Composite Material Superstructures on Steel Naval Vessels

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Presentation Outline

- Presentation of Umoe Mandal
- EUCLID RTP3.21 program background
- Program objective and aims
- Program case scenario, WBS and philosophy
- Program phases and deliverables
- Cost Benefit Assessment model
- Test and modelling scheme with examples
- Design results: Final Designs
- Overall achievements
- Conclusions and suggested further work
- Acknowledgements

Presentation of Umoe Mandal

- Established in 1989 for an RNoN MCMV contract
- Facility optimised for FRP vessel production
- Currently 300 employees
- Main technology
  - Composites materials
  - Naval ship design
  - SES vessels
- Main naval vessels produced:
  - Oksoy class MCMV
  - Skjold class FPB
- High-end composite components
  - Lift fans, etc.
- Extensive in-house R&D

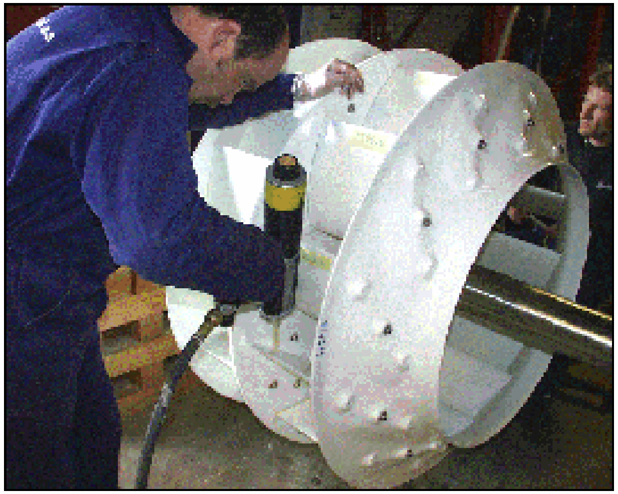
Umoe Mandal facility

UM Project Reference List

- 1994-97: 9 Mine Countermeasure Vessels (MCMVs) of the Oksoy class
- 1992: 12 m experimental Surface Effect Ship as a scaled model.
- 1997: “Innovation Kværner” Whitbread 60 Sail Racing Yacht.
- 1998: 25 meter monohull Search and Rescue/Coast guard vessel.
- 1999: Prototype of the Skjold class Fast Patrol Boat (FPB)
- 2003: Awarded the Skjold class series production contract of 5 vessels

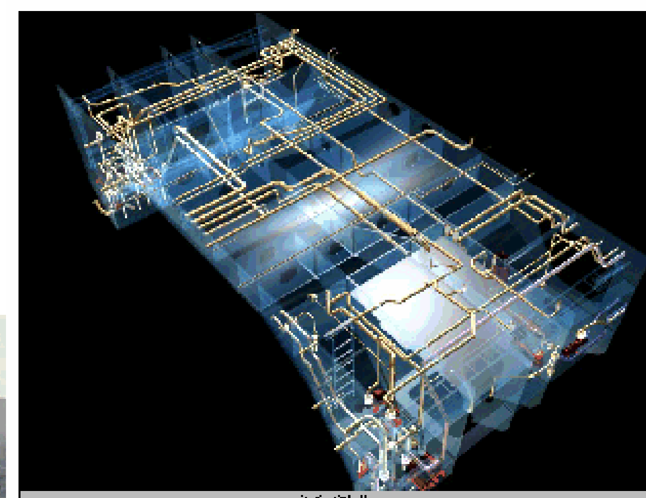
UM High-end Composite Components

- Lift fans for Norwegian Navy MCMV and FPB (RTM production)
- Lift fans for Finnish Navy ACV
- Cupola gun shield
- Towed body for mine sweep
- Wind turbine blades
- Etc.



UM Know-how and Technology

- Core Know-how:
  - Conceptual ship design
  - Detailed design of naval ships (Vulnerability, Survivability)
  - SES design
  - MCMV/FPB design
  - Composite material knowledge (prod., environmental, dynamic,..)
  - Highly optimised composite structures (weight, shock, slamming, etc.)
  - Systems Engineering
  - Integrated Logistics Support
- Core Technology
  - SES technology
  - Signature technology
  - Composite production and repair technology
  - EMI/EMC technology



EUCLID RTP3.21 background

- Executed between 2000 and 2004
- 24 Industrial Entities from six countries participating: Denmark, France, Holland, Italy, Norway, UK
- Total budget $12 million
- Formal customer: Western European Armaments Organisation
- Day-to-day customer: Management Group consisting of MoD representatives from each country
- Research and Technology Project (RTP) 3.21 “Survivability, Durability and Performance of Naval Composite Structures”, within the frame work of European Co-operation for the Long Term in Defence (EUCLID)

EUCLID RTP3.21 background (2)

