Bridging Design and Manufacturing in the Lean Enterprise

Using Lean Systems Engineering As a Catalyst to Achieve Customer Satisfaction!

Massachusetts Institute of Technology

Allen C. Haggerty
October 12, 2005

Lean Thinking

Lean **emerged from post-WWII Japanese automobile industry as a fundamentally more efficient system than *mass* production.**

	Craft	*Mass Production*	*Lean Thinking*
Focus	Task	Product	Customer
Operation	Single items	Batch and queue	Synchronized flow and pull
Overall Aim	Mastery of craft	Reduce cost and increase efficiency	Eliminate waste and add value
Quality	Integration (part of the craft)	Inspection (a second stage after production)	Inclusion (built in by design and methods)
Business Strategy	Customization	Economies of scale and automation	Flexibility and adaptability
Improvement	Master-driven continuous improvement	Expert-driven periodic improvement	Worker-driven continuous improvement

This talk focuses on applying Lean Thinking to Engineering

Source: Lean Enterprise Value: Insights from MIT's Lean Aerospace Initiative, Palgrave,

Lean Engineering:Doing the Right Thing Right

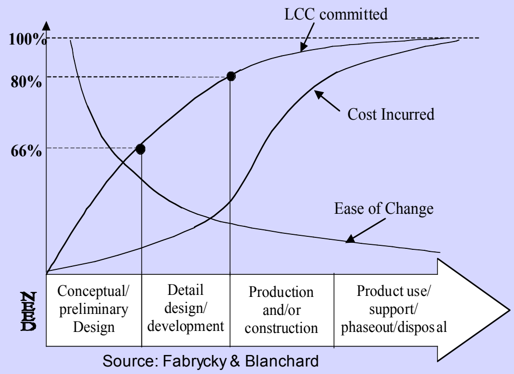
- Creating the right products…
  - Creating product architectures, families, and designs that increase value for all enterprise stakeholders.
- With effective lifecycle & enterprise integration…
  - Using lean engineering to create value throughout the product lifecycle and the enterprise.
- Using efficient engineering processes.
  - Applying lean thinking to eliminate wastes and improve cycle time and quality in engineering.

Source: McManus, H.L. "Product Development Value Stream Mapping Manual", LAI Release Beta, April 2004

Framework based upon a decade of Lean Aerospace Initiative research and industry/government implementation

Creating the Right Products:

Creating product architectures, families, and designs that increase value for all enterprise stakeholders.



Source: Fabrycky & Blanchard

"Fuzzy Front End" Challenges

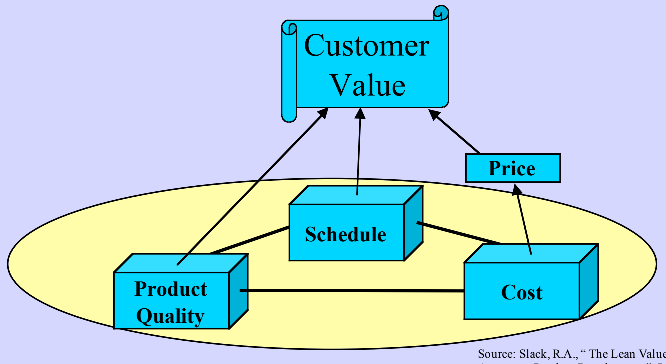
Understanding what the customer values

Deciding which product to pursue from amongst many opportunities

Selecting the right product concept

Early decisions are critical - Disciplined lean systems engineering process is essential!

Customer Defines Product Value

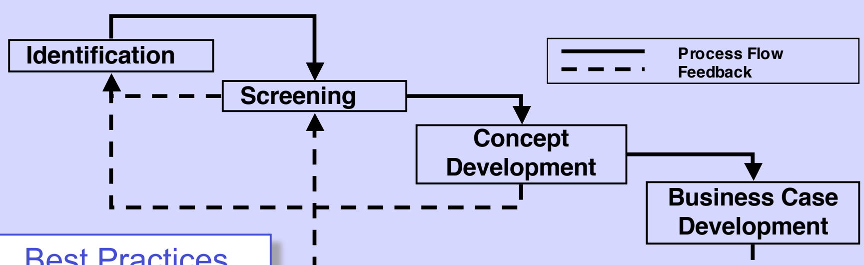


Source: Slack, R.A., " The Lean Value Principle in Military Aerospace Product Development", LAI RP99-01-16, Jul 1999. web.mit.edu/lean

Product Value is a function of the product
- **Features and attributes** to satisfy a customer need
- **Quality** or lack of defects
- **Availability** relative to when it is needed, and
- **Price and/or cost of ownership** to meet customer **requirements**

