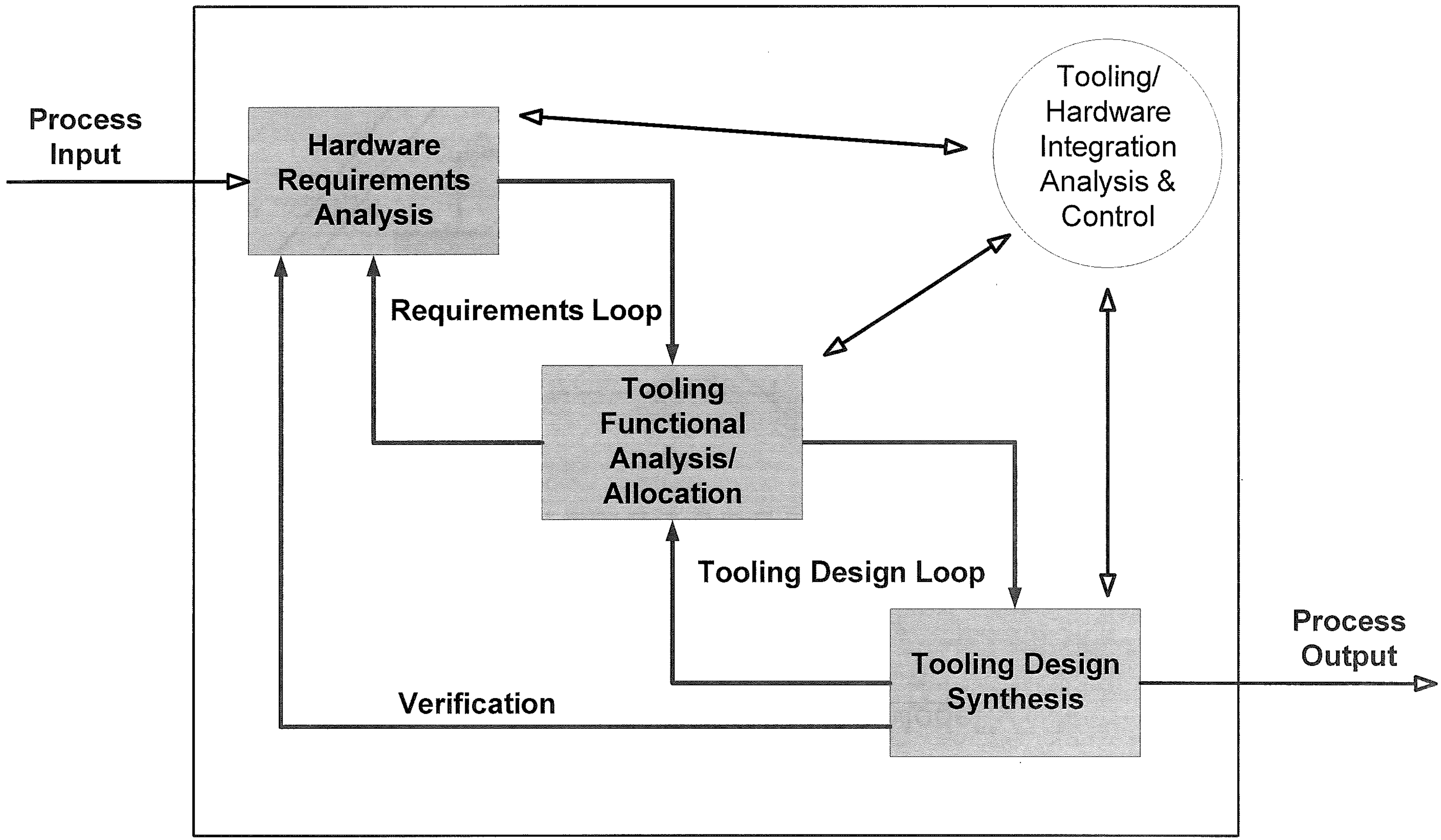
Requirements Development Process



Requirements Flowdown & Allocation

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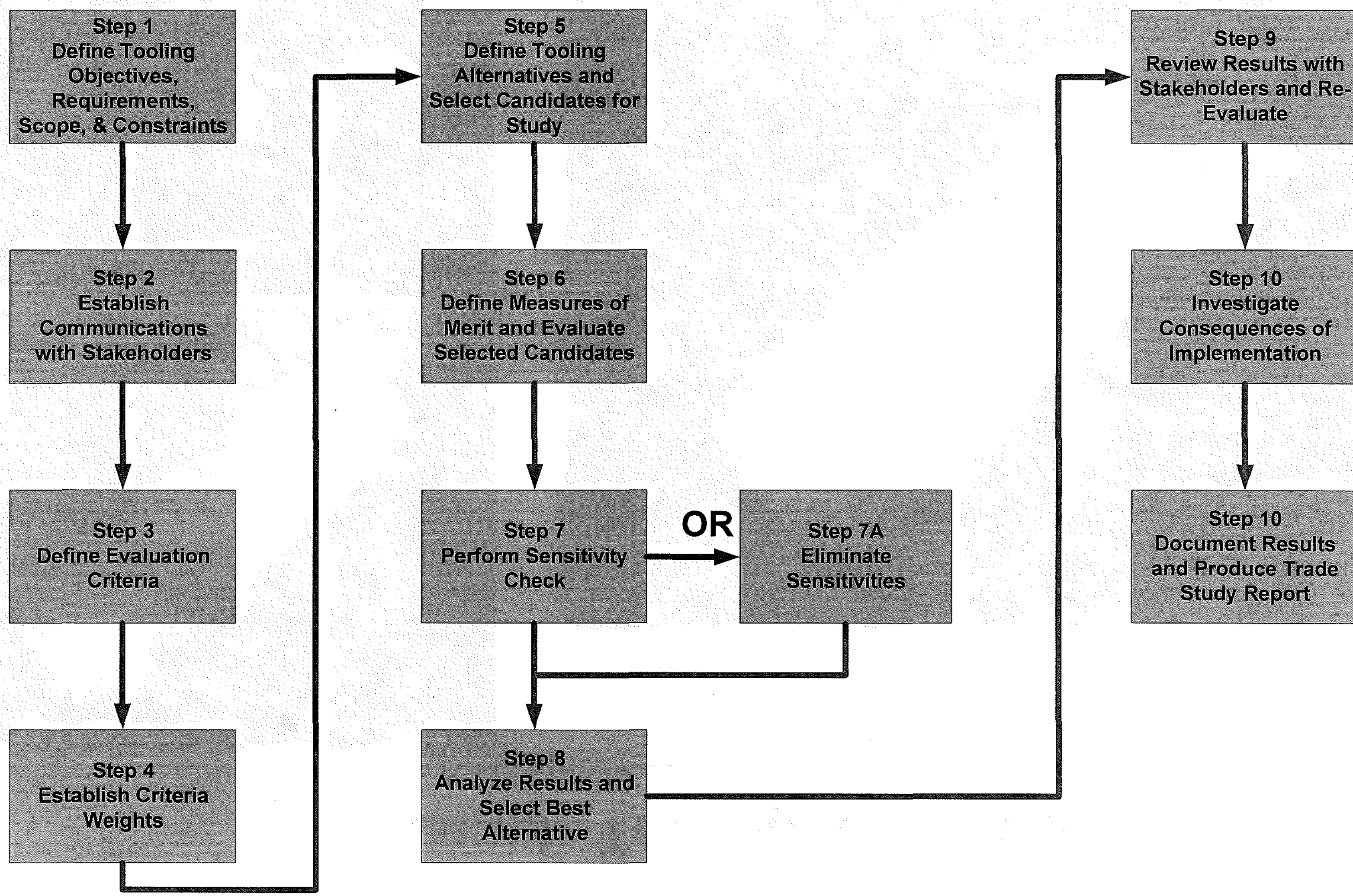
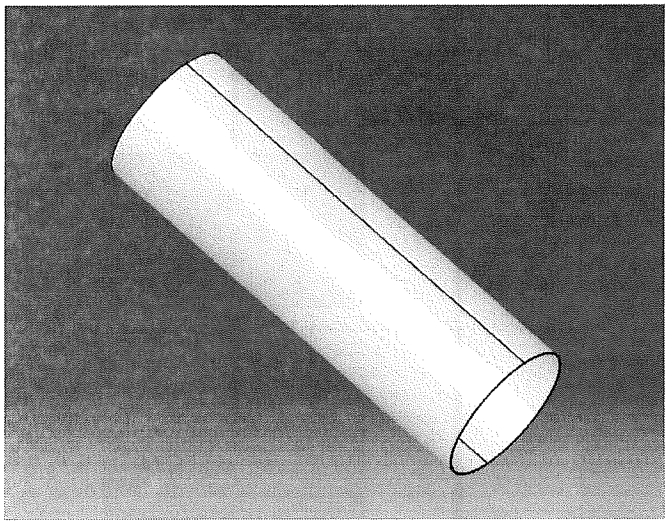
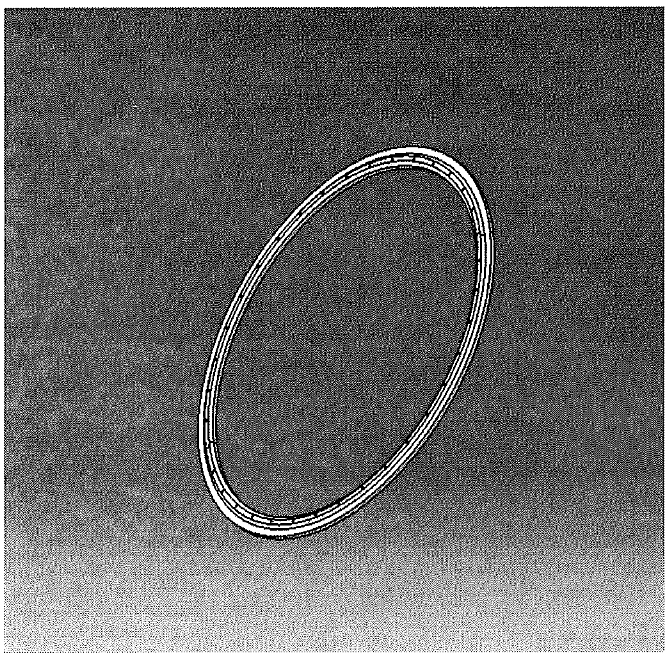
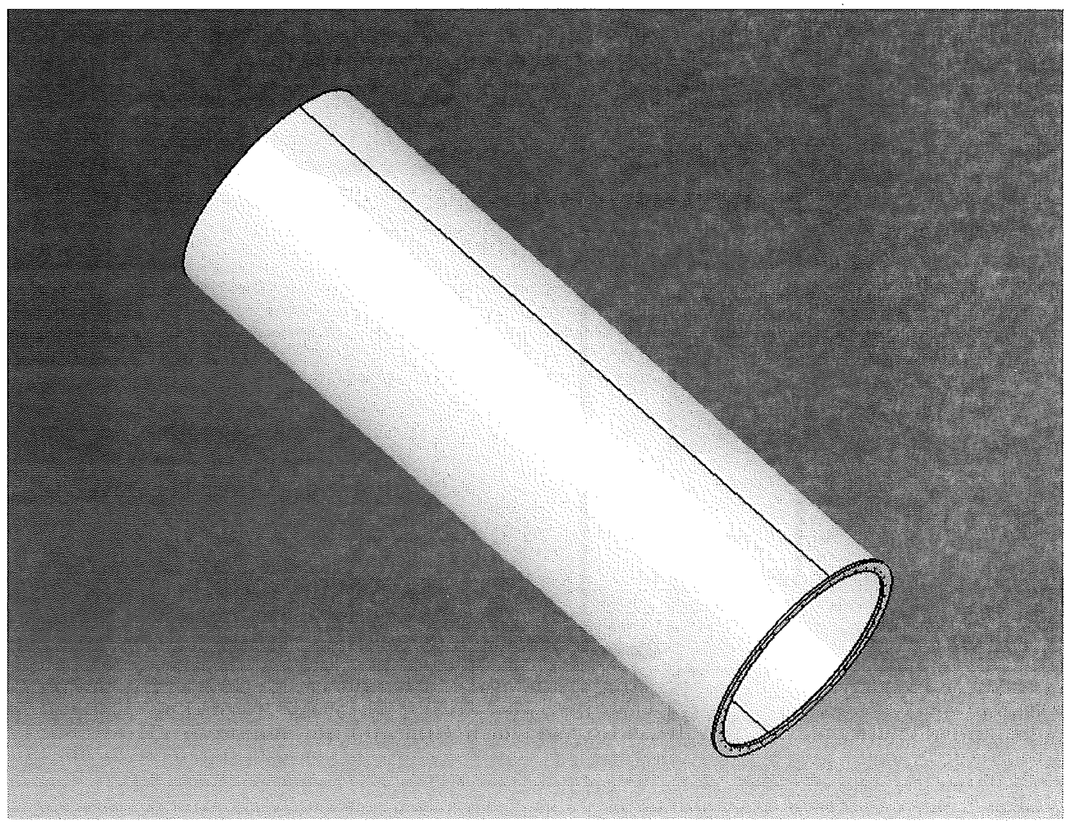
Trade Study