- Use of FRP composite material for naval vessels well established
  - Different requirements: weight (speed, pay load), non-magnetic, LCC, signature reduction, VCG, etc.
  - Mainly smaller ships, i.e. >50 meters
- Experience: Hard sell initially, but happy customers eventually
  - New way of thinking for a ”steel based” navy
  - Misconceptions, e.g. difficult to repair
- Idea: Present validated design solutions to the customer for **larger** ships or ship components

EUCLID RTP3.21 background (3)

- Advantages using composite materials also for larger naval vessels:
  - Low weight: high speed, high pay load, smaller machinery, lower fuel consumption, etc.
  - Lower CG: lower weight, better sea keeping
  - Integration of sensors into structure
  - Integration of special features into structure
  - Low maintenance cost
  - Large internal volume
- Composite superstructures interesting case
  - Lower signatures, sensor integration, lower weight/CG
  - Ideal test case for "steel navy"

EUCLID RTP3.21 Objective

EUCLID

RTP3.21: Survivability, Durability and Performance of **Naval Composite Structures**

- To strengthen the technological basis for the large-scale application of fibre-reinforced composite materials to naval vessels and structures, so that such vessels (or major parts thereof, e.g. superstructures) can be designed with confidence on the basis of modelling and failure prediction.

Program Aims

1. Develop and apply a method to estimate and document performance of alternative design solutions
2. Reduce vulnerability of composite structures for naval vessels
3. Reduce life-cycle costs (manufacturing, inspection, maintenance, repair) of naval vessels with composite structures.
4. Quantify competitiveness of naval composite structures compared to a traditional steel option
5. Establish or improve modelling capabilities for prediction of vulnerability of naval composite structures
6. Establish or improve models to predict life-cycle costs (manufacturing, operation) of naval vessels with composite structures

EUCLID RTP3.21 case scenario

- Frigate helo-hangar selected as case scenario
- Hazard identification work shop conducted for helo-hangar
  - Potential threats identified
  - Damage consequences analysed: UNDEX, internal blast, external blast, and fire ranked as most serious
  - Survivability of composite solution must be similar or better than steel, on an **functional level**
- Work Breakdown Structure established based on hazard identification
  - Weapon loads → joints (Stiffener-joint, T-joint, Metal/Composite-joint)
  - Combat fire load → hydro-carbon fire
  - Electromagnetic Shielding

EUCLID RTP3.21
Work Breakdown Structure

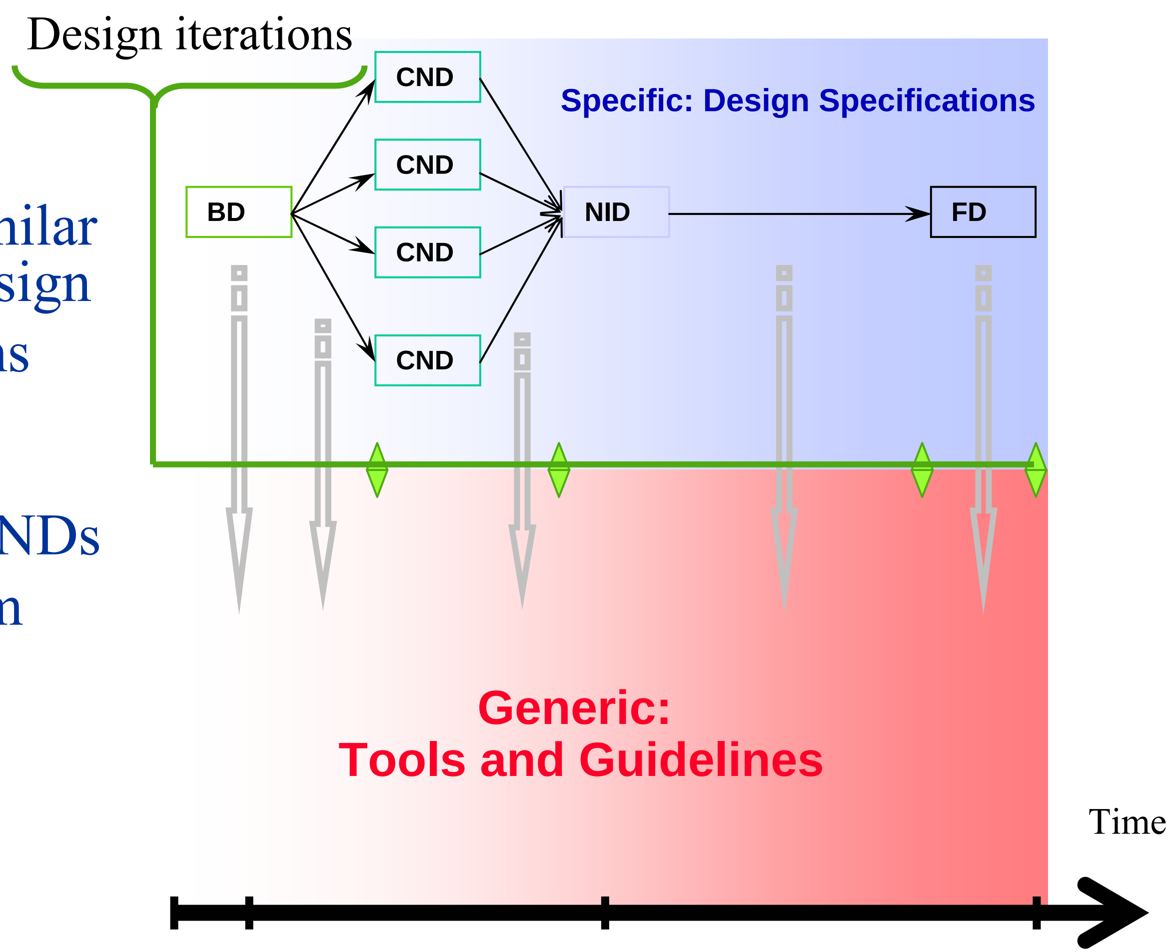
- **WP 0: Management**
- **WP 1: Technical co-ordination**
- **WP 2: Joints**
  - **WP 2.1: Joint material modelling and characterisation**
  - **WP 2.2: Joint design and performance**
  - **WP 2.3: Joint production and inspection**
- **WP 3: Fire**
  - **WP 3.1: Fire testing**
  - **WP 3.2: Simulation of structural response to fire**
- **WP 4: Electromagnetic Shielding (EMS)**