Source: "Lean Engineering", LAI Lean Academy™, V3, 2005

Framework For Effective Front-End Process



Best Practices

Identification
- Small multidisciplinary teams
- Adequate funding
- Multiple requirements ID methods used
- Independent assessment of solution

Screening
- Senior level decision
- Active portfolio management
- Strategic plan and resource constraints guide prioritization

Concept
- Requirements given as variables within desired range
- Team remains intact throughout process
- Data driven tradeoff analysis - use of prototypes

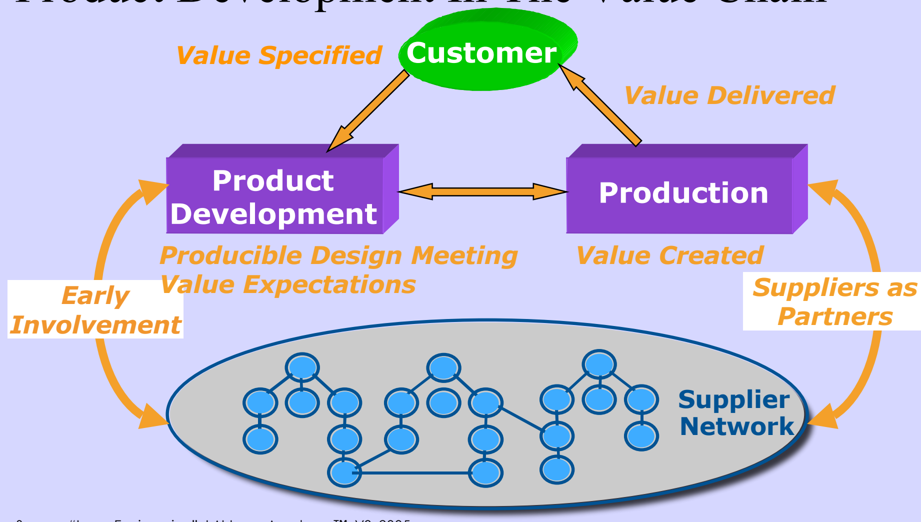
Business Case
- Clear, concise product concept, architecture and concept of employment
- Based upon:
  - Product lifecycle strategy
  - Fit with product portfolio
  - Returns to organization

Closure of Technical AND Business Case is Mandatory

Source: J. R. Withlin, "Best Practices in User Needs/Requirements Generation", MS Thesis, MIT 1994

With Effective Lifecycle & Enterprise Integration:
Using lean engineering to create value throughout the product lifecycle and the enterprise.

Product Development In The Value Chain



Source: "Lean Engineering", LAI Lean Academy™, V3, 2005

Integrated Product and Process Development - IPPD

- Preferred approach to develop producible design meeting value expectations
- Utilizes
  - Systems Engineering: Translates customer needs and requirements into product architecture and set of specifications
  - Integrated Product Teams (IPTs): Incorporate knowledge about all lifecycle phases
  - 3D CAD/CAM modeling, digital simulations, common data bases
  - Training

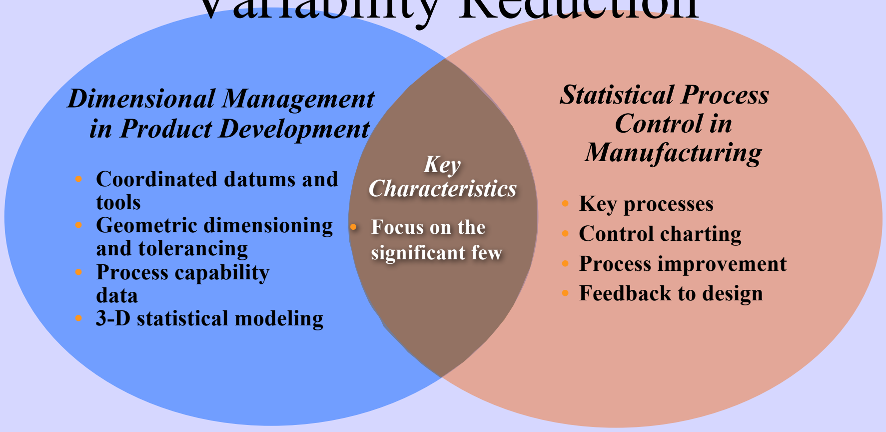
Capable people, processes and tools are required

Tools of Lean Engineering

- Integrated 3-D solids-based design
- Design for manufacturing and assembly (DFMA)
- Common parts / specifications / design reuse
- Dimensional management
- Variability reduction
- Production simulation

Source: "Lean Engineering", LAI Lean Academy™, V3, 2005

Variability Reduction



Lean manufacturing requires robust designs and capable processes!