Example Tooling & Hardware







Example Tooling & Hardware

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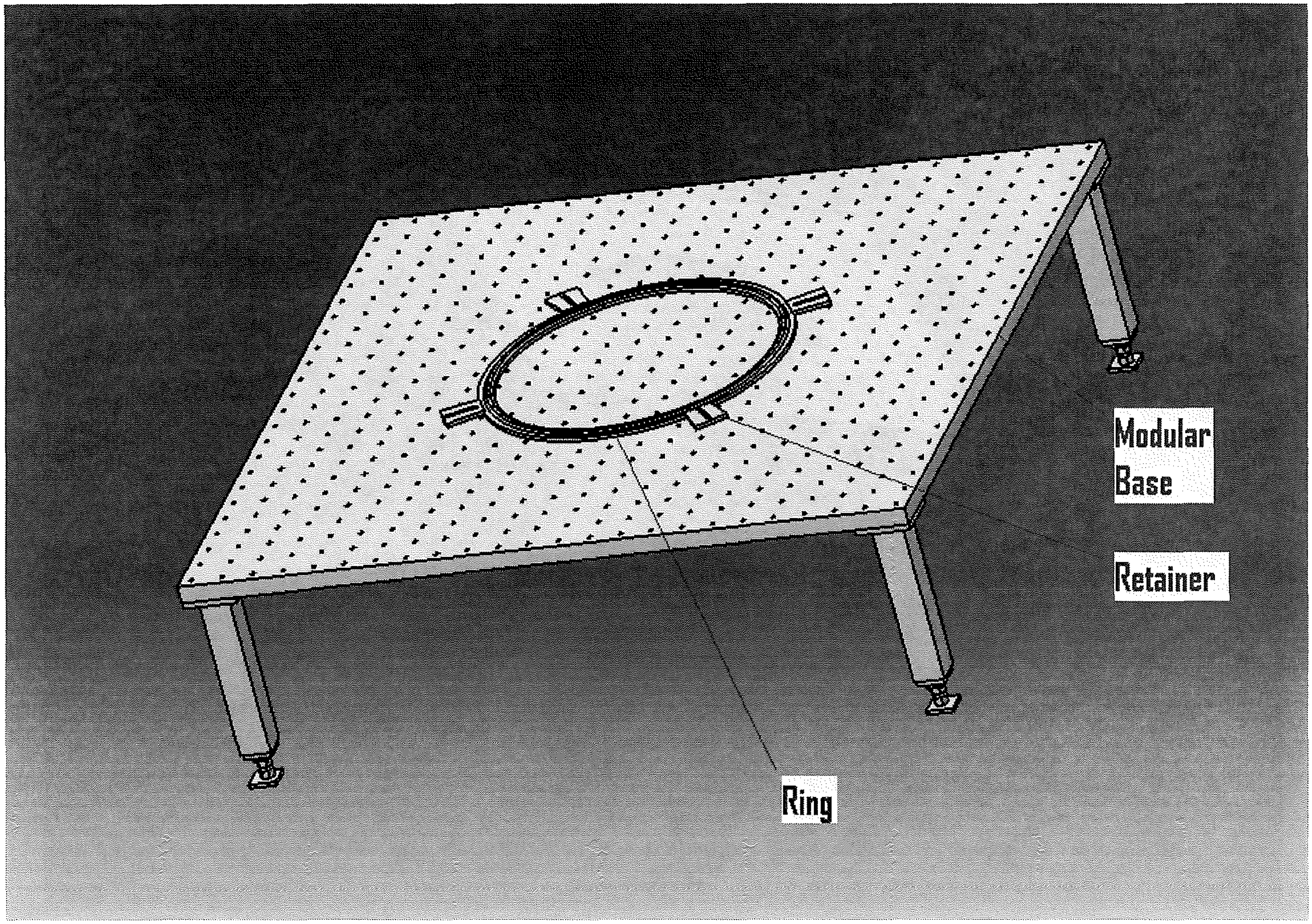
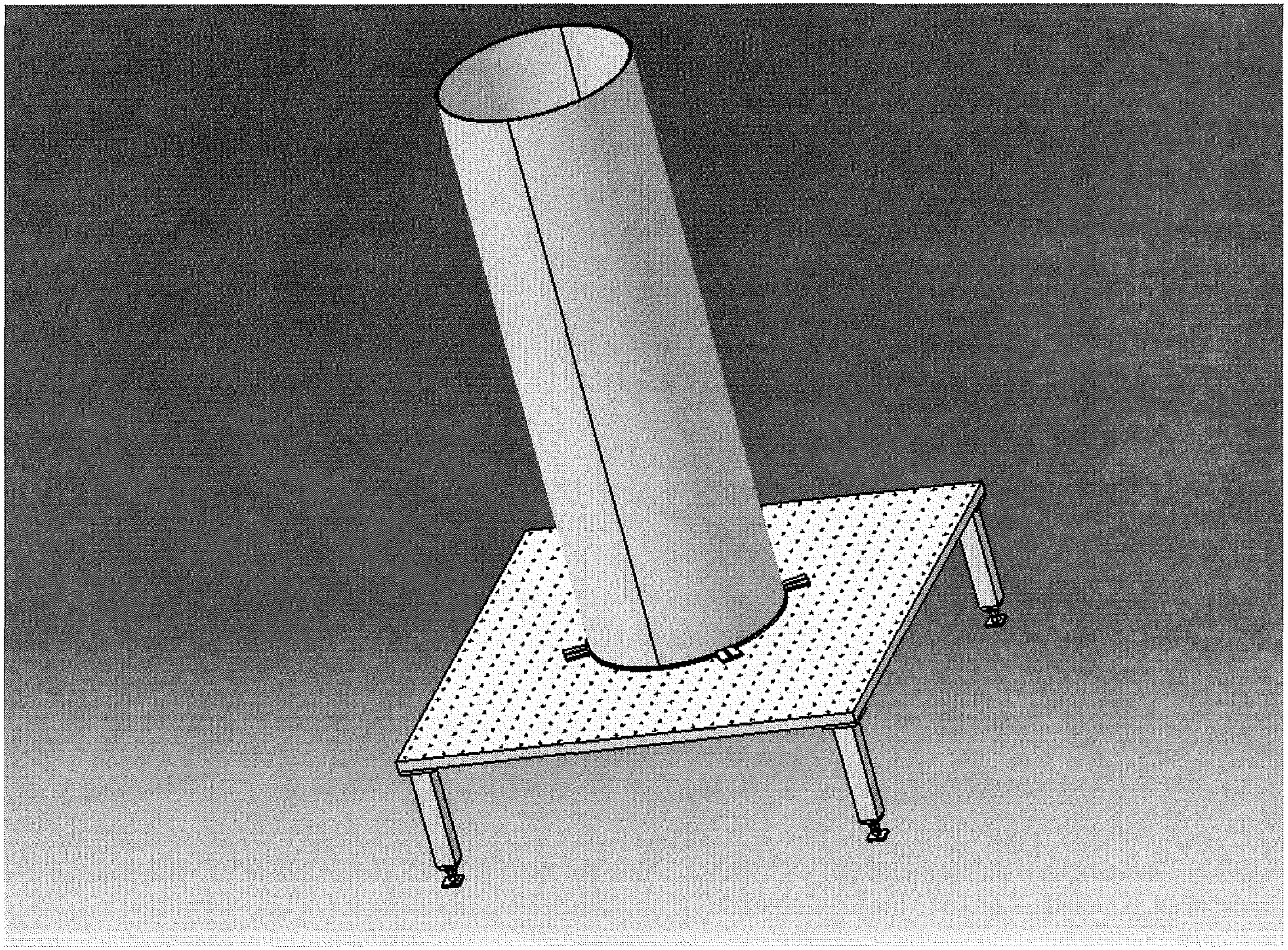