Program philosophy

- Qualify composite design solutions with realistic loads and a realistic operational environment
- All work with focus on industrial applications
  - testing and production
- All relevant results incorporated into industrial guidelines and production procedures
  - later design and production tasks
- Modeling and testing done in parallel to develop modeling and prediction capability
  - later design tasks
- Internal competition between designs suggested by the different countries: BD → CND → NID → FD
- Cost Benefit Assessment model used to quantify design improvements

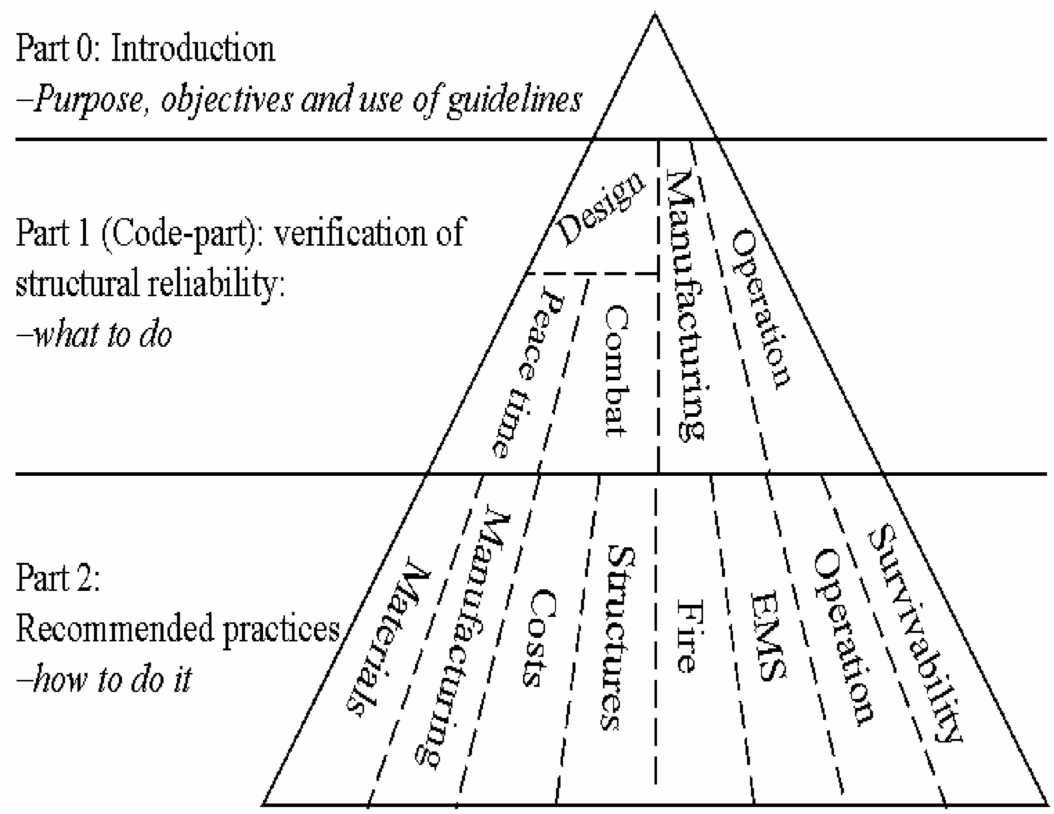
Program phases

- Base Design (BD): Similar to French Lafayette design
- Candidate New Designs (CNDs) suggested
- New Improved Design (NID) selected from CNDs
- Final Design (FD) from improved NID
- EMS work organised separately