Source: "Lean Engineering", LAI Lean Academy™, V3, 2005

Variability Reduction Affordability Projects

F/A-18E/F Cheek Skin ATA Project
$5,600 ROM Savings, 10 Tools Eliminated, 1 Shift Saved

C-17 Pylon ATA Project
$125,000 ROM Savings, Replaces 4 Assembly Jigs

F-15 Side Panel DMAPS Project
Gap/Shim Nonconformance Reduced by 70%

C-17 Cargo Door Bulkhead AIW/ATA
Assembly Hours Reduced by 61%
Cycle Reduced by 27%

3D solids, dimensional management,variability reduction enable affordability improvements on legacy programs!

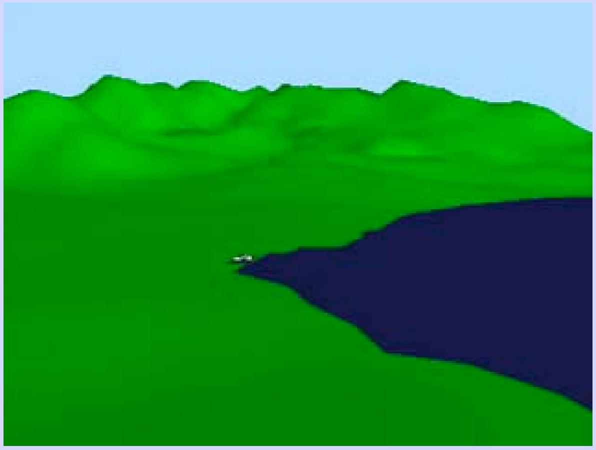
Benefits of Variability Reduction: Floor Beams for Commercial Aircraft


Source: www.boeing.com

	747	777
Assembly strategy	Tooling	Toolless
Hard tools	28	0
Soft tools	2/part #	1/part #
Major assembly steps	10	5
Assembly hrs	100%	47%
Process capability	$C_{pk}<1$ (3.0σ)	$C_{pk}>1.5$ (4.5σ)
Number of shims	18	0

Source:J.P. Koonmen, "Implementing Precision Assembly Techniques in the Commercial Aircraft Industry", Master's thesis, MIT (1994), and J.C.Hopps, "Lean Manufacturing Practices in the Defense Aircraft Industry", Master's Thesis, MIT (1994)

Final Check: Production Simulation



An engineer's job is not done until we have successfully conducted a <u>3D production simulation</u>

Source: "Lean Engineering", LAI Lean Academy™, V3, 2005

Using Efficient Engineering Processes:

Applying lean thinking to eliminate wastes and improve cycle time and quality in engineering.

- Effort is wasted
  - 40% of PD effort "pure waste", 29% "necessary waste" ***(workshop opinion survey)***
  - 30% of PD charged time "setup and waiting" ***(aero and auto industry survey)***
- *Time* is wasted
  - 62% of *tasks* idle at any given time ***(detailed member company study)***
  - 50-90% task idle time found in Kaizen-type events

Source: "Lean Engineering", LAI Lean Academy™, V3, 2005

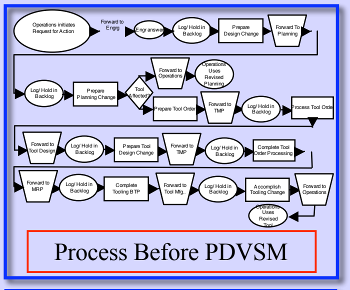
Source: McManus, H.L. "Product Development Value Stream Mapping Manual", LAI Release Beta, April 2004

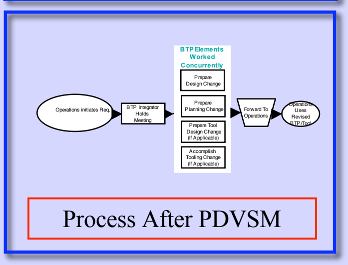
Five Lean Fundamentals

- Specify ***value***: Value is defined by customer in terms of specific products and services
- Identify the ***value stream***: Map out all end-to-end linked resources, inputs and outputs to identify and eliminate waste
- Make value ***flow*** continuously: Having eliminated waste, make remaining value-creating steps "flow"
- Let customers ***pull*** value: Customer's "pull" cascades all the way back to the lowest level supplier, enabling just-in-time production
- Pursue ***perfection***: Pursue continuous process of improvement striving for perfection

Source: James Womack and Daniel T. Jones, Lean Thinking (New York: Simon & Schuster, 1996).