Example Tooling & Hardware



Requirements Flowdown & Allocation

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Functional to Physical Allocation/Synthesis

FUCTIONAL ARCHITECTURE

PHYSICAL ARCHITECTURE

Tube & Ring Bonding Assembly Jig (System)

- Base (SubSystem 1)
- Tube Locators (SubSystem 2)
- Ring Locators (SubSystem 3)
- Retainers (SubSystem 4)

Functions	Base (SubSystem 1)		Tube Locators (SubSystem 2)		Ring Locators (SubSystem 3)		Retainers (SubSystem 4)
Flat/Even Surface	X						
Mount Locations for Additional Tooling	X						
Stable Platform	X						
Locate Ring Hardware					X		
Secure Ring Hardware							X
Locate Tube on Ring for Bonding			X				

Tooling Process Architecture

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- The System Views of the DoDAF can prove useful in describing hardware components and their interaction within a system. While often utilized on electronic hardware communications and infrastructure, the DoDAF the Systems Views can also be adapted to describe a tooling system.
- Complex tooling often consists of a number of sub-assemblies and components. As the tooling is realized the complexity of the assembly can lead to a lack of documentation on the necessity of certain features and their function in addressing the hardware and tooling requirements.
- The following System Views will utilize an example tool and demonstrate how these views can effectively describe a tooling system.

Tooling Process Architecture

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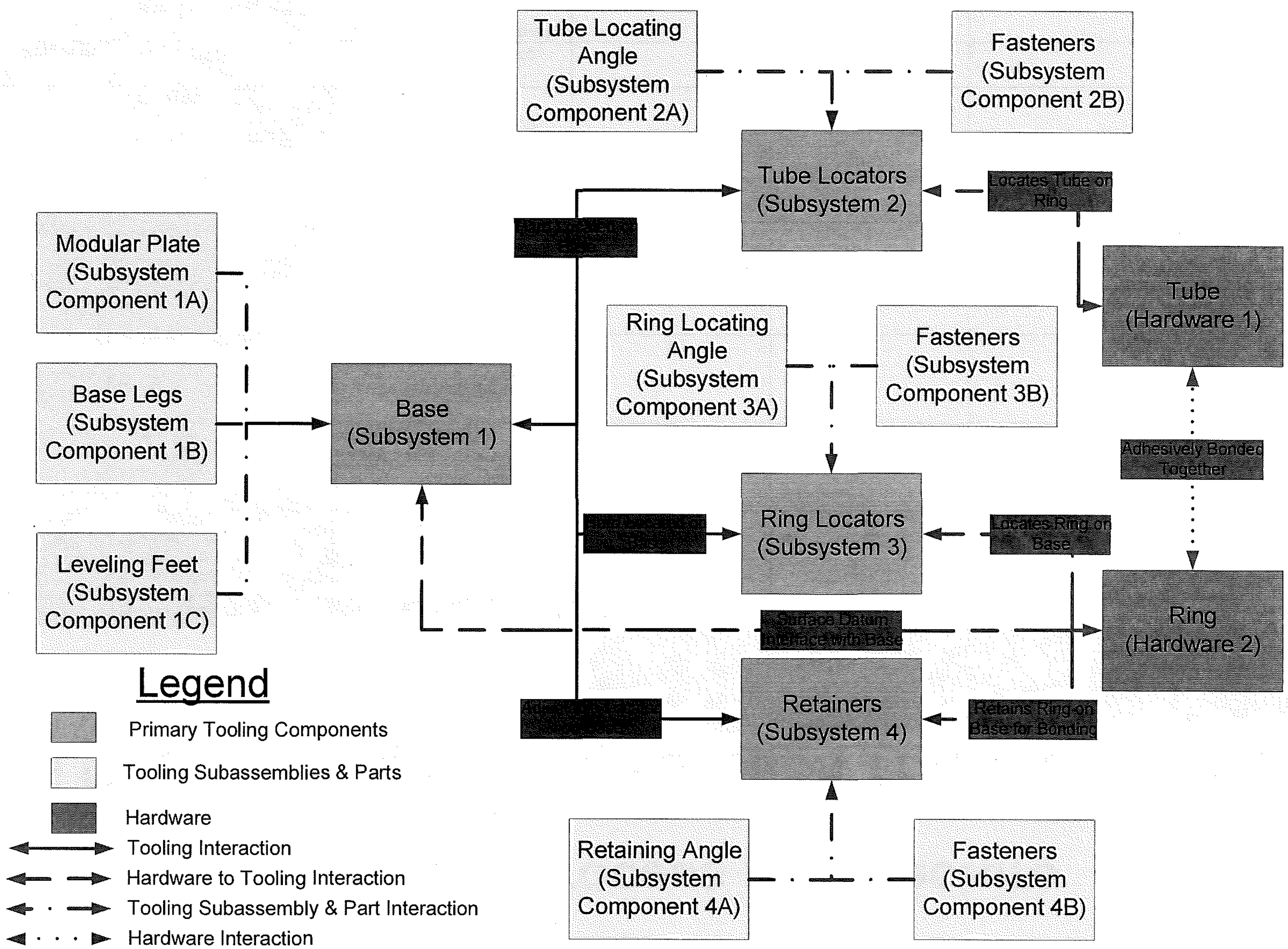
SV-1 System Interface View