Program deliverables

- Design Specifications
  - M/C-joint
  - T-joint
  - Stiffener joint
  - Fire protection
  - EMS solution
- Program Guidelines
  - Design verification
  - Recommended Practices
- Technical Reports
  - Input to Guidelines
  - Data



Guideline structure

Program deliverables (2)
TOC for Guidelines

- Part 0: Introduction
- Part 1: Verification of structural reliability (-*what to do)*
  1. Structural design of bonded joints in naval ships
  2. Design code for combat situations
  3. Prescriptive requirements to control fire vulnerability of naval composite structures
  4. Manufacturing and maintenance of naval composite structures
- Part 2: Recommended practises (-*how to do it)*
  1. Material modelling and characterisation
  2. Manufacturing of naval composite structures
  3. Structural design and assessment for naval composite structures
  4. Fire performance of naval composite structures
  5. Electromagnetic Shielding (EMS) of naval composite structures
  6. Cost benefit survivability assessment for naval ships

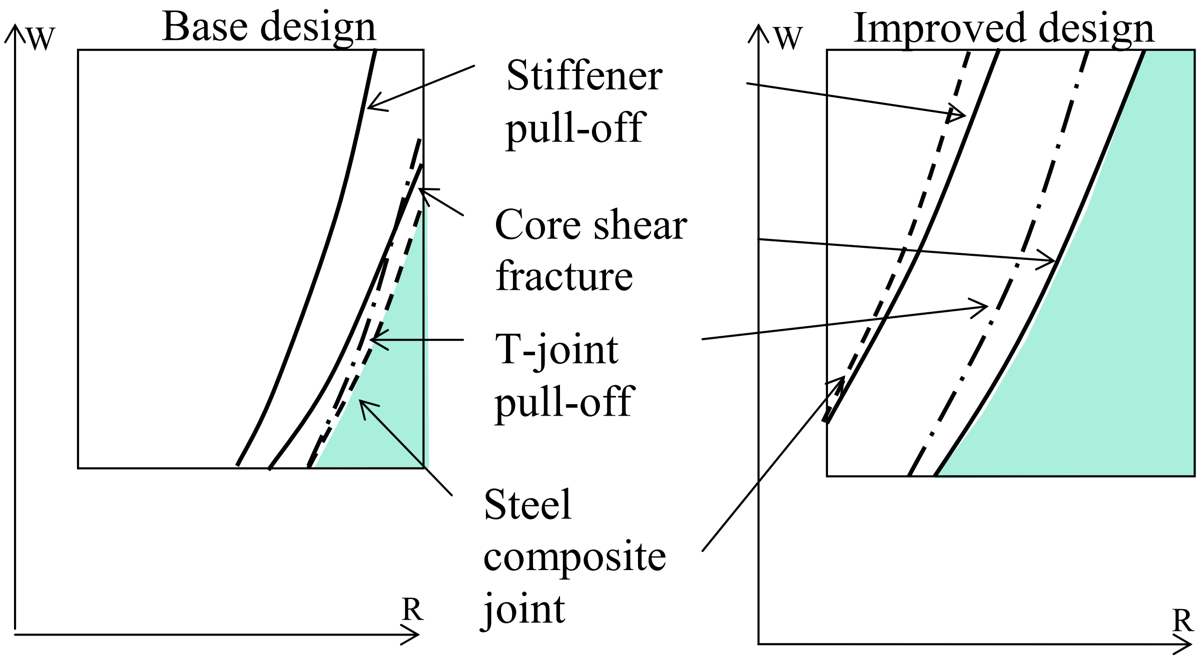
Cost Benefit Assessment model

- A Cost Benefit Assessment (CBA) model was needed
  - to select NID from suggested CNDs, i.e. quantify improvements
  - balance requirements, i.e. not steel requirements
- Survivability S
  - *V* is calculated vulnerability
  - *s* is an estimate of susceptibility
- Structural performance *P*; higher *P* get selected
  - *C* is a cost estimate for each design

$$S = 1 - Vs$$

$$P = S \big/ C = \frac{1 - Vs}{C}$$

Cost Benefit Assessment model (2)



- Failure mode in a blast event as a function of charge weight W and stand off distance R: Green area indicates survival
- A clear improvement can be seen from the Base Design to the New Improved Design: Steel/Composite joint is governing for BD structure, core shear failure for NID structure