F-16 Lean Build-To-Package Support Center PDVSM Results





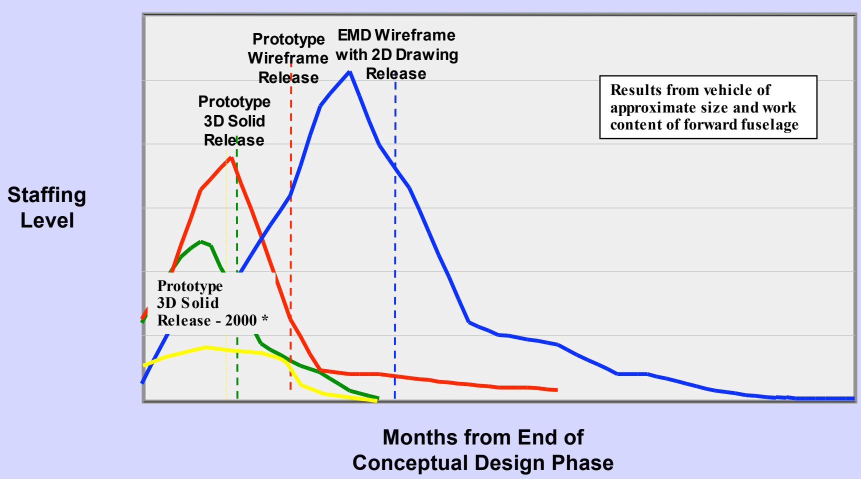
849 BTP packages

Category	Reduction
Cycle-Time	**75%**
Process Steps	**40%**
No. of Handoffs	**75%**
Travel Distance	**90%**

Source: "F-16 Build-T- Package Support Center Process", Gary Goodman, Lockheed Martin Tactical Aircraft Systems LAI Product Development Team Presentation, Jan 2000

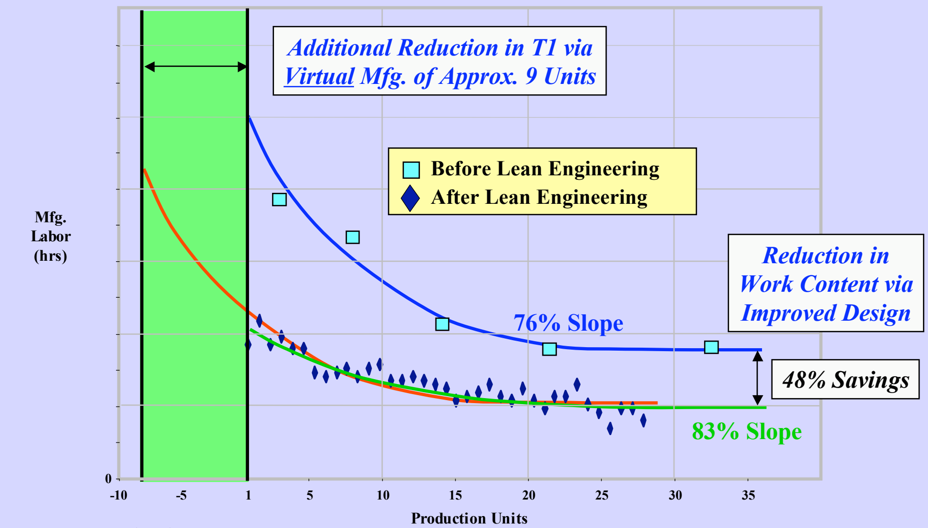
Lean Engineering Enables Faster and More Efficient Design

Forward Fuselage Development Total IPT Labor



Source: "Lean Engineering", LAI Lean Academy™, V3, 2005
Source: "Lean Engineering ", John Coyle (Boeing), LAI Executive Board Presentation, June 1, 2000

Lean Engineering
Improves Manufacturing



Source: "Lean Engineering", LAI Lean Academy™, V3, 2005
Source: "Lean Engineering ", John Coyle (Boeing), LAI Executive Board Presentation, June 1, 2000

Lean Engineering Leads To Faster Delivery Times

Iridium Manufacturing

- **Cycle time of 25 days vs. industry standard of 12-18 months**
- **Dock-to-Dock rate of 4.3 Days**

Iridium Deployment

- 72 Satellites in 12 Months, 12 Days
- 14 Satellites on 3 Launch Vehicles, from 3 Countries, in 13 Days
- 22 Consecutive Successful Launches !