Tooling Process Architecture

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SV-5 Operation Activity to Function Traceability Matrix

System	Part Identification	Function	Mount Ring	Locate Ring	Secure Ring	Locate Tube to Ring
Base	**Subsystem 1**	Provide a Stable, Flat/Even Surface which allows for mounting of tooling.	X	X	X	X
Modular Plate	Subsystem Component 1A	Provide a Stable, Flat/Even Surface which allows for mounting of tooling.	x	x	x	x
Base Legs	Subsystem Component 1B	Elevate Working Surface to an Ergonomic & Functional Level.	x	x	x	x
Leveling Feet	Subsystem Component 1C	Accommodate Height and Level Adjustment.	x	x	x	x
Tube Locators	**Subsystem 2**	Locate Tube Hardware with Respect to Ring Hardware per Requirements.				X
Tube Locating Angle	Subsystem Component 2A	Locating Surface for Tube.				x
Fasteners	Subsystem Component 2B	Secure Tooling Components to Base.				x
Ring Locators	**Subsystem 3**	Locate Ring Hardware on Mounting Surface.		X		X
Ring Locating Angle	Subsystem Component 3A	Locating Surface for Ring.		x		x
Fasteners	Subsystem Component 3B	Secure Tooling Components to Base.		x		x
Retainers	**Subsystem 4**	Retain and Secure Ring Hardware on Mounting Surface.			X	X
Retaining Angle	Subsystem Component 4A	Retaining Surface for Ring.			x	x
Fasteners	Subsystem Component 4B	Secure Tooling Components to Base.			x	x

Tooling Process Architecture

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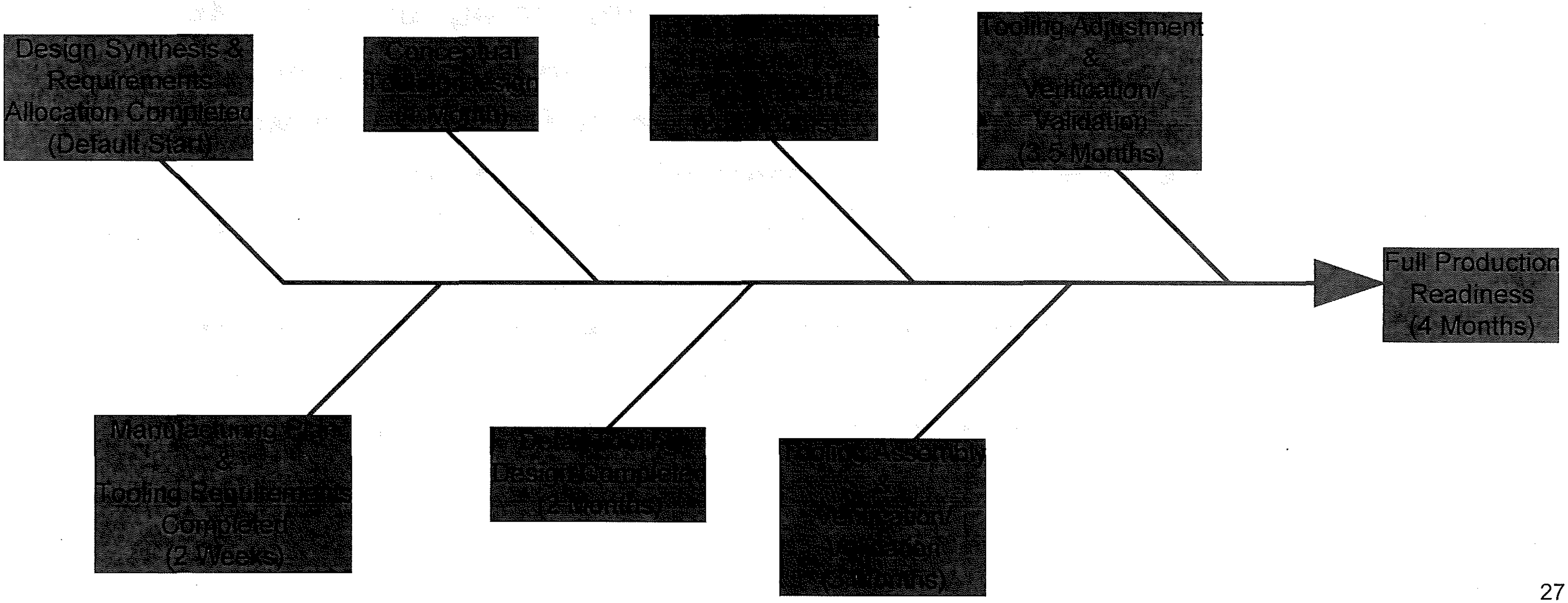
SV-8 System Evolution Description

Tube & Ring Bonding Assembly Jig



Design

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- By using a parallel design and evaluation approach to Hardware and Tooling Design schedule and cost risk can be reduced while encouraging inter-discipline interaction resulting in more robust hardware and tooling designs.
- As noted in the Integrated Schedule, the Production Engineer and Tool Designer should be involved on an advisory basis during the hardware design synthesis process. In this way their expertise can be brought to bear on potential hardware concepts.
- By involving the production disciplines early in the project lifecycle and making use of modern Computer Aided Design for hardware and tooling a program can find itself "half way there", in terms of production planning and tooling design, by the time they achieve a stable hardware design.

Design

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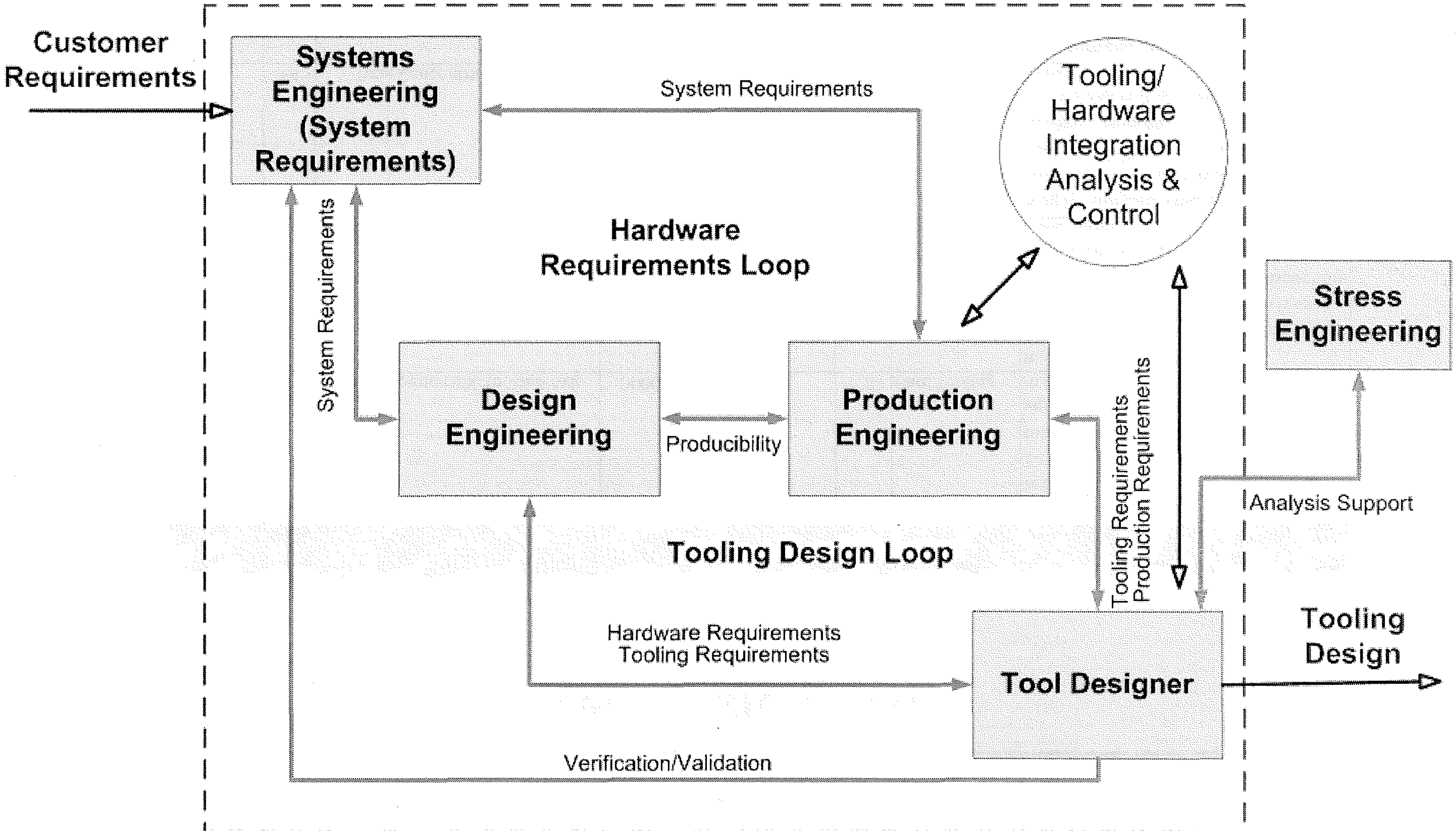
Tooling Design Synthesis Loop



