The role of set-based design in successful shipbuilding project execution. Experiences from Umoe.

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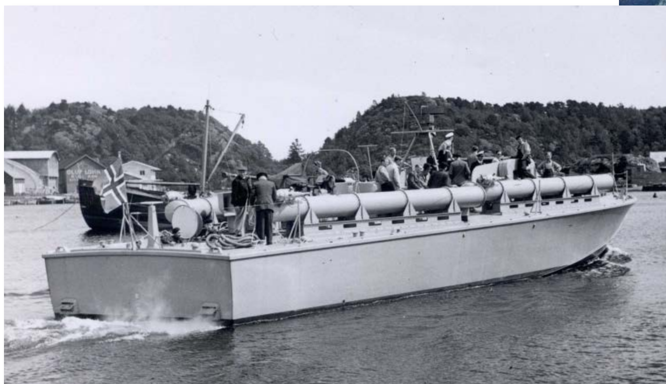
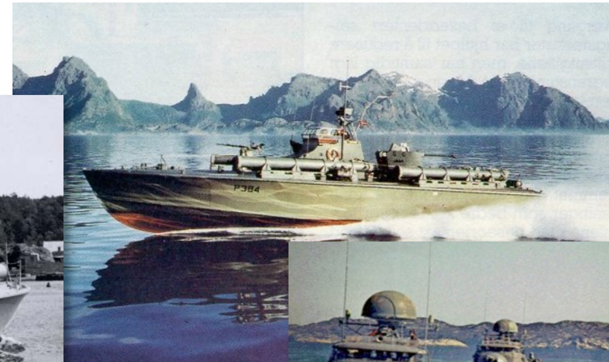
Content

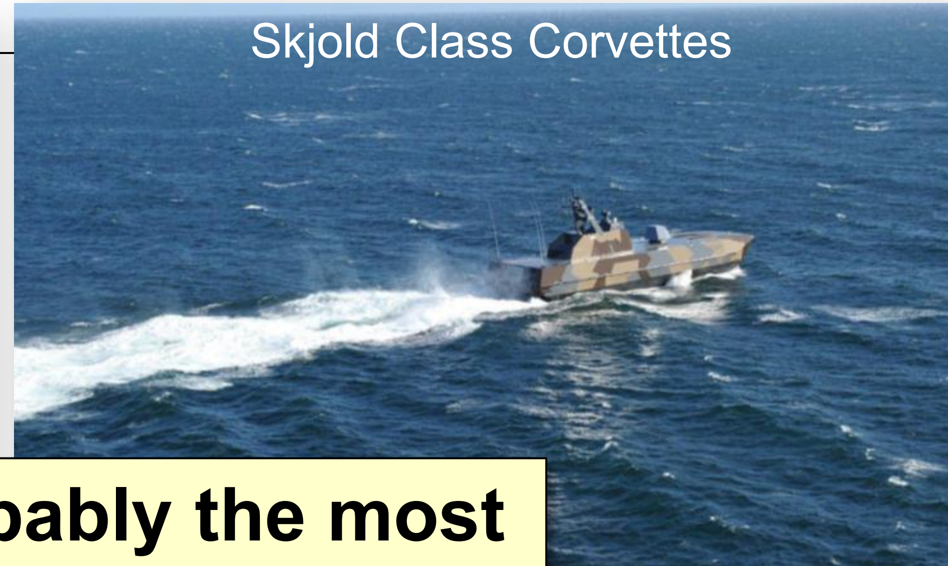
- Umoe Mandal
- Experience from actual development programs
  - MCMV
  - Skjold
  - T-Craft
- Experiences with set-based design
  - US Navy: Set-based design
  - T-Craft
- Important success criteria

60 years of naval shipbuilding in Mandal, Norway





Umoe Mandal: Proud builders of



Probably the most complex ships designed and built in Norway

SES MCMVs from Umoe Mandal

Main data

Displacement	: 396 t
Length	: 55,2 m
Speed	: 20 kn
Crew	: 37 (13/7/17)

Main weapons

Mistral SAM

Main sensors

MH: ROV, Hugin MRS, sonar
MS: Elma og Agate sveip

Oksøy class minehunter (MH)

M341	KNM Karmøy	1994
M342	KNM Måløy	1995
M343	KNM Hinnøy	1995

Måløy class minesweeper (MS)

M350	KNM Alta	1996
M351	KNM Otra	1996
M352	KNM Rauma	1996

Agate influence sweep

KNM Alta

Hugin AUV

Skjold Class Corvettes in the Navy

Main data Skjold-class

Displacement	: 274 t
Lenght	: 47,5 m
Speed	: 60 kn
Range	: 800 nm / 40 kn
Crew	: 20 (13/4/3)

Main armament

NSM
76 mm OTO
Mistral MANPADS

Skjold-class corvette

P961	KNM Storm	2010
P962	KNM Skudd	2010
P963	KNM Steil	2011
P964	KNM Glimt	2012
P965	KNM Gnist	2012
P960	KNM Skjold	2013

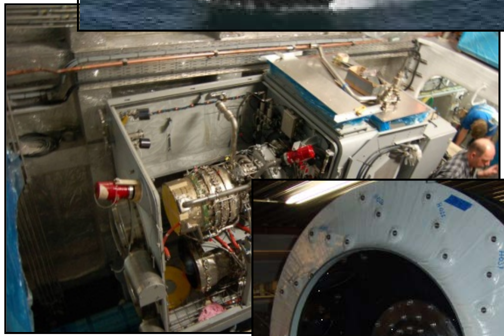
NSM

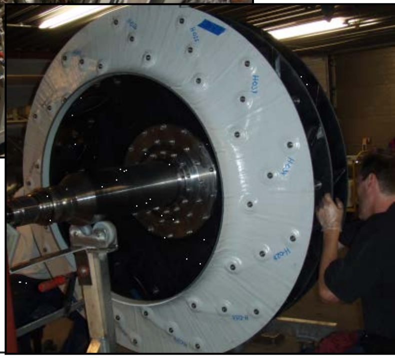
KNM Storm

Built by Umoe Mandal

20 years with air cushion vehicles

- Umoe Mandal is the **world leader in Air Cushion and Surface Effect Ships**
  - Unrivalled experience in design, building and maintenance of operational high performance naval craft
- Umoe Mandal has extensive experience in design and construction of **naval composite structures**
  - Umoe Mandal Composite Technology
- Umoe Mandal has the **leading experience** in high speed craft **gas turbine** applications
- Umoe Mandal is the **leading supplier** of advanced high capacity **lift fans**
  - 4 design generations in service



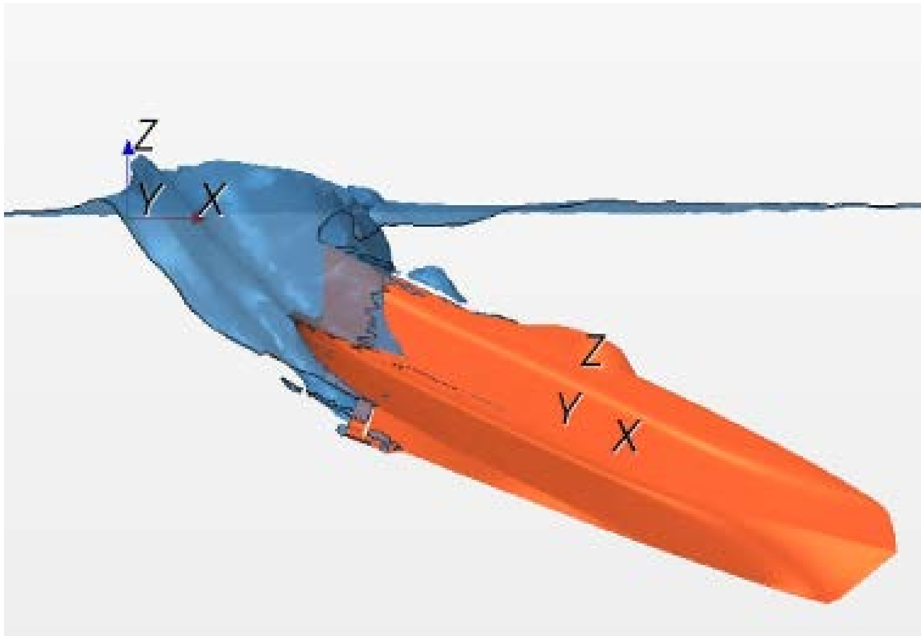


Umoe Mandal: Leading ship designers

- Leading ship designers for advanced ships and structures with
  - Advanced propulsion solutions
  - Composite materials/light weight solutions
  - Air cushion technologies
  - Military requirements and logistics support
  - Extensive CFD/FEM/3D-CAD capabilities