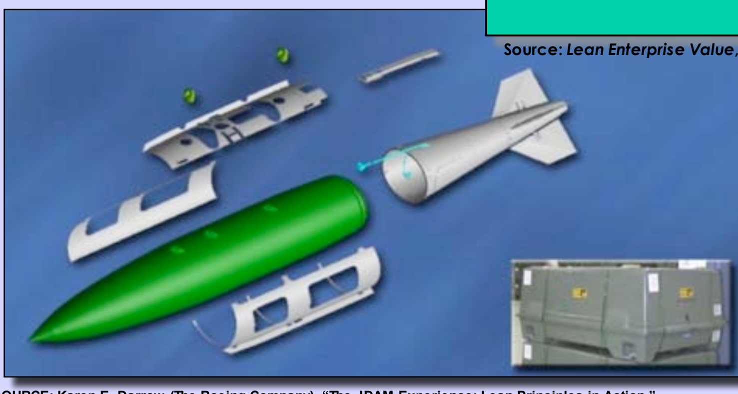
9-1-98
Source: "Lean Engineering", LAI Lean Academy™, V3, 2005
Source: Ray Leopold, MIT Minta Martin Lecture, May 2004

Lean Engineering Creates Product Value

JDAM - Joint Direct Attack Munition

Impact of Lean
- Original cost est. - $68+ K
- Final actual cost - $15 K
- Unit costs reduced > 75%
- Total savings > $2.9 B

Source: *Lean Enterprise Value*, pp 138-140, 206-207



SOURCE: Karen E. Darrow (The Boeing Company), "The JDAM Experience: Lean Principles in Action," Presentation at the SAE Aerospace and Automated Fastening Conference & Exhibition, September 22, 2004

The F/A-18E/F Super Hornet as a Case Study in"Value-Based" Systems Engineering

Allen C. Haggerty June, 2004 INCOSE, Toulouse, France

F/A-18E/F Background

- Significant upgrade to successful F/A-18C/D
- 25% larger aircraft and 33% more payload
- 40% increase in unrefueled range
- 80% longer “on-station” time @200 nm
- 3 times greater “bring back” ordnance
- 5 times more survivable
- Improved reliability and maintainability

Aerospace Systems That Succeed

What makes modern aerospace systems and programs “successful”?[1.]

A balance between technical capability and programmatic performance, for the lifecycle of the system!

1. Alexis Stanke, MIT,2000

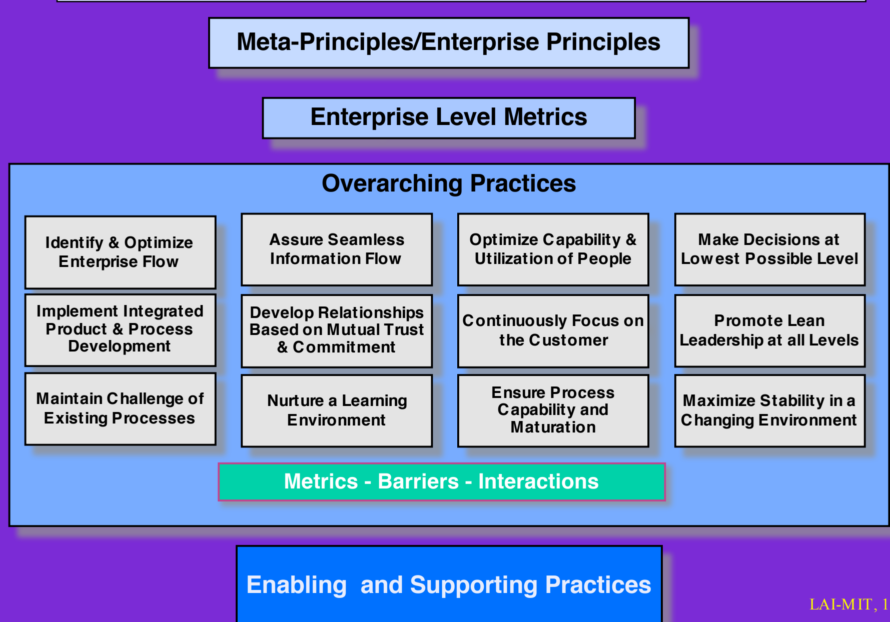
Lifecycle Value Defined

Balanced stakeholder expectation for effective **system performance** (quality, cost, and schedule) and the **associated risks** to deliver **best value** throughout the **life of the system**.[2]

Rooted in value management, lifecycle costing, and *systems engineering !*

2.Alexis Stanke, MIT,2000

LEAN ENTERPRISE MODEL



LAI-MIT, 1993

Value-Based Systems Engineering Model

Meta Principles:

RIGHT JOB; JOB RIGHT!