Design

Verification Plan

Verification Plan

Drawing Number: XXXXXX-XXX

Description: Tube & Ring Bonding Assembly Jig

Hardware Dwg. Sht.	Zone	Feature	Tooling Dwg. #	Tool Dwg. Sht.	Zone	Verification Methodology	Comment
1	B2	Ring Perpendicular to Tube Axis	TXXXXXX-XXX	1	C8	Hard Tooling	The ring is restrained using the ring retainers to the flat base maintaining perpendicularity for the subsequent tube bonding. The base flatness is verified using laser tracker prior to use in assembly.
1	E4	Tube Axis Perpendicular to Ring	TXXXXXX-XXX	2	D4	Hard Tooling & Laser Tracker	Ring Locator detail maintains perpedicularity of tube to the base/ring setup. Laser tracker verification is used to align ring locators on base. Inspection is used on the ring locators to verify dimensions.
1	E4	Tube Concentric with Ring	TXXXXXX-XXX	2	D4	Hard Tooling & Laser Tracker	Ring Locator detail maintains concentricity of tube to the base/ring setup. Laser tracker verification is used to align ring locators on base. Inspection is used on the ring locators to verify dimensions.
2	C6	Tube Length from Bottom Ring Surface	N/A	N/A	N/A	Tube & Ring Part Inspection	Tube trim and ring height will be verified prior to assembly. By verifying assembly bondline thickness the tube length from the ring bottom suface is assured.
2	D3	Orientation of Ring Hole Datum to Tube Seam	TXXXXXX-XXX	2	E5	Tool Verification & Manual Inspection	The ring is oriented using existing holes in the base. The base holes are verified at the tooling level prior to use on assembly. The tube is oriented with respect to the ring using a pi tape.

Implimentation/Fabrication

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- The realization of tooling comes to a head when the tooling is fabricated and subsequently verified and validated for its intended purpose.
- The implementation and fabrication of tooling is a group effort relying on a core team and effective management with support from project personnel and engineering disciplines.
- The realization of effective tooling in the implementation and fabrication stage, while similar to the production of hardware, must remain flexible and subject to the appropriate level of scrutiny dependent on its intended purpose.
- As with hardware design, the support of the project team should be available to the fabrication team but the production disciplines must lead the tooling fabrication effort.

Implimentation/Fabrication

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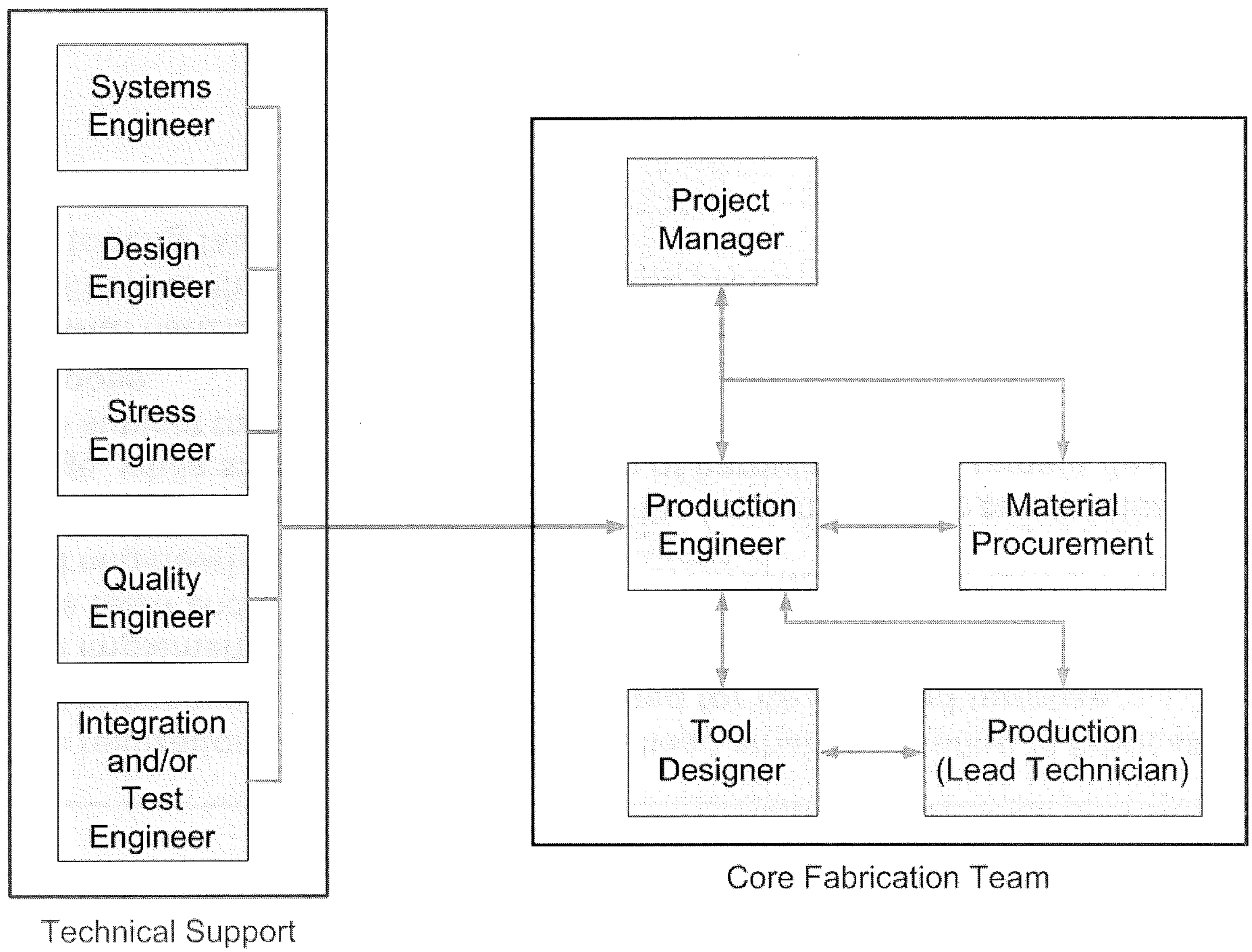
Fabrication Team



Conclusion

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- The paper has sought to balance influences of the Systems Engineering process, as the author was taught in his pursuit of a Master's of Science degree in Systems Engineering, and the cumulative work experience of the author as an engineer practicing in the field of production and tooling.
- The paper has illustrated the necessity of involvement of production/tooling engineers within Integrated Product Teams early in the hardware product life cycle.
- It has emphasized concurrent engineering practices and asserts that they are imperative to the efficient establishment of tooling needs and processes.
- The paper demonstrated how Systems Engineering and Architecting tools can be used to a tooling projects benefit through the phases normally associated with hardware or software product development.
- The use of these tools and best practices with tooling was cited as being scope dependent.
- This paper is intended to be an outline for experimental use of Systems Engineering tools and processes along with best industry practices.
- Despite the need for future work on these tools and process the papers conclusion stands that a tooling process, based on Systems Engineering principles, that is ingrained in the product life cycle and which thoroughly documents associated technical and producibility requirements will reduce the issues currently prevalent in complex tooling realization.