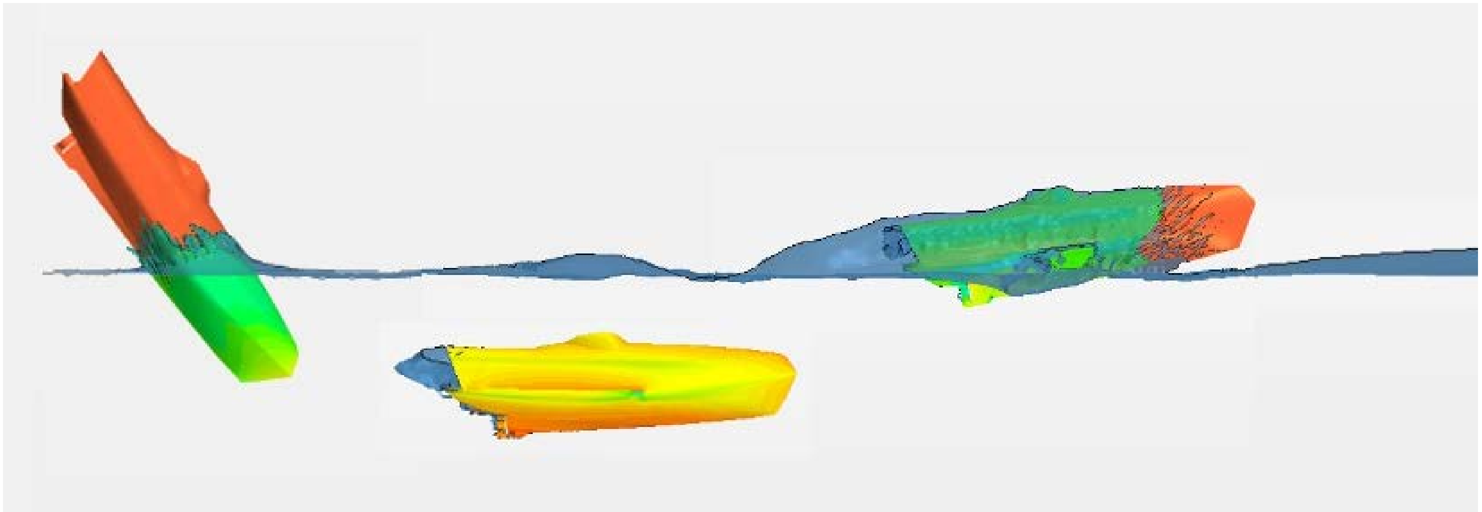
- Applying lean and efficient design methods and advanced design tools to reduce development time and costs
- Leveraging competitive and successful design work for demanding Norwegian and international Navy customers
- 26 highly skilled engineers within Naval Architecture/Marine Engineering

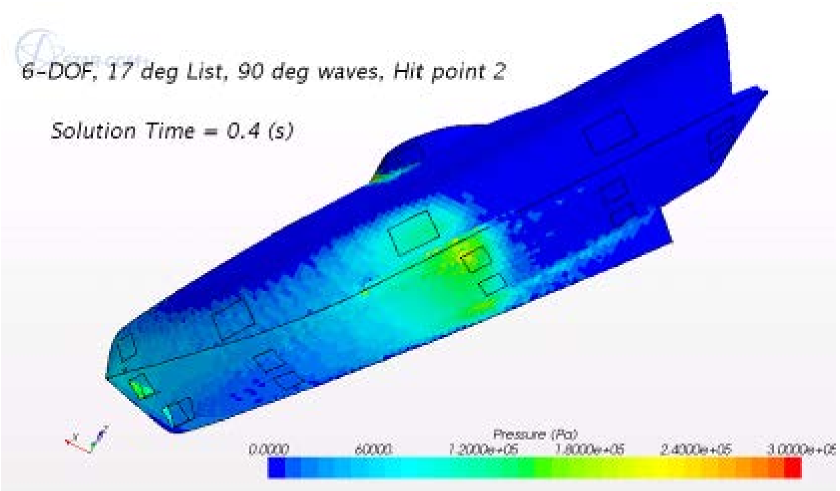
Extensive CFD capabilities

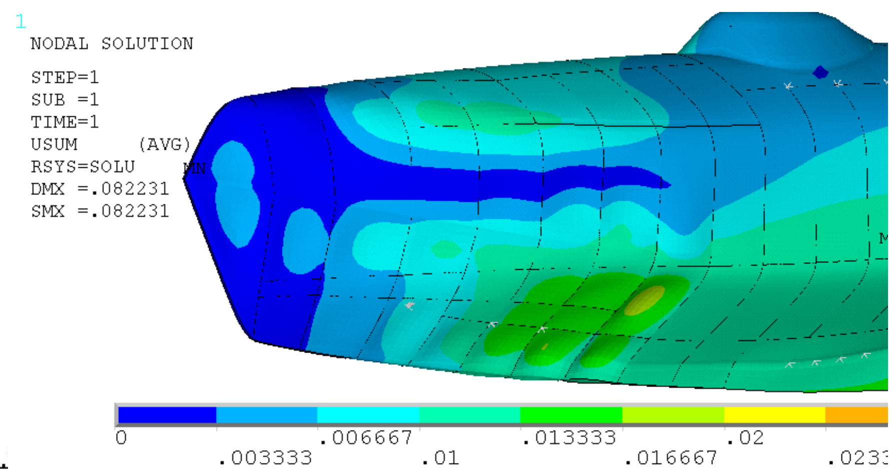


Umoe Mandal is designing the next generation free fall lifeboats from Harding Safety

