L4c

SUMMARY ON STRUCTURAL DESIGN METHODS and CASE STUDIES

1. DESIGN PROBLEM FORMULATION
2. DESIGN PROBLEM SOLUTION
3. APPLICATIONS

CONCLUSIONS

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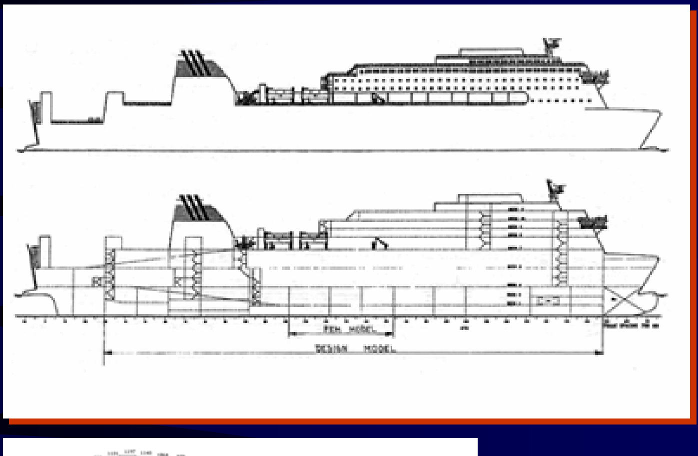
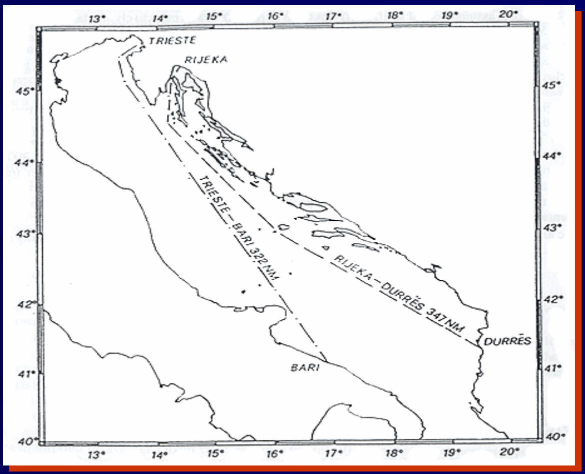
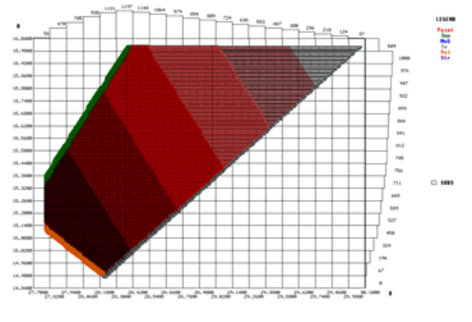
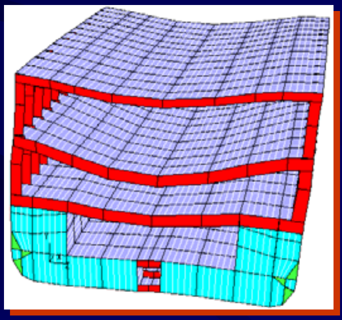
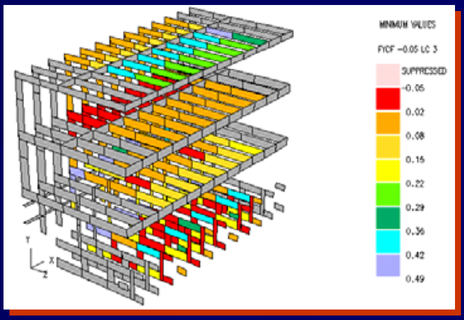
1. DESIGN PROBLEM FORMULATION











DESIGN PHASES

❑ Concept design
❑ Reliability-based design
❑ Preliminary design

using :

- multi-criteria decision making techniques
- design space exploration via Pareto frontier (non-dominated designs)
- development of new macroelements and ultimate strength failure criteria
- development of integrated design procedures

SOFTWARE USED IN EXAMPLES

TORO 1979 ... / (FEM shear flow analysis in bending and torsion) at Zagreb Uni.

MAESTRO/SHIPOPT 1975 ...2006 / (FEM analysis + synthesis) with Profs. O.F.Hughes and F. Mistree for ABS and later for PROTEUS Eng. USA.