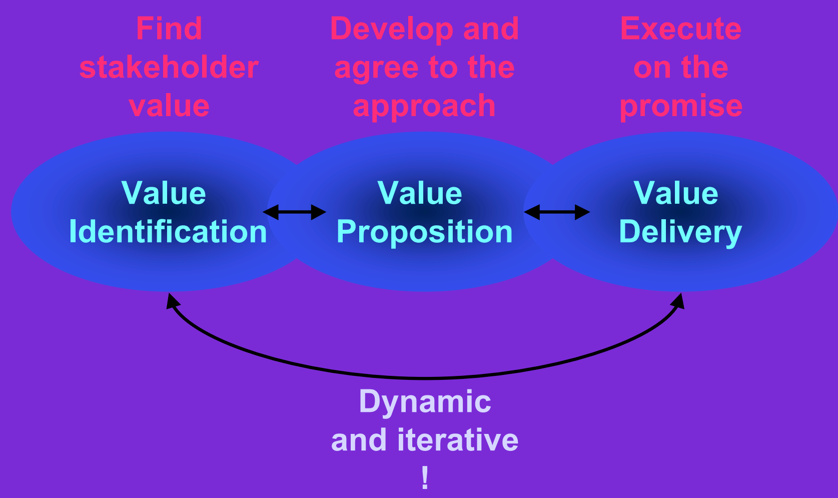
Value-Based Systems Engineering Enterprise Principles:

- **TECHNICAL EXCELLENCE, EFFECTIVE LEADERSHIP & ORGANIZATION**
- **PROGRAMMATIC SUCCESS**
- **EFFICIENT PROCESS EXECUTION**

Lean + Systems Engineering="Value-Based" Systems Engineering

- **"Not sure what it is , but we know it when we see it!!"**
- High correlation between demonstrated performance on F/A-18E/F's successful development and the combination of Lean Enterprise "over-arching" / enabling principles with good Systems Engineering processes.

Value Creation Framework



Murman,et al,MIT, 2001

F/A-18E/F Systems Engineering

- Rigorous Requirements Flowdown
- Disciplined Technical Reviews
- Configuration / Data Mgt.
- Systems Cost-effectiveness/
- LCC Trade studies
- Producibility / DFMA
- Risk Management / TPM
- Program Independent Audits
- Reliability/ Maintainability/Safety
- HFE/ Integrated Logistics

IPPD Environment

The Process

HAND- PICKED LEADERS

INTEGRATED PRODUCT DEFINITION

SYSTEMS ENGINEERING

CONFIGURATION CONTROL

RISK MANAGEMENT

INTEGRATED MANAGEMENT CONTROL SYSTEM

WEIGHT MANAGEMENT

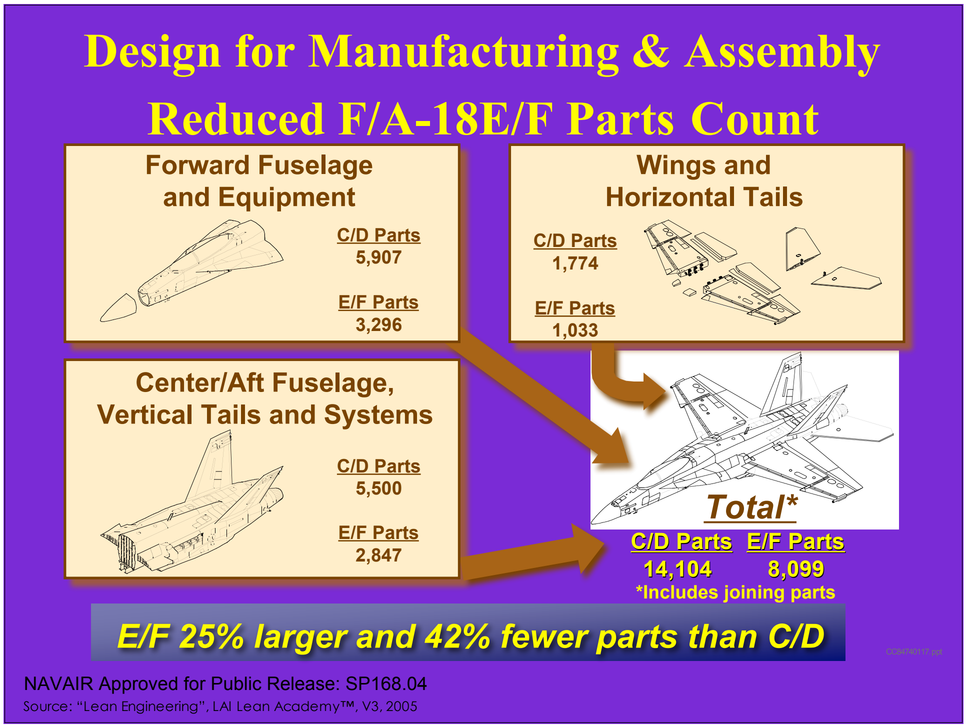
CO-LOCATED TEAMS

EARNED VALUE MGT.