Integrated hydrodynamics/structural design





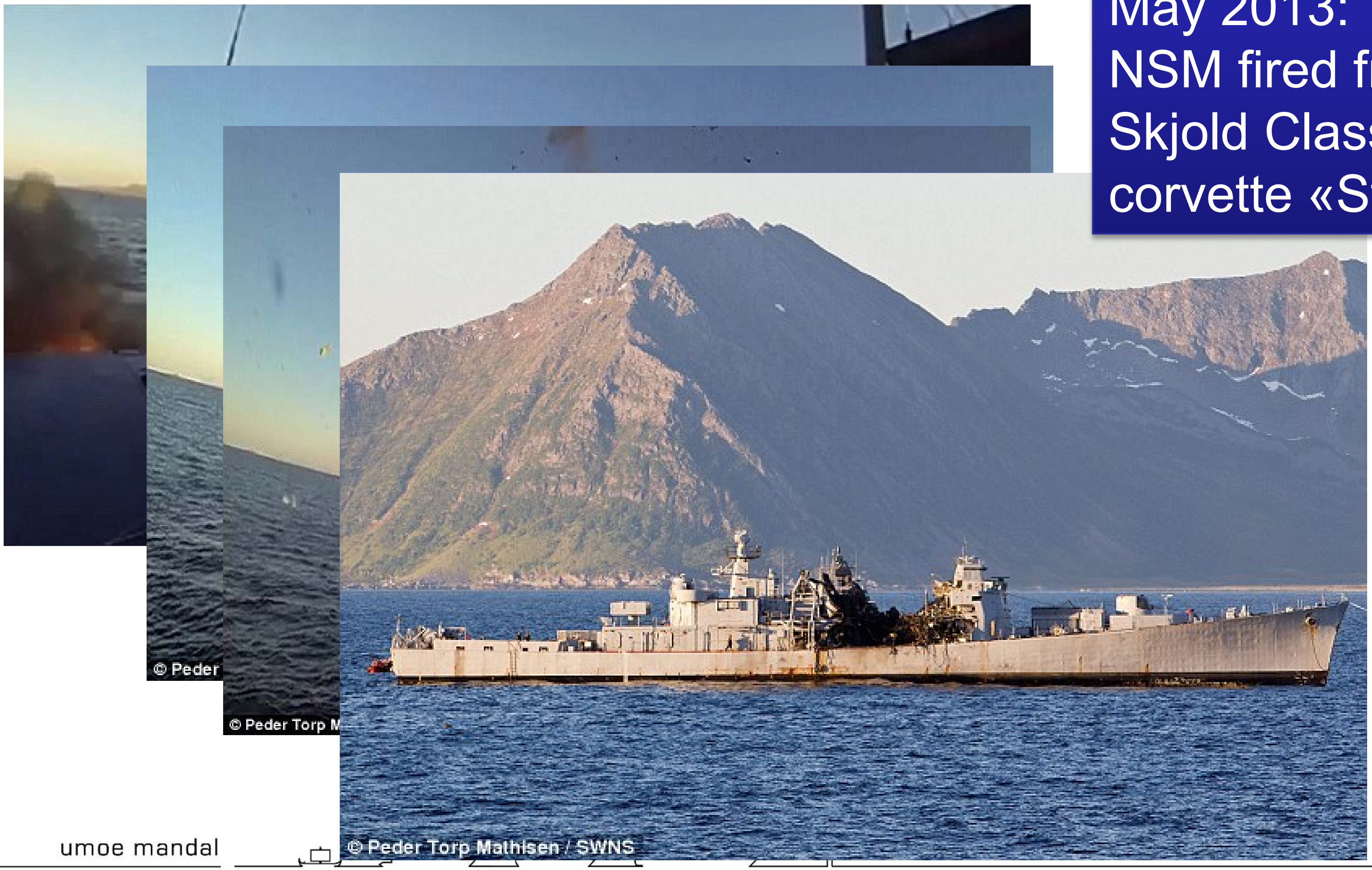


SKJOLD Corvettes – a success

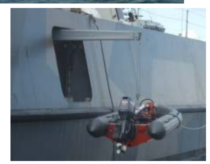
- **Successful operations in NATO exercises**
- **Successful first launches of the new Naval Strike Missile**
- **Last vessel delivered April 2013**
- **First implementation of RAS (Replenishment-At-Sea) completed**
- **International promotion focusing on Brazil, Turkey, Singapore and the US**

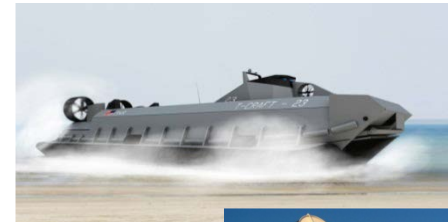
The formidable firepower of the Skjold class

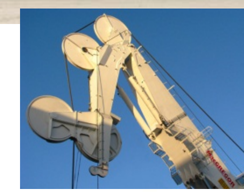
May 2013:
NSM fired from
Skjold Class
corvette «Steil»



Umoe Mandal - a history of innovation







1990-1997 | 1999-2013 | 2002-2004 | 2006-2007 | 2008-2013….

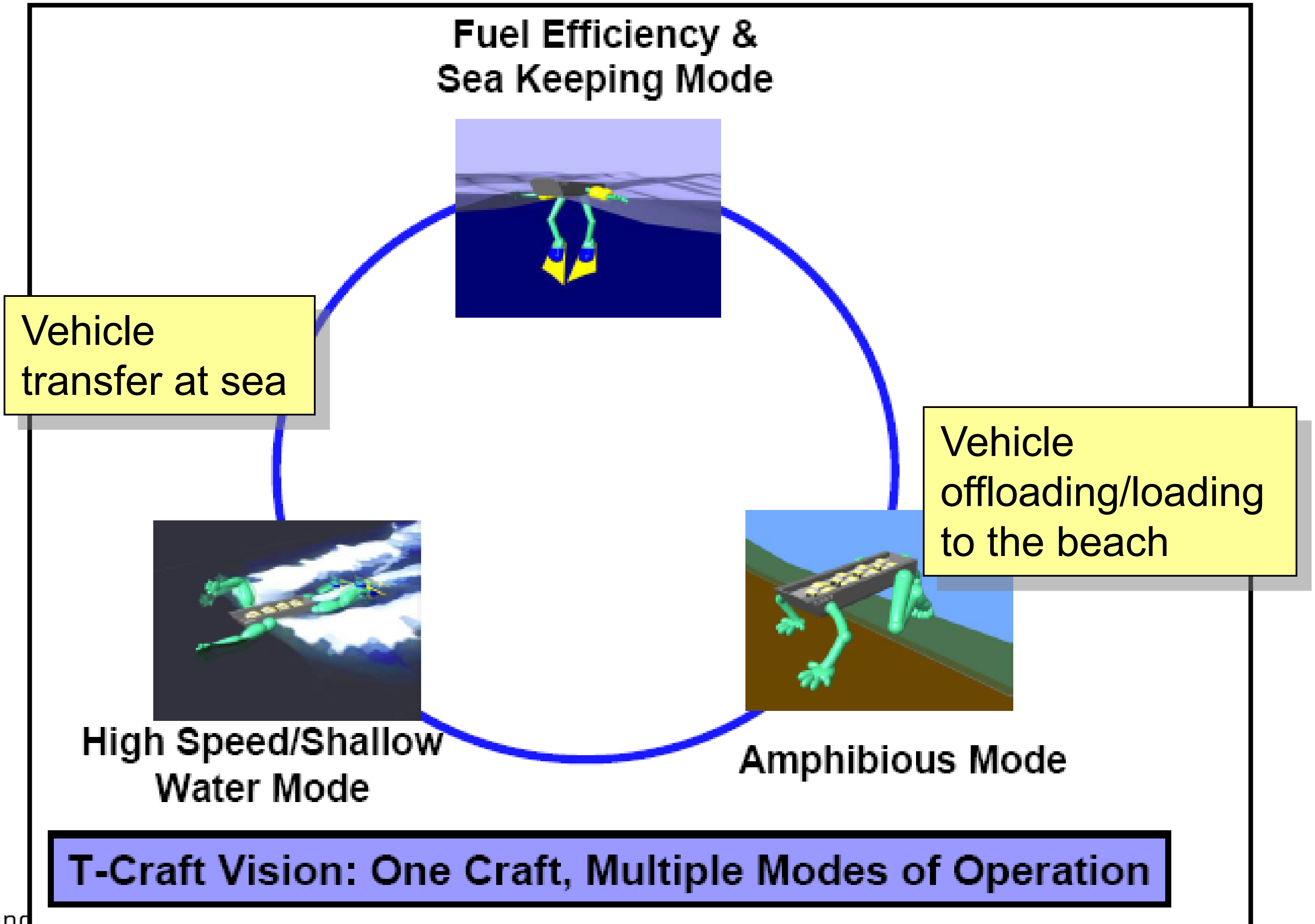
UM epoxy/carbon lift fan technology

- Fan blades produced with RTM
- Shrouds and centredisk produced with vacuum infusion
- 4 generations of lift fans in operation (>50 units)
- In operation by NAVSEA/LCAC since August 07

Design and production of composite components

- BAe Bofors MK3 Gun Cupola pptimized design by Umoe
  - Increased load capacity
  - Reduced weight
  - Reduced part count
    - Integrated features

The T-Craft Challenge



T-Craft: few requirements – as targets

Capability List:

1. Un-refueled range, in a no cargo condition, of 2,500 nautical miles in a Fuel Efficient/ Good Sea Keeping Mode (20 knots, through Sea State 5)
2. Open ocean operations through Sea State 6 (through Sea State 4 in High Speed/Shallow Water Mode) and survivable in Sea State 8.
3. Maximum Speed, full load condition in High Speed, Shallow Water Mode = ~40 knots through top end of Sea State 4.