Overall test and modelling scheme

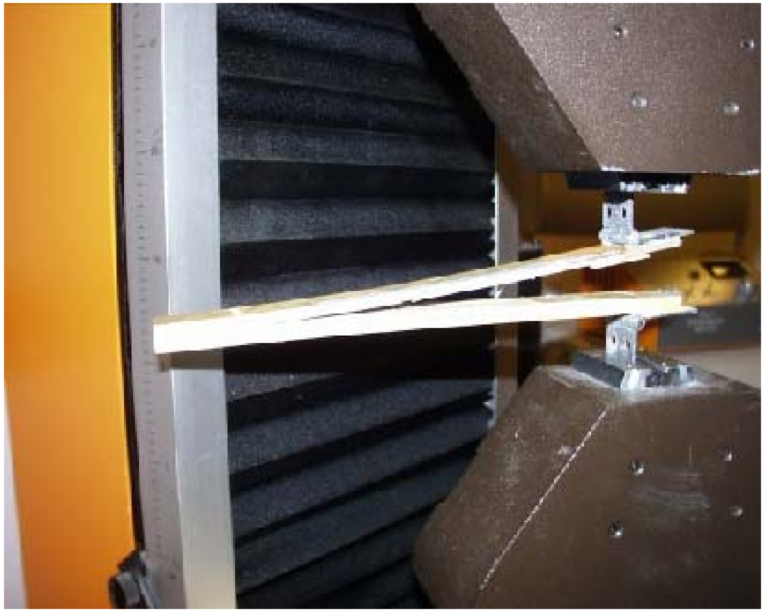
- Material testing
  - Static, dynamic
  - Fatigue, environmental
  - Fire reaction and resistance
- Joint testing
  - Static, dynamic
  - Fatigue, environmental
  - Freeze/thaw
  - Fire
- Testing of full scale sections with joints
  - Blast
  - Blast with fragments
  - Fire, fire after fragments

→

- Optimized material selection
- Optimized and validated designs
- Tools needed for modelling and simulation
- Validation and tuning of prediction models
- **Below examples of testing and modelling are only a small part of the total program**

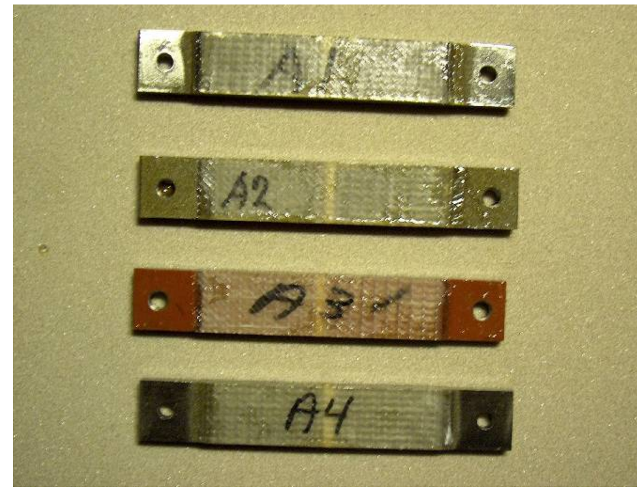
Examples of material characterisation

- DCB/Wedge test
  - Adhesive selection
  - Resin selection



Courtesy Umoe Mandal, Norway

Examples of material characterisation (2)



Courtesy DNV, Norway

- Accelerated ageing
  - Adhesive selection
  - Primer selection
  - Surface treatment

Examples of joint testing

- Static testing
  - Compression
  - Tension
  - Bending

Courtesy FiReCo, Norway

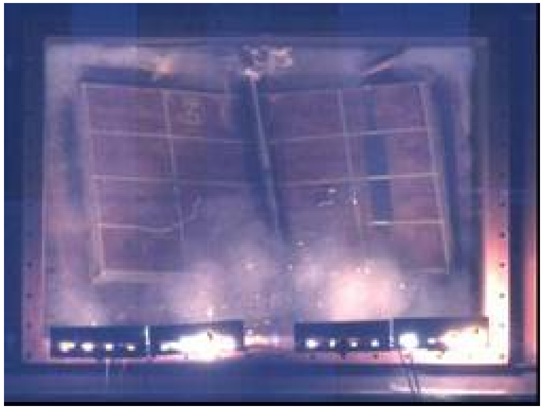
Examples of joint testing (2)

- Dynamic testing
  - External blast
  - UNDEX

Courtesy QinetiQ, UK and
TNO, The Netherlands

Examples of testing of full scale sections with joints

- Full scale section testing
  - Internal blast
  - External blast



Courtesy DCE/GERBAM, France and OTO-Breda, Italy

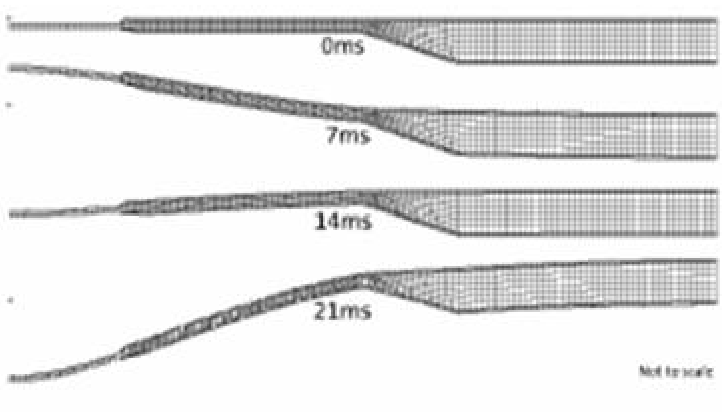
Examples of fire testing

- Fire testing
  - Insulation after fragments
  - Identical steel and composite corridor