Backup Slides

Example Statement of Work

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- Scope
-
- This Statement of Work is to provide a technical and management overview of the requirements for the design and fabrication of the Tool. Design of the Tooling shall be performed by Tool Design in conjunction with Production Engineering and Design Engineering. Fabrication of the tool shall be carried out by the appropriate Production Department in conjunction with Production Engineering. All conditions relative to this SOW will be approved in writing by Project Management prior to the start of performance on this project. Project Management reserves the right to review and inspect the deliverables outlined for the Tooling.
-
- Management
-
- Semi-monthly management reviews and/or Technical Interface Meetings (TIM) will be conducted at the discretion of Project Management. The reviews will address technical concerns, schedule, quality and key personnel. Notification of key personnel changes will be made to the responsible Project Management. Key personnel changes are meant to include responsible Project Management, Quality, Production Management, Design Engineers, Production Engineer, Tool Designer, and technicians for design and fabrication of the Tooling. Progress of the project will be made available to Project Management electronically via Microsoft Project or "Gating" charts or another mutually agreed to format.
-
- A Preliminary Design Review (PDR) will be held prior to the final approval of Tooling design. Requirements for the PDR are as follows:
-
- Representatives: Project Management, Design Engineering, Production Engineering, Tool Design, Quality Engineering, Materials & Process Engineering
- A detailed CAD model.
- The first level basic drawing identifying all critical hardware interface locations. These locations should be dimensioned and geometrically toleranced, as appropriate, to illustrate the functional capacity of the Tooling. Individual detail level drawings are not necessary at this time.
- A basic Bill of Materials (BOM) with all major component materials identified. Long lead materials and items are to be identified at this time. Off the shelf items, such as fasteners, need not be definitively quantified or identified at this time if they are readily available.
- A detailed schedule in Microsoft Project format shall be included in the review. The schedule shall reflect the completion of the part design effort and the availability of fabrication resources.
- The PDR shall also address the following:
  - Technical risks with mitigation plans
  - Unique or new materials and/or processes.
  - Inspection plan.

Example Statement of Work Cont.

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- A Manufacturing Readiness Review (MRR) will be held XX months from the start of fabrication of the Tooling. Requirements for the MRR are as follows:
-
- A completed Tooling Drawing.
- Concurrence and signoff from the core engineering team including, at a minimum, Production Engineering, Design Engineering, and Tool Design.
- A detailed manufacturing plan, using a flowchart or comparable format.
- The detail plan shall contain all the manufacturing operations required to produce the Tooling, along with the associated tooling, machine tools, facilities and processes. The detail plan shall include inspection points and processes.
- A detailed schedule in Microsoft Project format shall be included in the review. The schedule level of detail shall match the manufacturing operation level of detail including inspection operations.
- The MRR shall also address the following:
  - Technical risks with mitigation plans
  - Unique or new materials and/or processes.
  - Inspection plan.
-
-
-
- Technical Requirements
- Tooling
  - Application: Assembly Jig for Part XXXXXX Quantity: X
    - Design per released part Design XXXXXX Rev. XX
  - Dimensions: (X) Long X (X) Wide
    - Minimum Deck Height
    - X" or Greater Deck Height requires a Step
    - Multiple Sections to Achieve Total Length is Acceptable
      - Section or Table Weight cannot Exceed X Tons for transportation purposes in the work area.
    - Total Length Flatness of .XXX" or Better
  - Modular Hole Pattern: (X) X (X)Alternating Through Hole & Threaded Hole
    - Through Hole .XXX" +.XXX"/+.XXX"
    - Threaded Hole X-X, X" depth, Starter Hole to Penetrate Total Thickness of Deck
    - Holes are to Align along Length of Base and Width of Base to within .XXX" from First Hole to Last Hole. This Applies to Total Length Despite the use of Multiple Base Sections.
  - Material: Minimal CTE, Maximum Stability

Example Statement of Work Cont.

- **Support Requirements**
  - Tooling Base Shall be Capable of Supporting the Following with Minimal Distortion (Less than .XXX")
    - Less than XXXlbs of Assembly Weight
    - X Technicians, Each Less than 300lbs
    - XX" X XX" Isolated Load Should not Exceed XXXlbs
    - Total Distributed Load Should not Exceed XXXXlbs
- **Features**
  - Adjustable Leveling Feet
  - Base Shall be Free of Trip Hazards
  - Prepare and Paint on Non-Interface Surfaces
  - Rust Inhibiting Treatment on Un-Painted Surfaces

- **Design Requirements**
- **ANSI/ASME 14.5 2009**
- **XXXXX Company Design Standards**
- **XXXXX Company Drawing Format**
- **XXXXX Company Quality Requirements**
- **XXXXX Company Safety Standards**
- **OSHA Safety Standards**

- **Fabrication Requirements**
- **XXXXX Company Fabrication Standards**
- **XXXXX Company Process Requirements Specifications**
- **XXXXX Company Quality Requirements**
- **XXXXX Company Safety Standards**
- **OSHA Safety Standards**

- **Schedule**
- **Design and production schedule (Microsoft Project based) shall be maintained by Program Management with the support of Production Engineering, Tool Design, and the shop floor. Any deviation from established schedule in excess of XX weeks may require a working group review at the discretion of Project Management.**

- **Quality Assurance Requirements**
- **Existing organization and Product Assurance system shall be utilized to the maximum extent possible to meet the project requirements. The design and fabrication groups shall maintain a Quality Assurance System that complies with XXXX and XXXX. The Quality organization will have the option to survey and verify conformance yearly.**

Reduced Dimension Drawings and Solid Models

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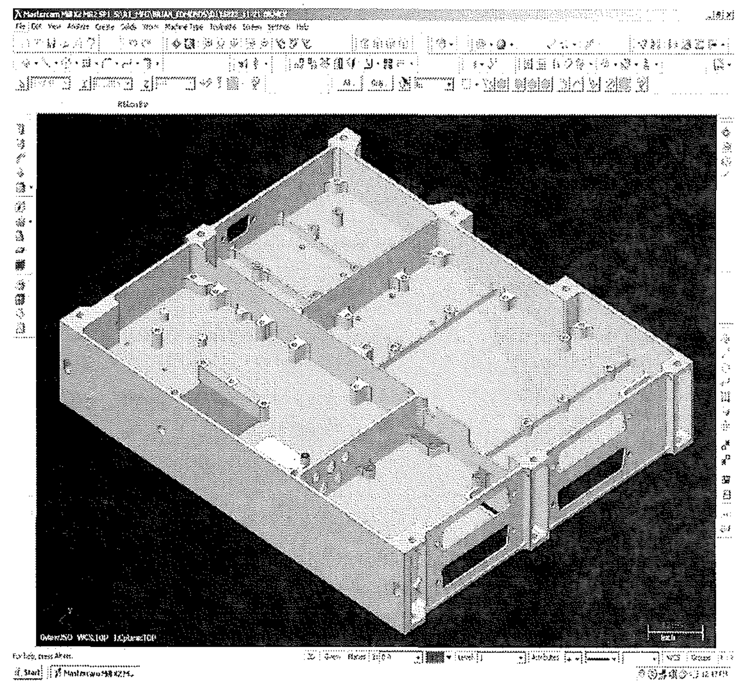
- **The Design:**
  - Every threaded feature should be modeled at the minor thread diameter and noted as a threaded hole on the drawing
  - Relax the requirements for non-critical features.
  - Notate performance critical features for inspection purposes.
  - Model made to nominal tolerance to aid manufacuring.



- **The Alternative:**
  - Fully dimensioned drawing
- **The Impact:**
  - A much less costly design that still meets the requirements of functionality.
  - Reduced programming time.
  - Reduced inspection time.

The Lesson: Understanding of what feature is critical and what is not in a design, can help avoid costly manufacturing processes and could reduce inspection time.

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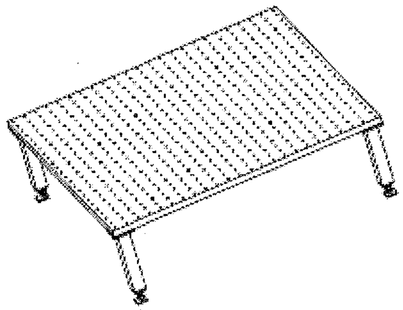
DWG NO	**DWGNO**	REV ---

APPLICATION			NEXT ASSY QTY REQD
USED ON	CI NO.	NEXT ASSY	
PROJ	CI NUBR	NXTASSY	QT

Private/Proprietary

REVISIONS

REV	DESCRIPTION	DATE	APPROVED



ISOMETRIC VIEW
SCALE: 1:50

PARTS LIST

ITAR/EAR-Controlled Information
Do not export or release to the public without USG approval.

Private/Proprietary

SPECS

APPLICABLE SPECIFICATIONS

THE ABOVE NORTHROP GRUMMAN SPACE TECH. SPECS FORM A PART OF THIS DRAWING

FINISH: FINISH

HEAT TREAT: HEAT TREAT

UNLESS OTHERWISE SPECIFIED

1. DO NOT SCALE DRAWING.
2. INTERPRET PER ASME Y14.100M.
3. DIMENSIONS ARE IN INCHES.
4. SURFACE TEXTURE SHALL BE 125 ✓
5. REMOVE BURRS AND SHARP EDGES.
6. DIMENSIONS APPLY BEFORE PLATING OR CONVERSION COATING.