Amphibious capability, in Amphibious Mode, to traverse sand bars and mud flats ...by providing a "feet dry on the beach" capability.

...convert between modes at-sea without any external assistance.

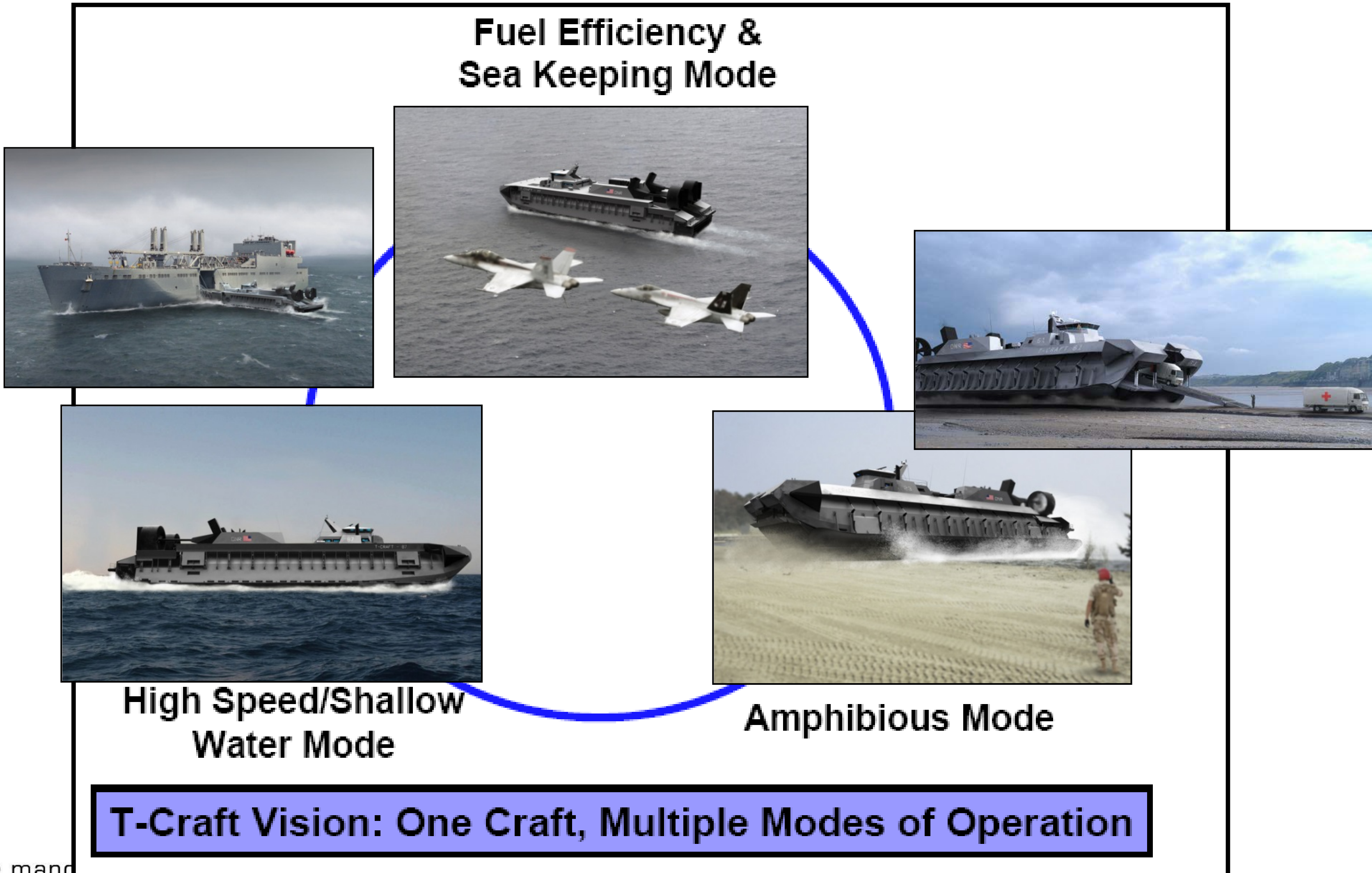
...fueled range in High Speed/Shallow Water Mode = ~500-600 ...ots, through Sea State 4).

...duced motions in Sea State 4/5 to enable rapid vehicle ...ween the T-CRAFT and a Maritime Prepositioning ...istics connector.

Thresholds/Objectives:

Notional Requirements	**Threshold**	**Objectives**
Cargo Payload Weight	300 lt	750 lt
Cargo Payload Area	2,200 sqft	5,500 sqft
Crew Size	3	2
Beach Slope Climbing	0.5%	2%
Vehicle Ramp Angle	15.0 degrees	12.5 degrees
Vehicle Deck Loading	350 psf	550 psf

The Umoe Response:



The Three Modal UM T-Craft Concept

Fulfills all three desired capabilities

1. Fuel economy based on
   - fuel efficient diesel engine powering high efficiency waterjets
   - SES vessel operating between humps
2. High speed and shallow draft
   - CODAG Diesel engine powered waterjets, gas turbine powered air propellers
   - SES vessel operating above hump speed
3. Amphibious mode
   – Gas turbine powered air propellers
   – Large air cushion area with a high air gap (1.5 m) to pass sandbars/mudflats and with beach ascending capability
   – operating below hump speed

Long range good seakeeping and high speed shallow draft mode: SES

Bow tandem connection to an LSD

…at sea cargo transfer made possible


Loading from the WATSON Class
side port….

The UM T-Craft…..

…delivering the cargo dry feet on the beach…..

Break-through contract in the US:

TEXTRON/Ship to Shore Connector

- *Development + Test Craft + 8 vessels*
- *Ambition to win additional series of 65 vessels 2019->:*

Making Offshore Wind Possible

UM Wave Craft

Speed, Access, Comfort

SET-BASED DESIGN

(OR KNOWLEDGE-BASED DESIGN)

We have tried two development processes

1. Requirement driven design (Structure-based design):
   - The design process aims to verify that the product will satisfy a large number of (>2k) detailed functional requirements
   - Formal process for evaluation and acceptance
   - Process focused management (rule-based)
     - The process is more important than the technical result
     - Progress reporting based on counting of finished documents

Norwegian naval programs: Ex: SKJOLD/LSV

2. Set-based design (Knowledge-based design):
   - A low number of requirements – more like targets
   - Focus placed on technical alternative solutions which are accessed and (down)selected at agreed milestones
   - Knowledge-based management