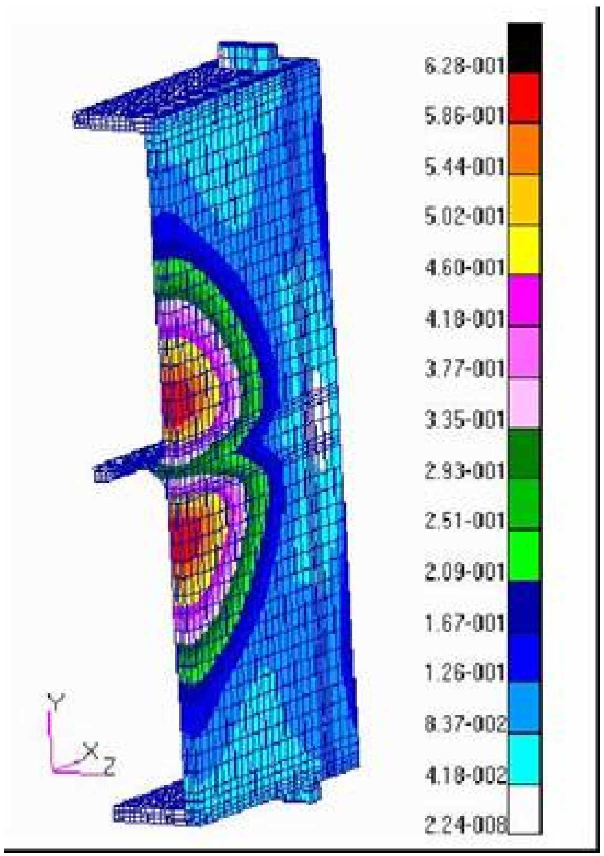
Courtesy DCE/GERBAM, France and OTO-Breda, Italy

Examples of modelling activities

- Modelling activities accompanying testing
  - Blast

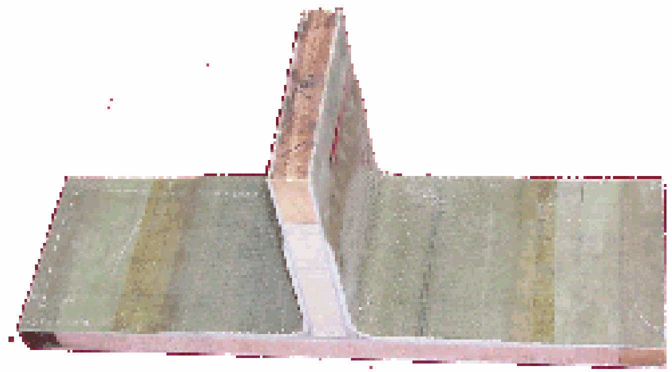


Courtesy QinetiQ, UK
and CETENA, Italy



Selected Final Design (FD)

- Norwegian CNDs selected as Final Design for all three joints
  - M/C-joint
  - T-joint
  - Stiffener joint
- Norwegian fire protection system selected
- Several EMS solutions developed



Courtesy Umoe Mandal, Norway

Overall achievements made on:

- Structural reliability
- Durability
- Cost effective survivability
- Vulnerability reduction
- Fire safety and survivability
- Weight reduction
- Susceptibility reduction
- Electromagnetic shielding
- Cost
- Modelling and failure prediction

Structural reliability

- Reduction of structural performance variability
  - Step by step manufacturing procedures developed for all critical details
    - Documented in Guidelines for implementation into the quality system (shipyard, class, navy)
    - Careful implementation and training are keys to obtain constant production quality
  - Procedures to demonstrate joint reliability through testing and modelling developed
  - Reliable and efficient NDT methods