TOLERANCES ON DECIMAL DIMENSIONS:
.XXX ±.010
.XX ±.03
.X ±.1

TOLERANCES ON ANGULAR DIMENSIONS:
MACHINED ±0°30'
LOCATING ±0°30'
FORMED ±2°
CHAMFERS ±5°

TOLERANCES ON ALL HOLE DIAMETERS

FROM	THRU	TOL.
UNDER	.0140	+.0020 -.0005
.014	.125	+.004 -.001
.126	.250	+.005 -.001
.251	.500	+.006 -.001
.501	.750	+.008 -.001
.751	1.000	+.010 -.001
1.001	2.000	+.012 -.001

CONTRACT NO. **CONTRACT NO**

DRAWN	*DRAWN BY*	YR-MO-DY
ENGINEER	*ENGINEER*	

SEE PDMS FOR APPROVALS

THE FOLLOWING EO'S HAVE BEEN ATTACHED TO THIS PRINT

TITLE

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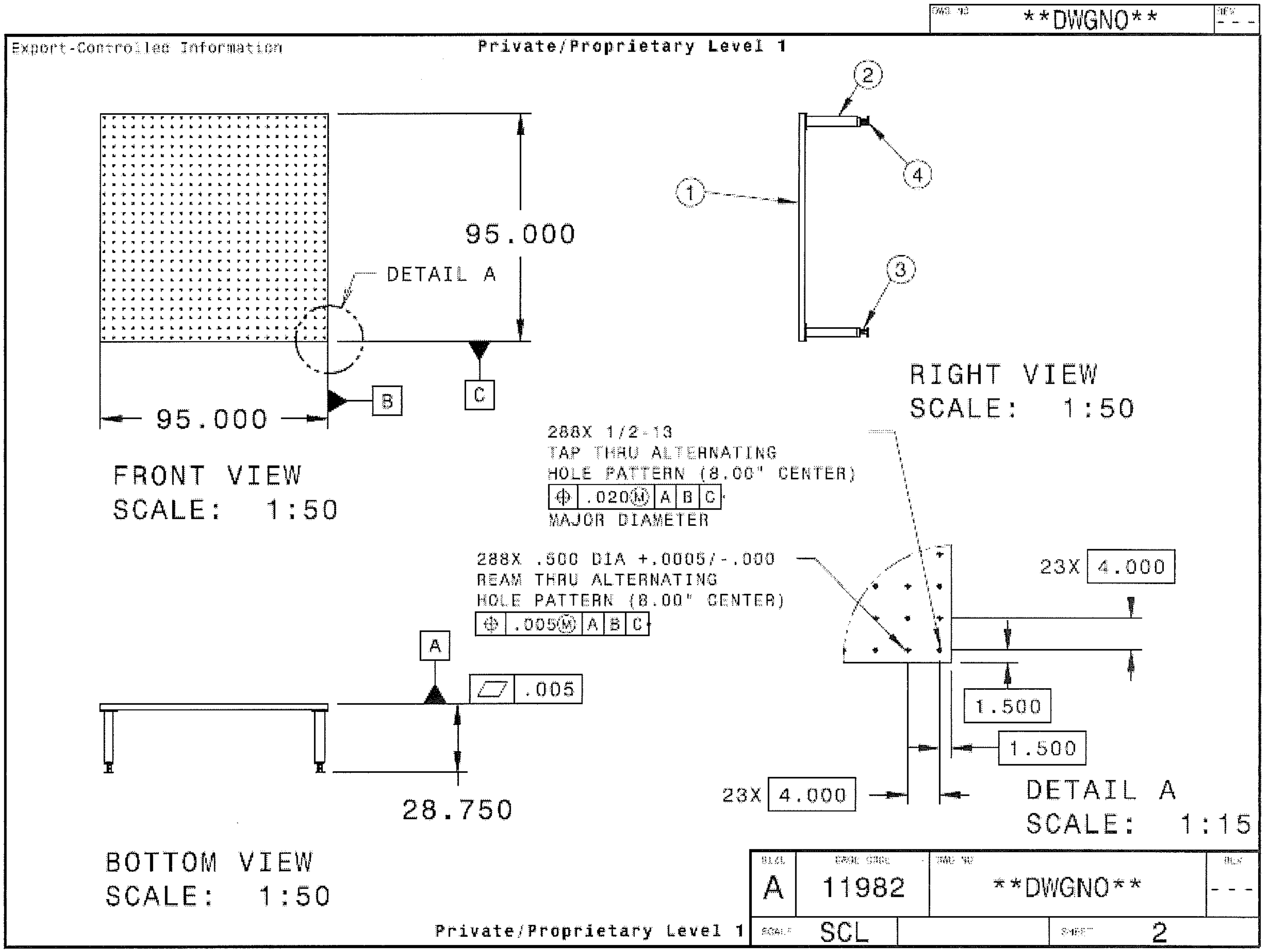
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95.000
B
C
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SCALE: 1:50
1
2
3
4
RIGHT VIEW
SCALE: 1:50
288X 1/2-13
TAP THRU ALTERNATING
HOLE PATTERN (8.00" CENTER)
⌖ .020Ⓜ A B C
MAJOR DIAMETER
288X .500 DIA +.0005/-.000
REAM THRU ALTERNATING
HOLE PATTERN (8.00" CENTER)
⌖ .005Ⓜ A B C
23X 4.000
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1.500
23X 4.000
DETAIL A
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28.750
BOTTOM VIEW
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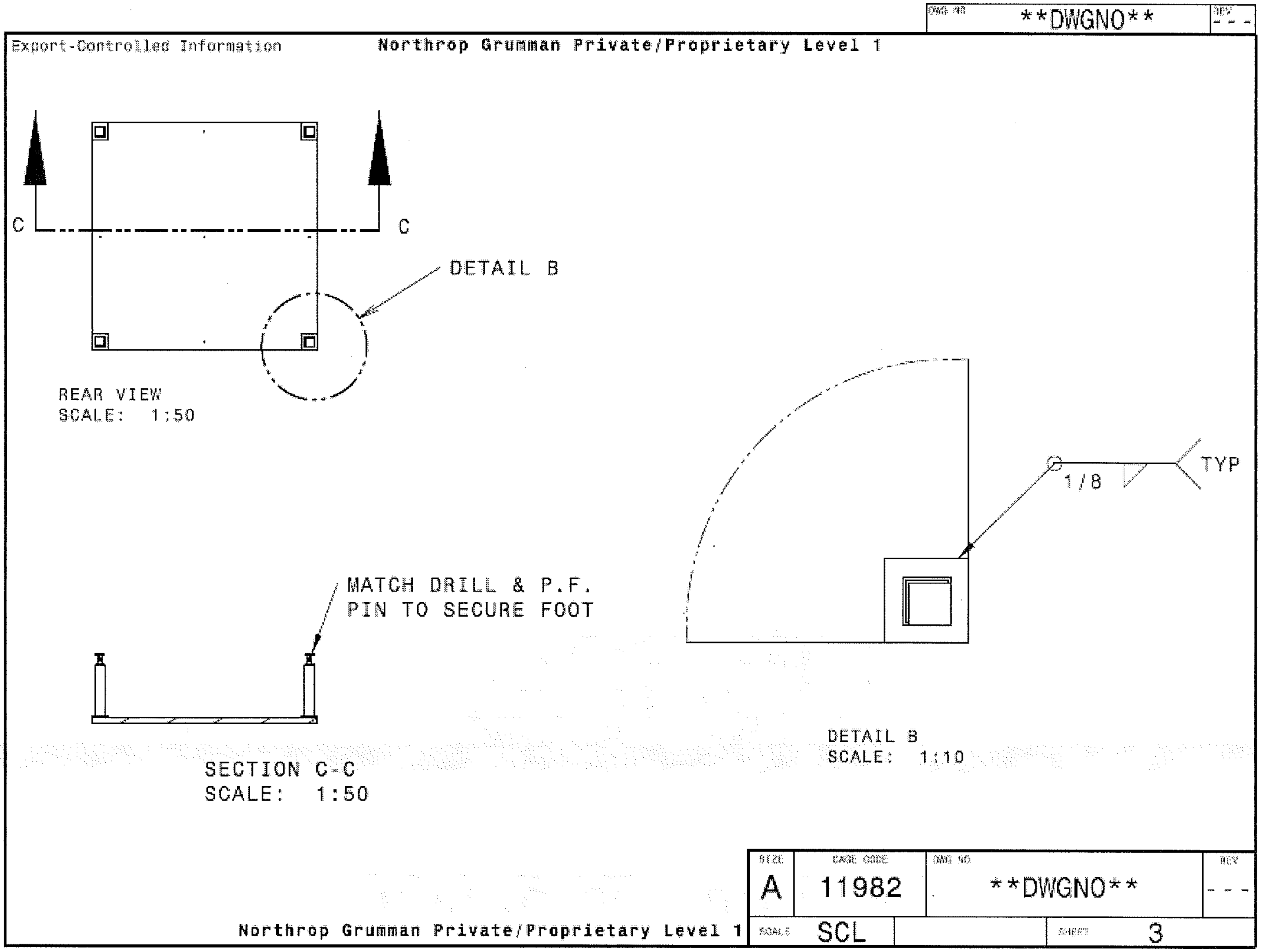
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1/8
TYP
MATCH DRILL & P.F.
PIN TO SECURE FOOT
SECTION C-C
SCALE: 1:50
DETAIL B
SCALE: 1:10
SIZE A
CAGE CODE 11982
DWG NO **DWGNO**
REV - - -
SCALE SCL
SHEET 3
Northrop Grumman Private/Proprietary Level 1