SUPPLIER INTEGRATION

LEADERSHIP PRINCIPLES

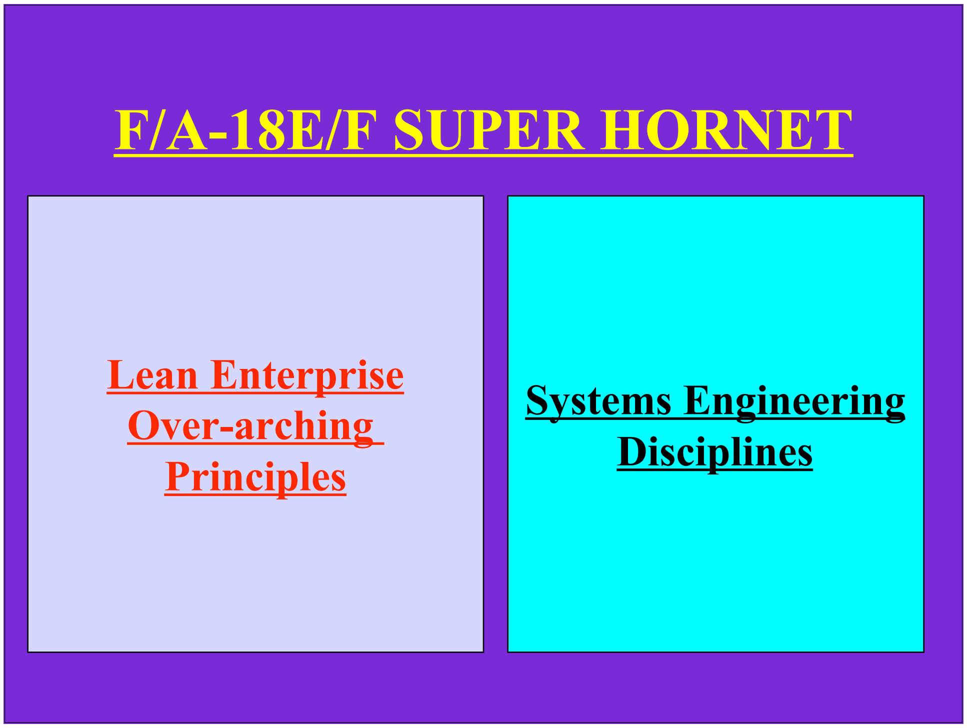
- CUSTOMER SATISFACTION
- OPEN, HONEST COMMUNICATION
- SUPPLIERS AS PARTNERS
- TEAMWORK
- PERFORMANCE TO PLAN