Durability

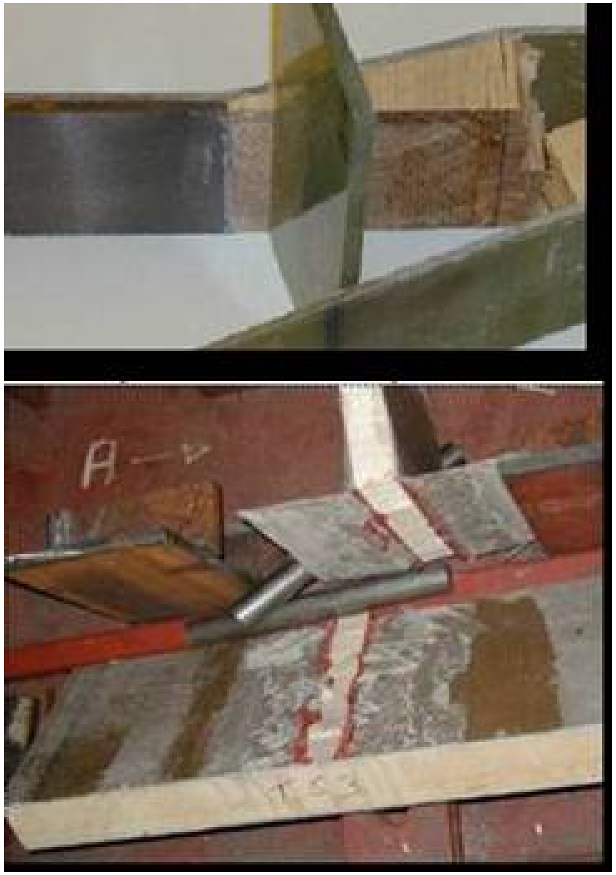
- Background:
  - Composite construction has proven extremely durable and requires little maintenance
- For superstructures, durability of the M/C joint has been proven:
  - Thermal cycling: no effect
  - Cyclic loading not a problem
  - Long term exposure to humidity, load and varying temperature:
    - No evidence of significant permanent degradation from accelerated ageing tests

Cost-effective survivability

- Background:
  - Composites offer advantages as well as disadvantages
  - Potential and limitations must be identified for optimal use of composite materials
  - A rational basis for selecting the most cost-effective design is necessary
- Joints developed and optimized to realistic loads
  - Not to *a priori* steel requirements
- Cost Benefit Assessment model developed
  - Reviewed by customer experts
  - Used to select improved designs on objective grounds
  - Included in Guidelines for other design cases

Vulnerability reduction

- Background:
  - Joints were critical for Base Designs
  - Joint failure mechanisms were catastrophic
- Focus has been on joint improvement
  - Strength and failure mechanism
- Core becomes critical when FD joints are used
  - Stronger core reduce vulnerability



Courtesy of FiReCo, Norway

Vulnerability reduction (2)

- Catastrophic initial failures eliminated
- Joints remained critical in internal blast
  - Manufacturing mistakes adversely affected internal blast resistance
- Survivability doubled
- Still scope for improvement
  - Better implementation of manufacturing procedures
  - Further optimisation of joint design probably required to obtain acceptable internal blast performance

Courtesy of OTO-Breda, Italy

Fire safety and survivability

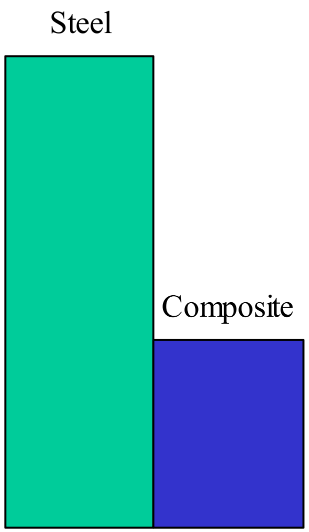
- FD passive fire protection:
  - Satisfies IMO HSC requirements with good margin
  - Excellent performance in HC fire
  - Excellent blast resistance
  - Negligible effect of fragment damage
- The corridor test
  - Composite material does not contribute to fire within 20 minute requirement
  - Outside surface temperature stays low
  - Fire fighting through partition is very effective

Courtesy DCE/GERBAM, France

- Lesson learnt: improve robustness of fastening system
- Active measures must reflect properties of composite structures:
  - Plug holes in structure if damaged instead of boundary cooling
  - Provide controlled access to fire for active fire fighting
- On this basis, composites can be used with confidence

Weight reduction

- Low weight is a major advantage of composite structures
  - VCG, speed, fuel consumption, pay-load, machinery size, etc.
- Composite hangar compared to optimized steel helo-hangar
- Composite hangar vs. steel hangar:
  - BD hangar 60% lighter than steel
  - FD hangar 55% lighter than steel, with double survivability vs. BD
  - With only operational loads hangar could be 70% lighter than steel



Susceptibility reduction

- Quantification (of *s*) outside scope
- Some opportunities with FRP unavailable with steel:
  - Almost perfect flatness
  - Nonmagnetic and nonconductive
  - Thermal insulation
  - Integration of functions
  - Complex shapes
  - Indirect advantages