US naval programs: T-Craft and SSC

Classical Point Ship Design

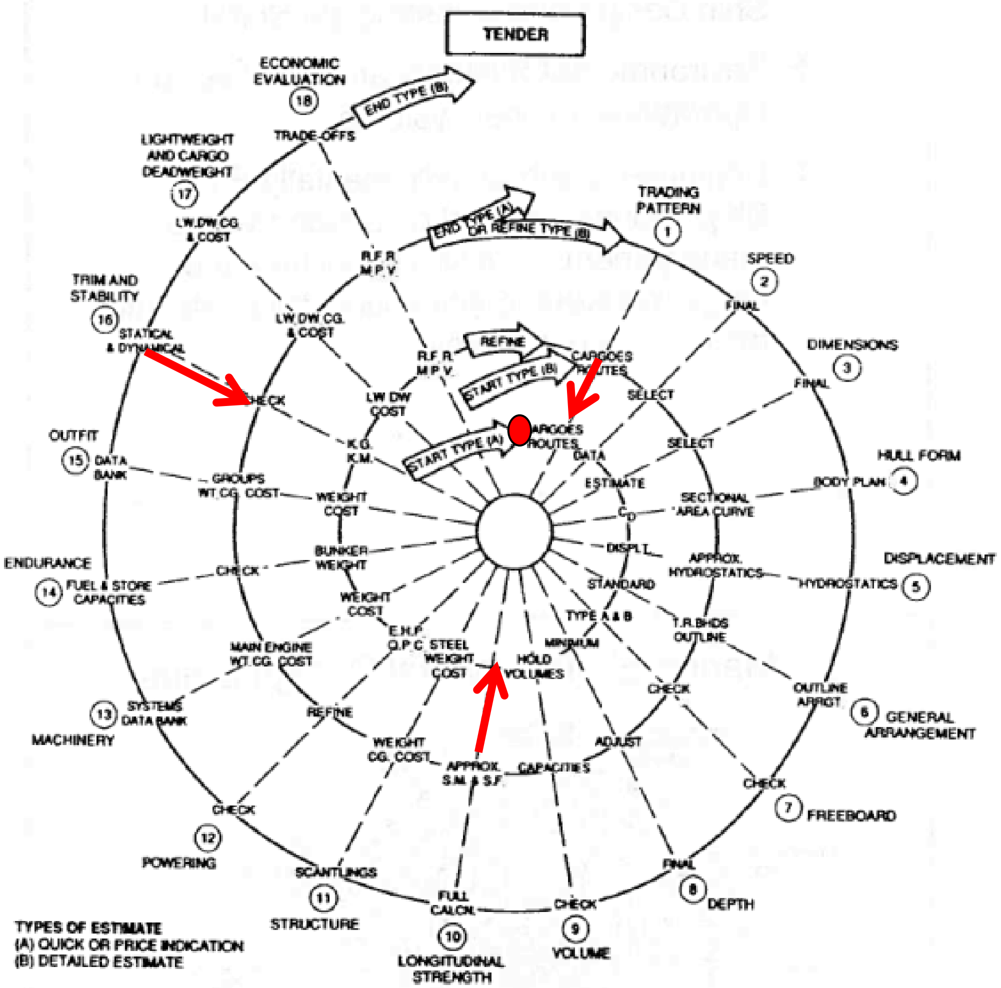
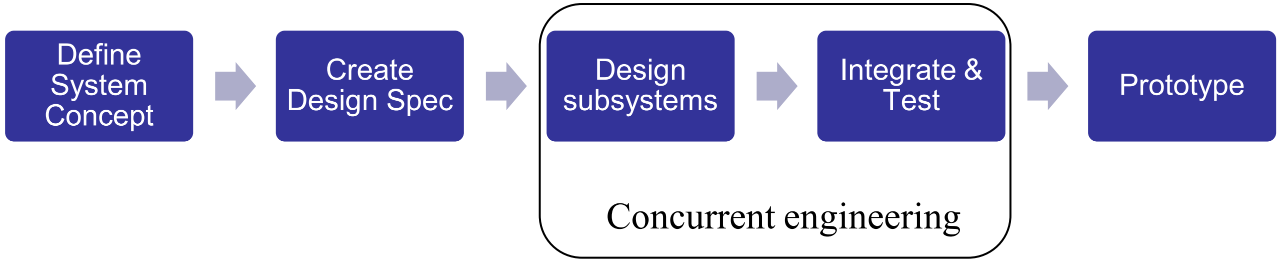


Figure 2: Classical Design Spiral. (Evans 1959)

- Major loopbacks often necessary when starting from scratch….
- Mange rotations are necessary….

Point design in practice

This is the plan:



- Major unplanned re-engineering occurs
- Costly loop-backs implying late changes on a large number of “finished” documents

Norwegian naval projects: Requirement driven design

- Several thousands functional and performance requirements established by the client
- For Umoe this meant:
  - Focus placed on «closing requirements» throughout the design process
  - Conflicting requirements create demanding processes when discovered
    - Results in major re-engineering and revisions of already issued documents
  - The energy is used on the process and to document the process steps rather than finding the best solutions
    - Counting requirement status and compliance, punches, document nos. and revisions, prove traceability, audit deviations and waivers, changes, progress
- Result: The requirements are satisfied in the end, however,
    - Delayed and to a higher cost
    - Uncertainty whether the result is at all close to the optimum

Requirement Engineering (RE)

- Defining the solution «in abstract» terms
- Used in US since WWII, however now NOT in use in US Navy today
- Continues to be used for naval ship design programs in UK and Norway

Andrews (2011):

- RE is «not appropriate for warships»
- RE is «bad Systems Engineering practice»

Andrews, D. J. (2011). Marine Requirements Elucidation and the Nature of Preliminary Ship Design
Transactions of the Royal Institution of Naval Architects Part A:
International Journal of Maritime Engineering, 153 (Part A1)

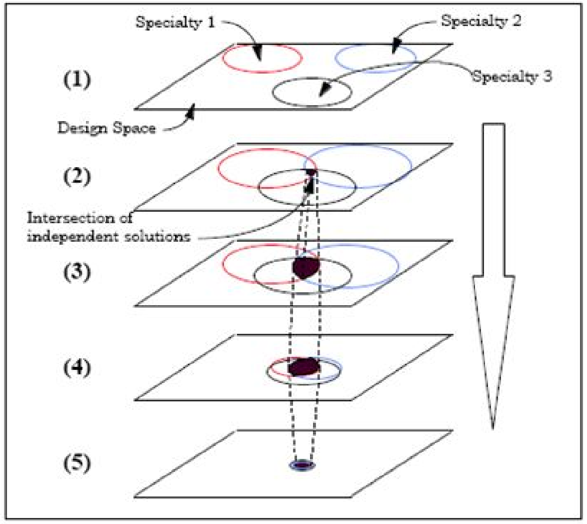
US Navy Introduces Set-based Design

- Based on many failed, too late and too expensive ship design efforts since the 1990'ies
- Ship Design and Analysis Tool Goals
  - Letter issued in 2008 by Admiral Paul Sullivan, Commander of the Naval Sea Systems Command,

NAVSEA
NAVAL SEA SYSTEMS COMMAND

2009: Set-based design is used by US Navy for the SSC-program:

1. Consider a (large) number of design alternatives by understanding the design space
2. Allow specialists to consider a design from their own perspective and use the intersection between individual sets to optimize a design
3. Establish feasibility before commitment
   a) Narrowing sets gradually while increasing detail
   b) Staying within a set once committed
   c) Maintaining control by managing uncertainty at process gates



Result:

- Conceptually robust designs
- Promises a capacity to adapt quickly to changing requirements and design discoveries.