Indentured Parts List

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Item Number	Revision	Dwg. #	Dash No.	Qty.	Order of Assembly			Drawing Title	Material	Spec.	Zone
1	N/C	WWW	1	1	1			Base	Steel	W	
2	N/C	XXX	1	4		2		Leg Assy.	Steel	X	
3	N/C	YYY	1	1			3	Leg Adjust.	Steel	Y	
4	N/C	ZZZ	1	1			3	Foot	Steel	Z	

Verification Based Tooling & Methods

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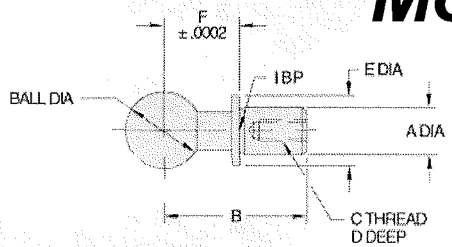
Tooling/Construction Ball & Mount



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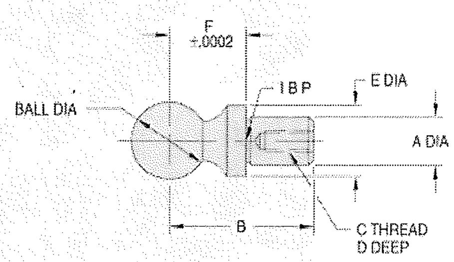

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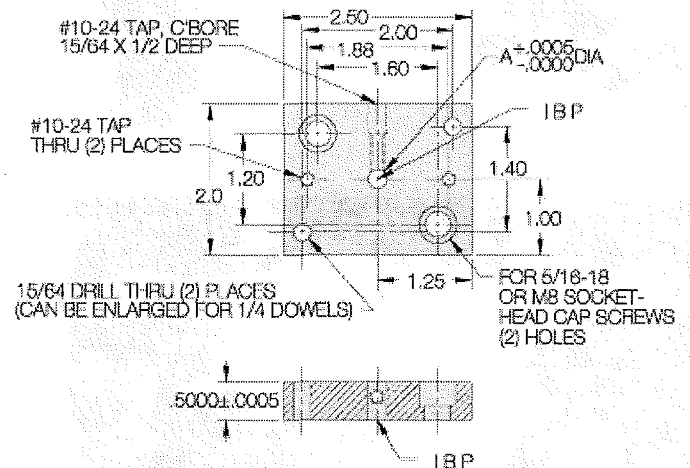
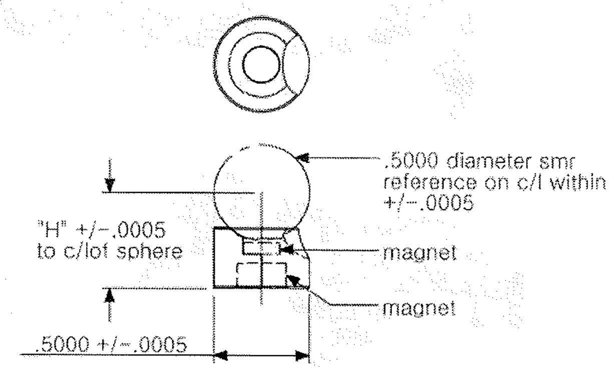
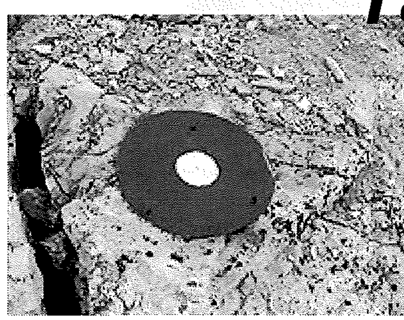


SMR & Mount



Photogrammetry Targets



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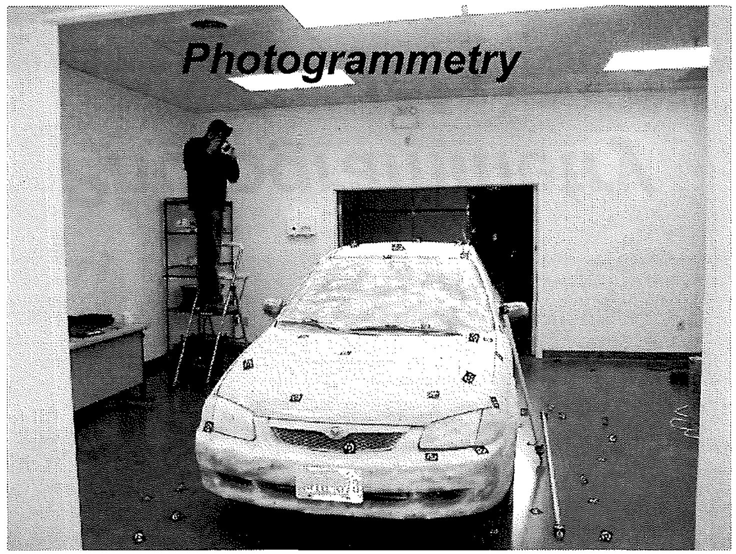
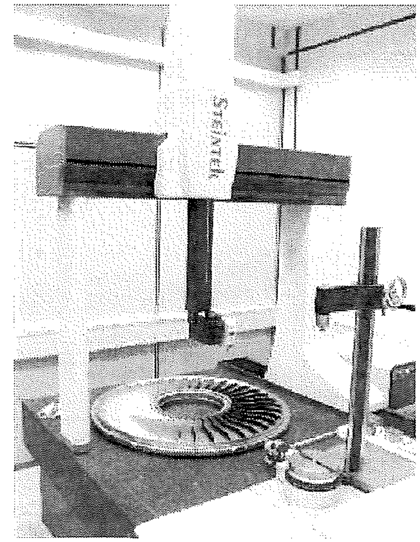
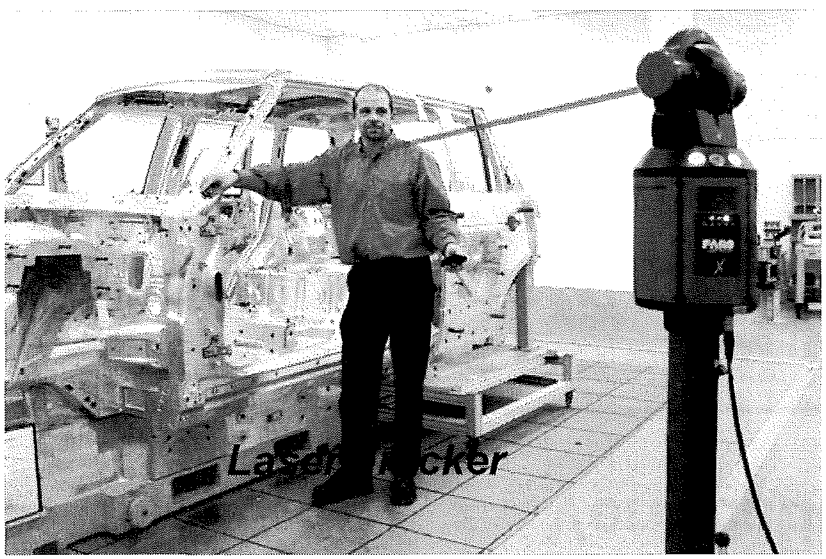
Verification Methods

Sight Level & Theodolite



Coordinate Measuring





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