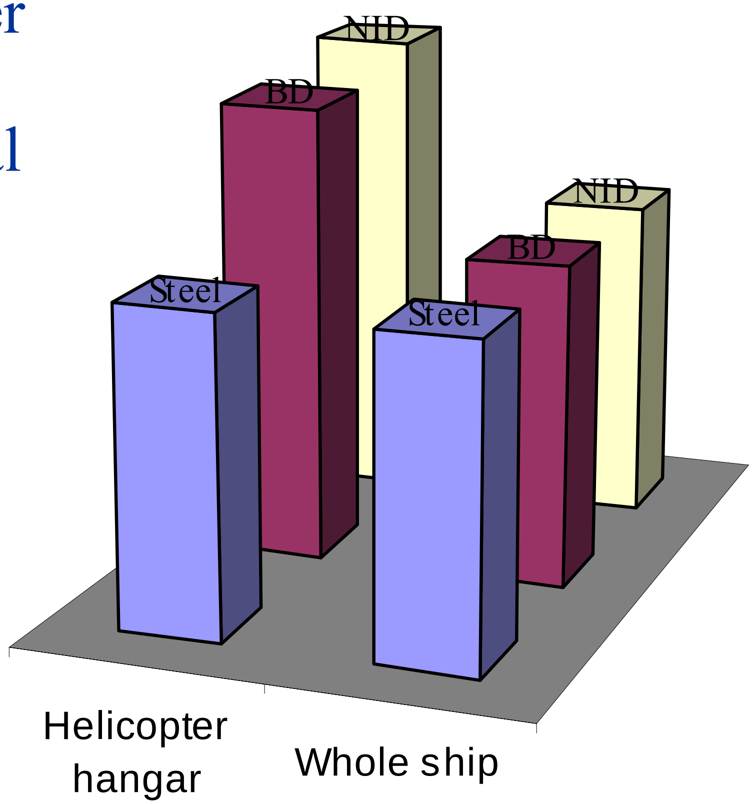
Electromagnetic shielding

- Reliable solutions existed at project start
- Cost/weight reduction through new CFRP solution
  - Adequate shielding efficiency
  - Solutions for joints, penetrations and openings developed
- Modelling capabilities improved

Courtesy Umoe Mandal, Norway

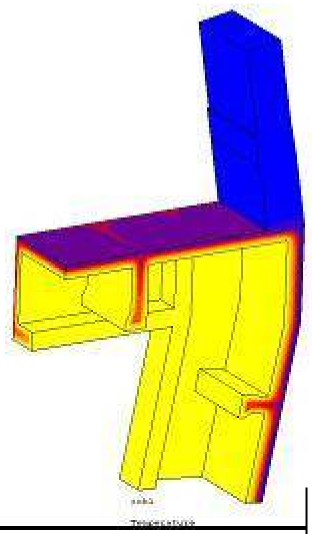
Costs

- Hangar build costs in composites is 40-50% higher than with steel
- Total ship cost approx. equal
- Limited scope for cutting costs further.
- Two novel technologies explored:
  - CFRP as EMS material
  - Bonding of prefabricated stiffeners
- Scope for reduced LCC
  - Maintenance reduced
  - Crew size reduced
  - Lower fuel consumption



Modelling and failure prediction

- Simple and reliable methods developed for modelling blast events
- Methods for joint strength prediction improved and proven helpful in design
- Testing still required as basis for joint qualification
- Fire and EMS modelling capabilities improved



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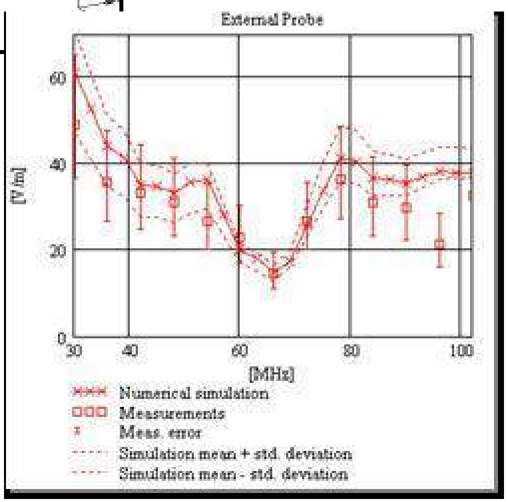

Courtesy of IDS, Italy

Conclusions

- The basis for large scale application of composite materials has been strengthened by:
  - Resistant and resilient joint designs developed and validated
  - Validated fire protection solutions developed
  - Basis for reliable, durable and affordable composite structures established
  - Possibilities and limitations of composite construction explored: vulnerability, weight and cost reduction
  - Susceptibility reduction is a major driver for composites in large naval vessels
  - Composites has a major potential to reduce LCC
- Modelling and failure prediction has been developed into a powerful tool
  - Identifying and comparing good design solutions and
  - Optimising designs for specific weapon-induced loads and fire
- For qualification, modelling must be complemented by testing

Further work

- Establish internal blast performance of composite structures
  - With high manufacturing quality
  - Explore new designs or optimise existing ones
- Extended fire engineering methods for vulnerability and safety assessment
- Electromagnetic shielding:
  - Explore ways to obtain contact between carbon fibres and steel (direct or not, durability)
  - Need for direct contact at low frequencies?
  - Resistance to RADHAZ needs to be established (safety)
- Further development of practical NDT equipment

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