*What Is Set-Based Design?
DJ Singer, N Doerry, ME Buckley - Naval Engineers Journal, 2009

The UM T-Craft design approach

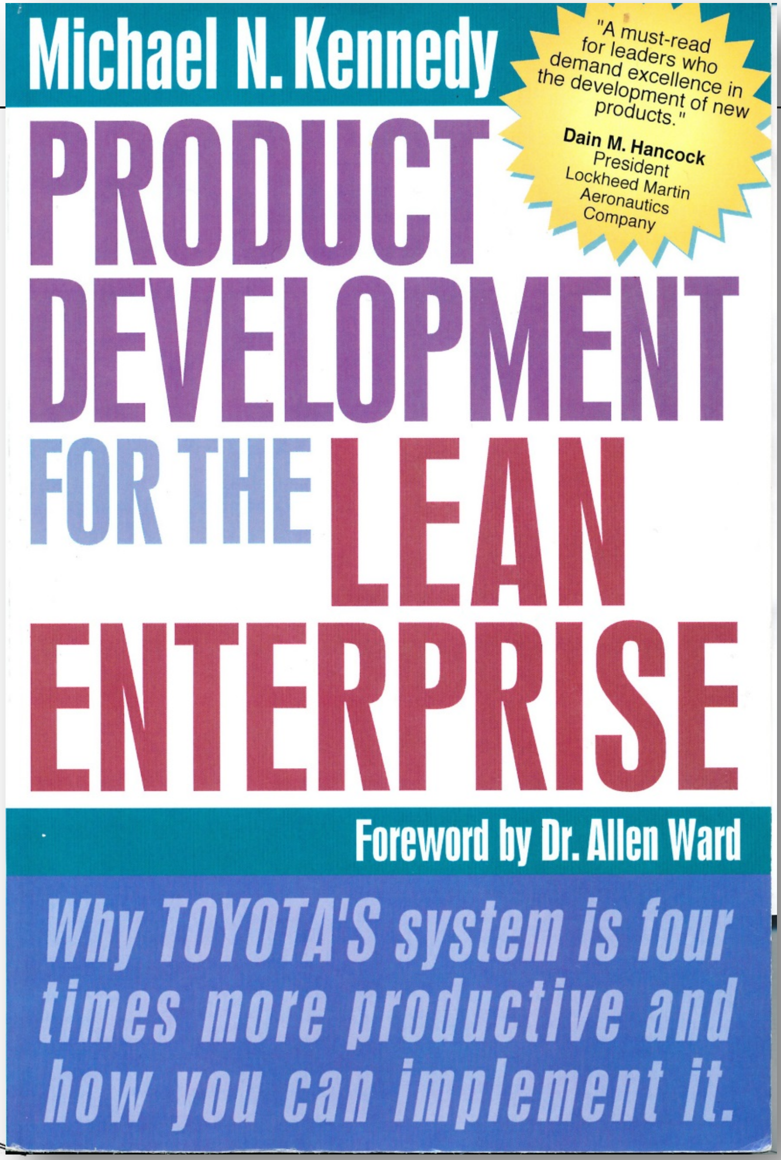
A knowledge based creative ship design process

successfully applied

2009:

- “Everybody” talked LEAN
- I received this book with the order:

READ



Development Environment

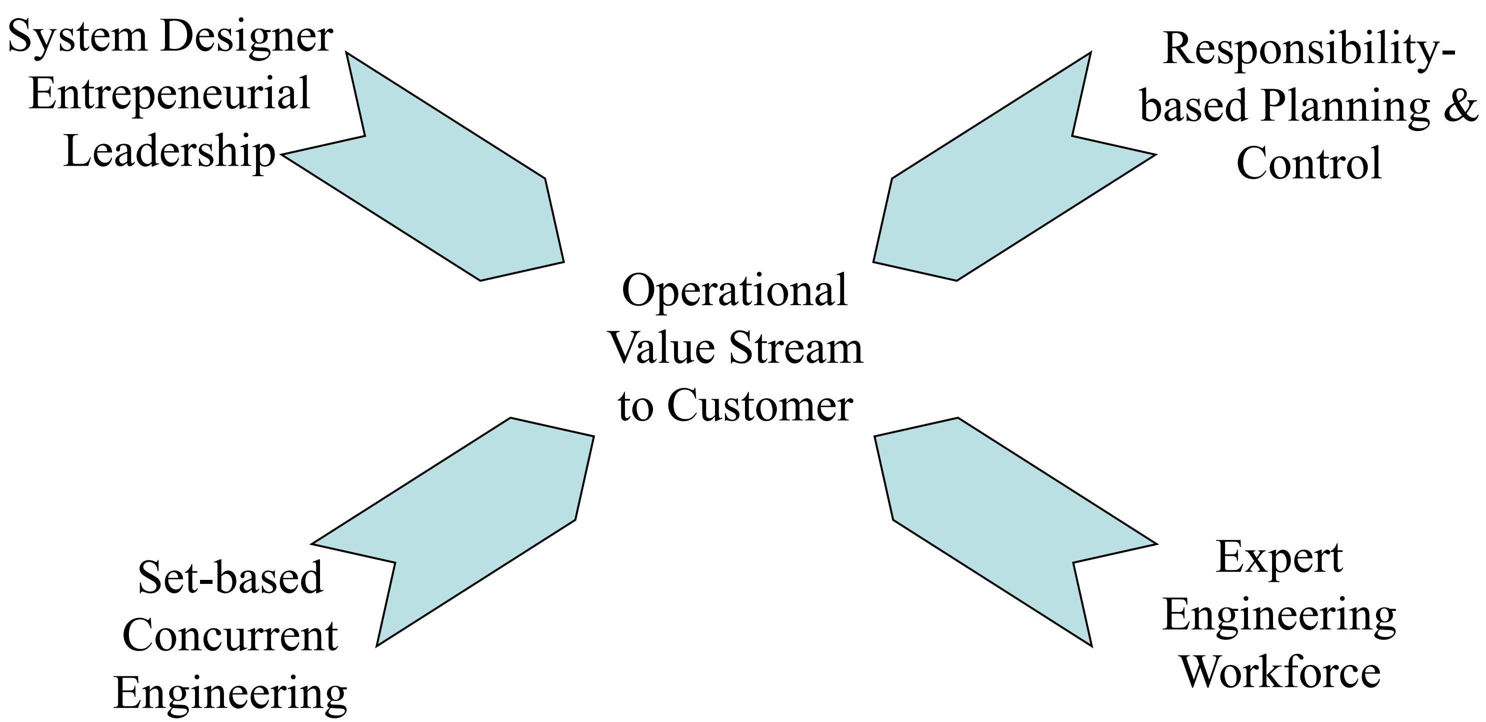
- The foundation for lasting change –

A Continuum

Structure-based	**Knowledge-based**
The basis of the engineering environment is the **structure of the operational activities:** procedures, control, compliance, related training	The basis of the engineering environment is the **knowledge of individual workers:** Understanding of needs, information availability, responsibility and teaming interaction
(Umoe in 2009?)	(Toyota)

Fra Kennedy 2003

The Lean Development System (Knowledge-based Development)