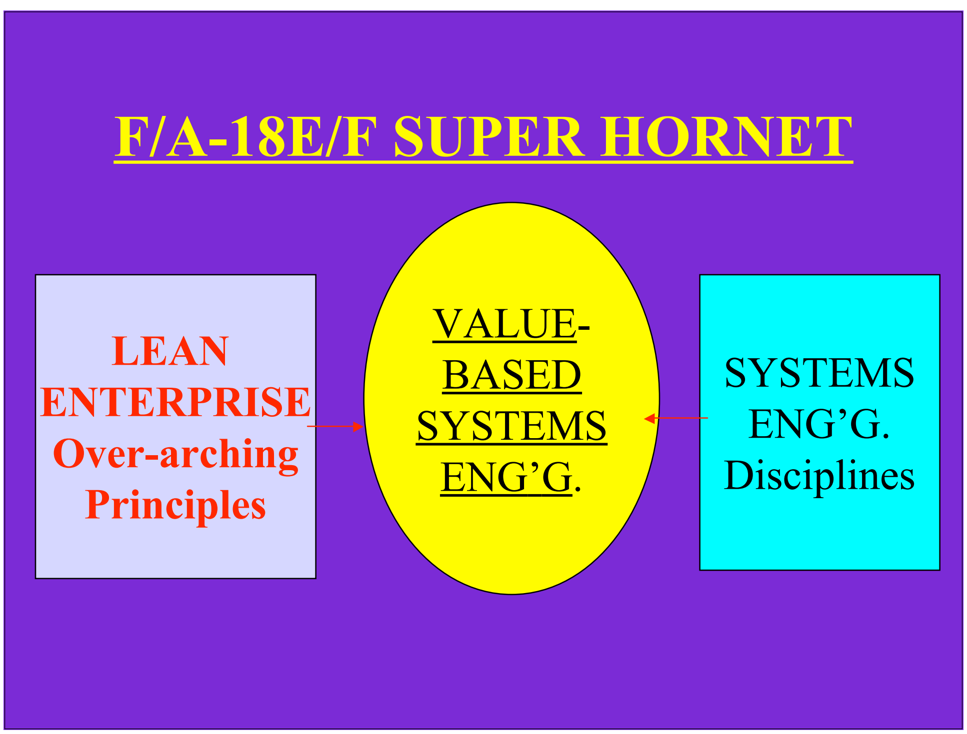

Design for Manufacturing & Assembly
Reduced F/A-18E/F Parts Count
Forward Fuselage and Equipment
C/D Parts 5,907
E/F Parts 3,296
Wings and Horizontal Tails
C/D Parts 1,774
E/F Parts 1,033
Center/Aft Fuselage, Vertical Tails and Systems
C/D Parts 5,500
E/F Parts 2,847
Total*
C/D Parts 14,104
E/F Parts 8,099
*Includes joining parts
E/F 25% larger and 42% fewer parts than C/D
NAVAIR Approved for Public Release: SP168.04
Source: "Lean Engineering", LAI Lean Academy™, V3, 2005

Lean Enterprise Principles Applied to F-18E/F

- Continuous Improvement !
- Optimal First -Unit Delivered Quality
- Metrics Tracked Weekly Across The
- the Extended Enterprise
- Seamless Information Flow (USN, NGC, GE Engines, Suppliers)
- Decisions Made at the Lowest Level of WBS Via "Delegated" RAA
- Joint Configuration Change Board
- Disciplined Weekly Earned Value Mgt. & Reporting

Performance To Plan!


F/A-18E/F SUPER HORNET
Lean Enterprise Over-arching Principles
Systems Engineering Disciplines


F/A-18E/F SUPER HORNET
LEAN ENTERPRISE Over-arching Principles
VALUE-BASED SYSTEMS ENG'G.
SYSTEMS ENG'G. Disciplines

THE PROCESS WORKS!

- 42% Fewer Structural Parts
- The Parts Fit the First Time
- 1029 Lbs. Below Specification Weight
- Reduced Engineering Change Activity
- Development Completed On Budget- $4.9B
- 1ST Flight Ahead of Schedule!

Achievement Recognized:1999 Collier Trophy!

RESULTS

- **A Department of Defense Program that Exceeded all Program Goals and Delivered the "Promised Value" to all Stakeholders.**

Preliminary Conclusion:

F/A-18E/F Super Hornet is an Example of a Successful "Value-based Systems Engineering" Application !

Conclusions

Lean Engineering enables ***Information and Knowledge Flow through Lean Practices:***

- Effective "front end" processes
- Integrated Product and Process Development
- Systems Engineering,
- Common Data Bases, 3D Solid Modeling,IPTs
- Product Development Value Stream Mapping

RESULTS:

Shorter Development Flow-time
Less Defects in Engineering, Tooling, Fabrication, Assy.
Improvement in "First Time Quality"
Less Cost and Waste from Idle Time, Scrap, Rework

Lean Practices Applied to Engineering Create Life-Cycle Value For the Customer and Enterprise Stakeholders !

References

1. LAI "Implementing Lean PD Workshop", presentation "Best Life-Cycle Value, the F/A-18E/F, and the Lean Enterprise Model", Sept.22, 2000; Alexis Stanke, MIT
2. "A Framework for Achieving Life Cycle Value in Aerospace Product Development", Alexis Stanke, Earll Murman, MIT presented at the ICAS 2002 Congress
3. "Lean Enterprise Value", Murman, Allen, Bozdogan, et al, MIT, 2002 , Palgrave-St. Martins Press

References (Continued)

4. McManus, Haggerty, Murman: "Lean Engineering: Doing the Right Thing Right"; 1st International Conference on Innovation and Integration In Aerospace Sciences, Belfast,Ireland, U.K., August 5, 2005

5. Haggerty: "The F/A-18E/F Super Hornet as a Case Study in Value-Based Systems Engineering"; INCOSE International Conference, Toulouse, France June, 2004

6. The MD-series of marks and the F/A-18E/F Super Hornet Trademarks of Boeing Management Company, used with permission

7. NavAir Approved for Public Release SP168.04

Acknowledgements

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- For more information visit the Lean Aerospace Initiative web site http://lean.mit.edu