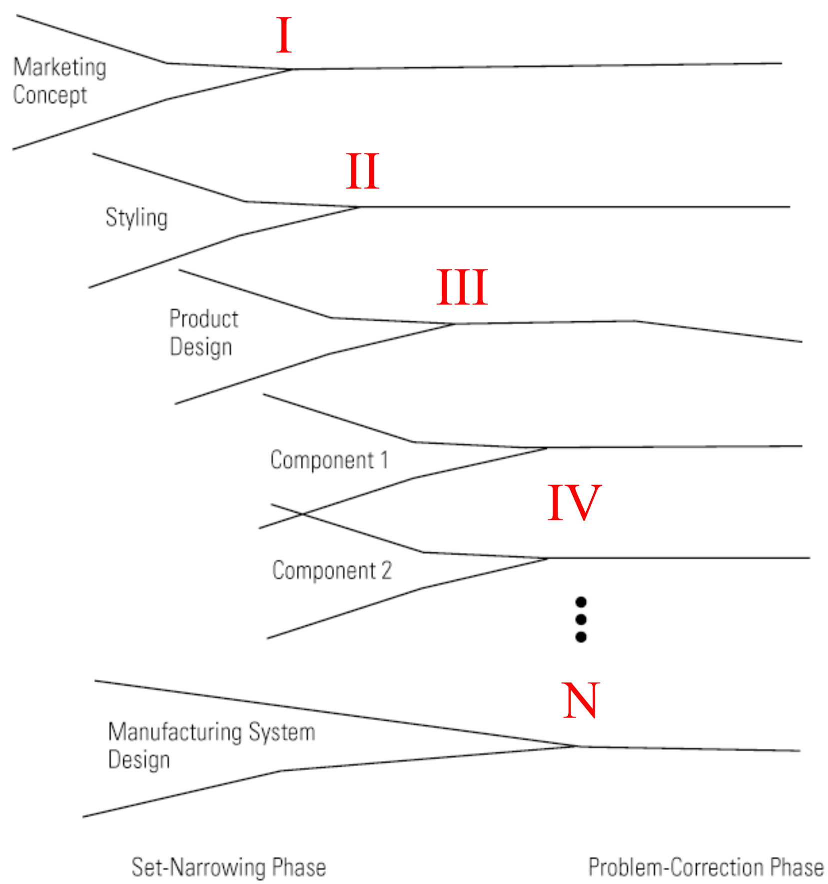


An operational value stream **emerges** from the interaction of four critical culture elements

Fra Kennedy 2003

Decision taken at defined process gates:

Figure 3 Toyota's Parallel Set-Narrowing Process

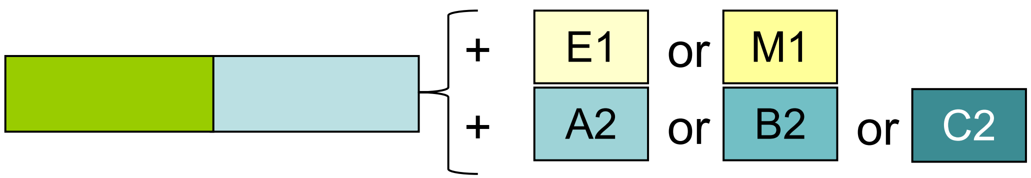


Note: Based on a sketch by Toyota's general manager of body engineering in 1993.

- Dates for the process gates are set and agreed by the design team
  - And always kept !
- At the process gates (integrating events):
  - Evaluation and (down)selection of design sets
  - Progress is assessed

T-Craft: Use knowledge-based design:

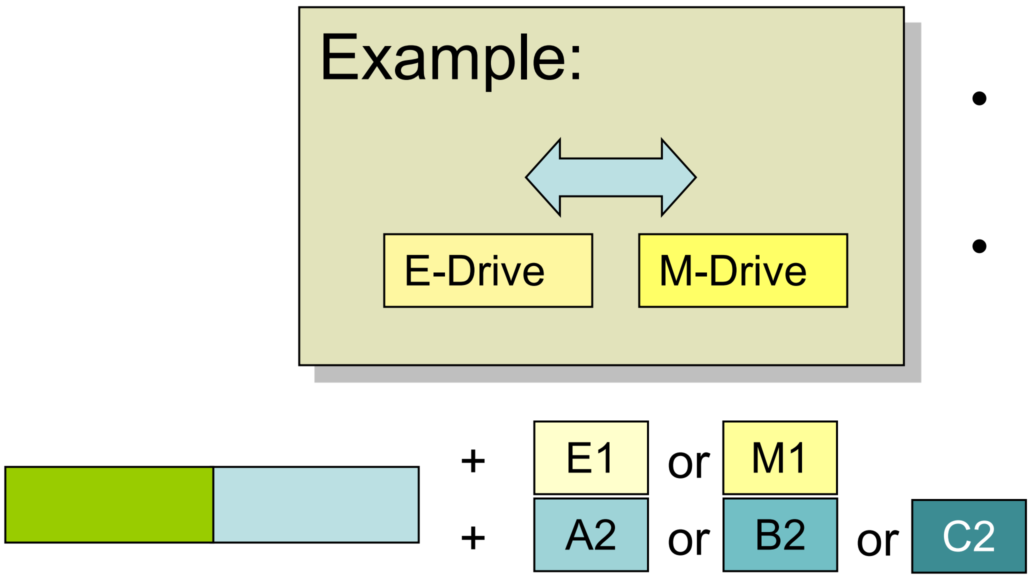
- During the T-Craft Phase 1 and 2 (2008-2011) we have actively tried out a novel (for UM) product development method
  - inspired by Toyota* product development methods
  - prof. Kai Levander, NTNU (Finland)
- Knowledge Based Design
  - Knowledge based design is based on complete design sets where alternative solutions <u>are tested</u> and selected
  - Other names: Set-based design, Lean product development



*See: Michael N Kennedy: Product Development for the Lean Enterprise: Why Toyota's System Is Four Times More Productive and How You Can Implement It. Oakley Press 2003

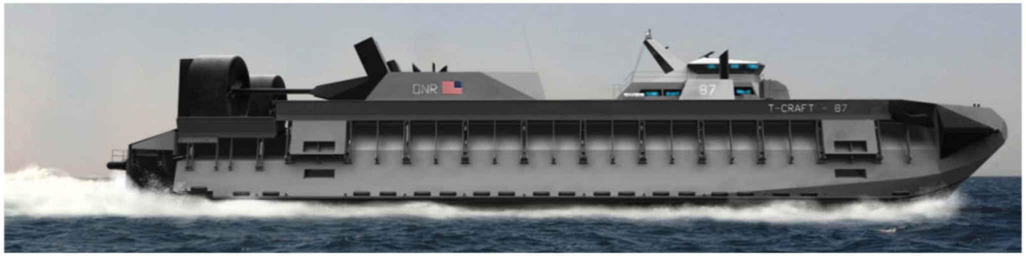
Knowledge Based Design:

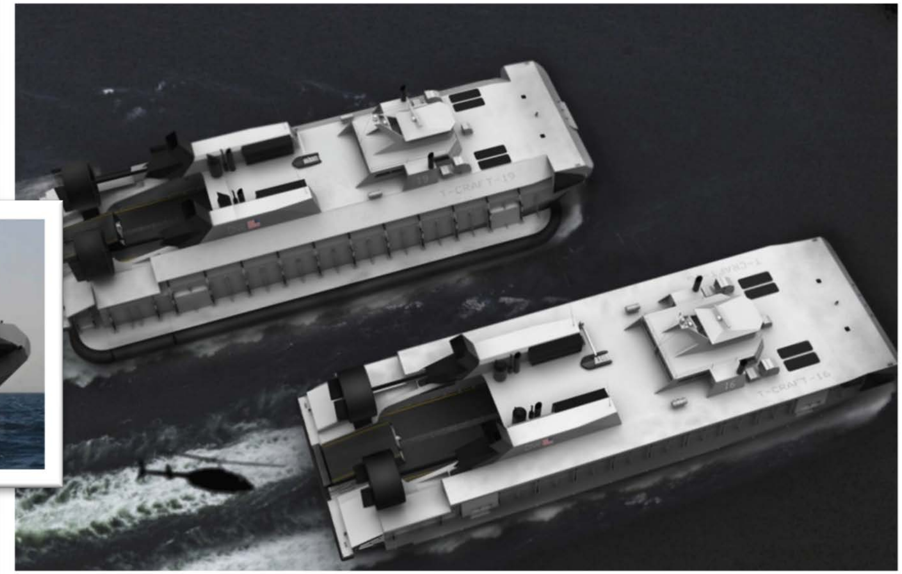
- Knowledge based design is based on complete design sets where alternative solutions are tested and selected



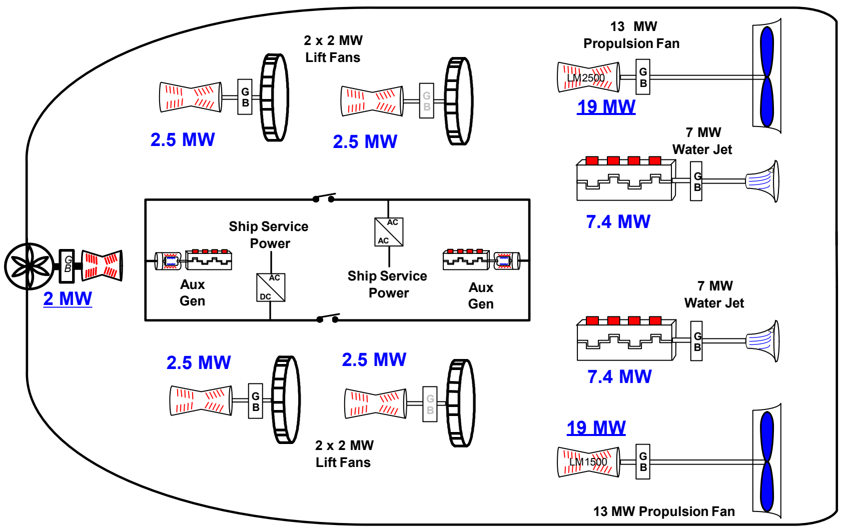
- The decision affected the whole ship and “all” drawings
- Decision to be taken as late as possible at an agreed milestone
  - Before drawings were made
  - When we had acquired sufficient and quantitive knowledge to take the right decision

T-Craft main drive alternatives

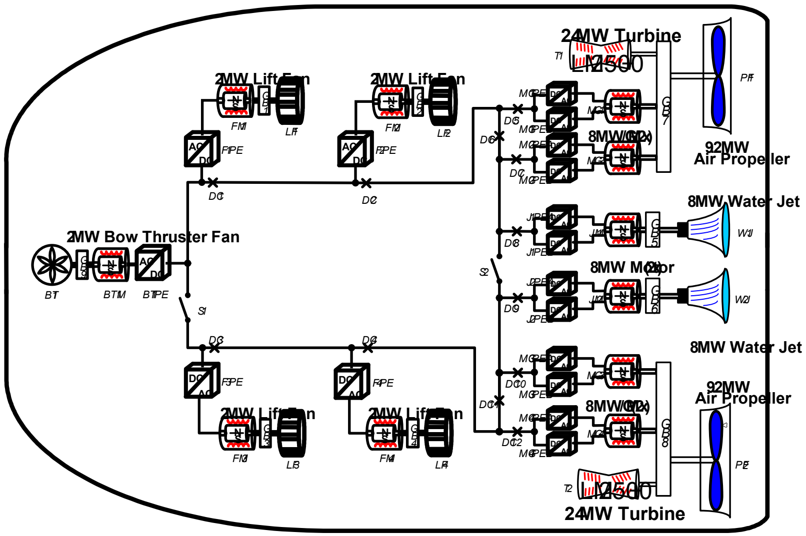




M-drive:



E-drive:



Example: A new ship type is to be developed

- Four new technologies are needed:
  - Transformation from SES toACV
  - Propulsion system effective at sea and over land
  - Mechanical or electrical Power transmission
  - Cargo transfer system ship to ship
- Assume 80% success rate for each technology

Point Design:

0.8 for Transformation x

0.8 for Propulsion x

0.8 for Power transmission x

0.8 for Cargo transfer

Probability for success with all solutions in the project:

$= 0.8^4 = \mathit{0.41}$

Set-based:

Probability of all three solutions for each technology fail:

$= (1 - 0.8)^3 = \mathit{0.008}$

Probability for success with all solutions in the project:

$= (1 - 0.008)^4 = \mathit{0.97}$

Set-basert design gives dramatic reduced risk in development projects

Knowledge based design vs traditional ship design

Knowledge based design process

- Set–based design process
- Always a plan B
- Extensive re-use of knowledge
- Model testing as early as possible to learn
- Milestones are kept
- Open development process – all team-members are kept informed and involved
- Publish documents (knowledge)
- Progress is measured at milestones
- Active use of the 3-D model, no artificial 2-D presentations of intentions
- Drawings are made as late as possible to avoid changes
- Solutions **emerge**

Traditional design process

- Revolving spiral process
- Point design
- Start from scratch
- Model testing as late as possible to verify
- Milestones are delayed
- People are informed on a need to know basis
- Archive documents
- Progress is measured by counting "finished" drawings
- 3-D mainly used for artists impressions
- Drawings are made as early as possible to show progress
- Solutions are given

Our experience from T-Craft

Knowledge based process

- Risk is continuously reduced
- Fully integrate suppliers into the product development system
- Progress estimates are more reliable
- Fewer late design changes
- Team members are involved and motivated – always learning
- Critical milestones never delayed
- Open working environment improves interdisciplinary interaction
- Model tests motivate design improvements

Traditional process

- Risks are often ignored – the easy solutions are done first
- Do not include suppliers before they can be contracted
- Progress is overestimated
- Many late design changes – drawings are revised repeatedly
- Team members are frustrated
- Delays are recognized too late
- Interdisciplinary check is a pure <u>formal</u> process
- Late model tests are to be taken as *fait accompli*

The requirement specifications govern the design process

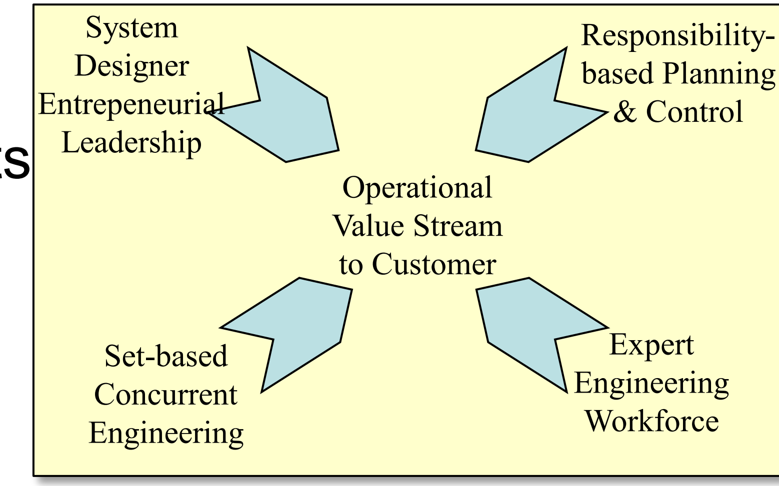
Therefore:

- Always better with few than many requirements
  - Reducing conflicting requirements
- Better with «targets» than absolute requirements
  - Targets facilitate trade-offs and optimizations between conflicting requirements
- Avoid that requirements are formulated too ambitious at “expert level”
  - Will create large problems when some requirements are only partly (or almost) achievable
- Describe what equipment is preferred instead of creating abstract requirements to functions and performances
  - Describe “what” and not “how to”
  - «Smart» functional requirements cause delays and cost increases

Why do not everybody use set-based design:

- Many requirement specifications are extremely structured
  - The client believes strongly that a high number of detailed requirements ensure quality
  - The reality is opposite!
- It is (more?) difficult to document (prove) progress
  - To use resources on alternatives seems expensive
  - Assessment of progress takes place at milestones/integrating events
    - The controllers/auditors prefer to count and measure
- Management and control is transferred from «management» to «chief engineers» and experts
  - These must be trusted
- Difficult to keep focus over time – a culture change is needed

Our experience



Knowledge-based development:

- Reduced manning levels in projects
- Reduced duration
- Reduced number of late changes
- Improved risk management
- More optimum solutions
- Many solutions available for the next project
- The time schedule holds

..as for a wedding

Thanks!