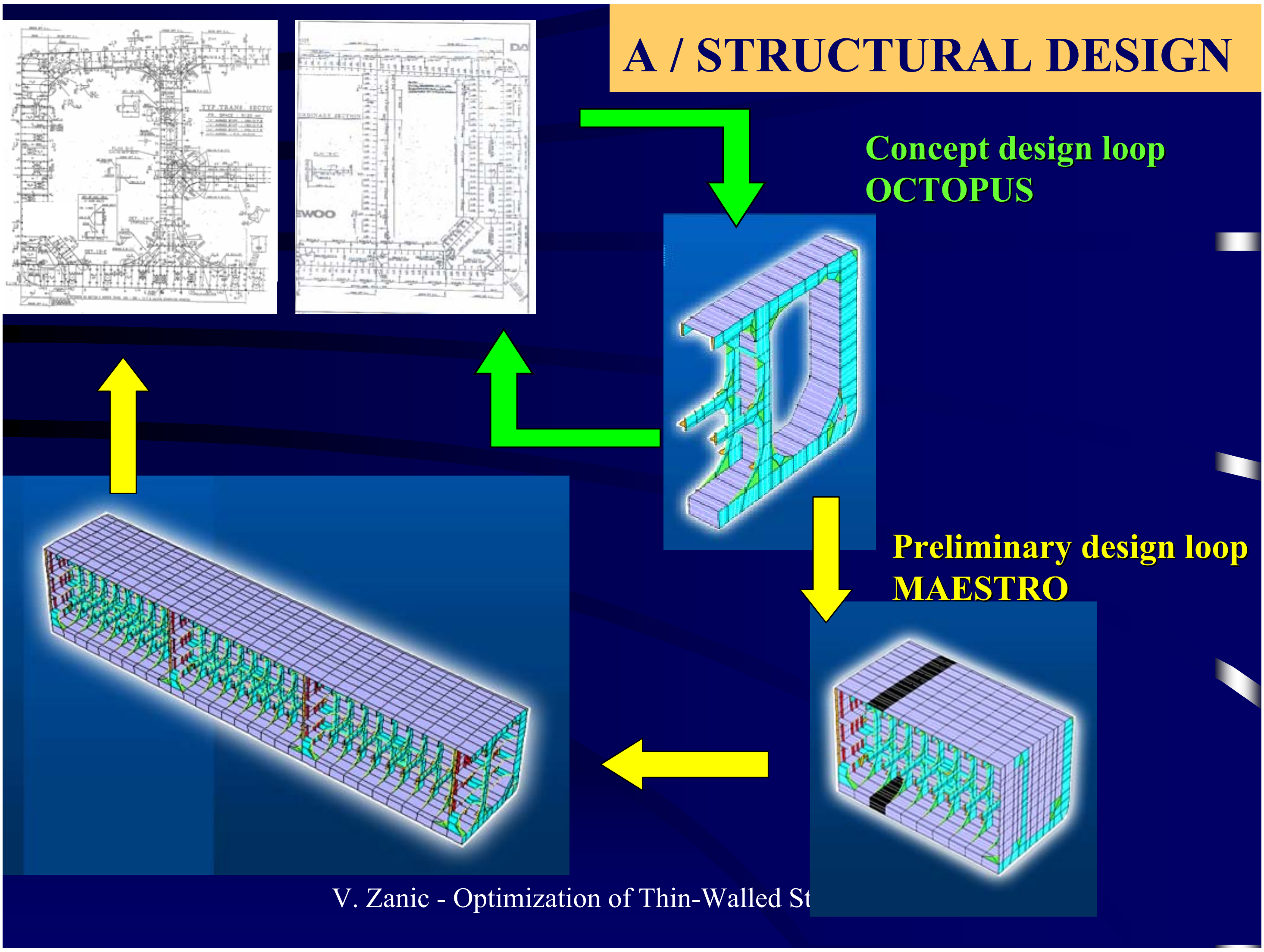
SOFTWARE (cont.)

OCTOPUS 1990 ...2006 / (FEM analysis, reliability based design) at Zagreb and Glasgow Uni.

CREST 1999 ... 2006 / (OCTOPUS integrated, FEM analysis, Croatian Register Rules, IACS CSR (T)

DEMAK 1990 ...2006 / (Synthesis using multicriterial decision making) at Zagreb Uni.

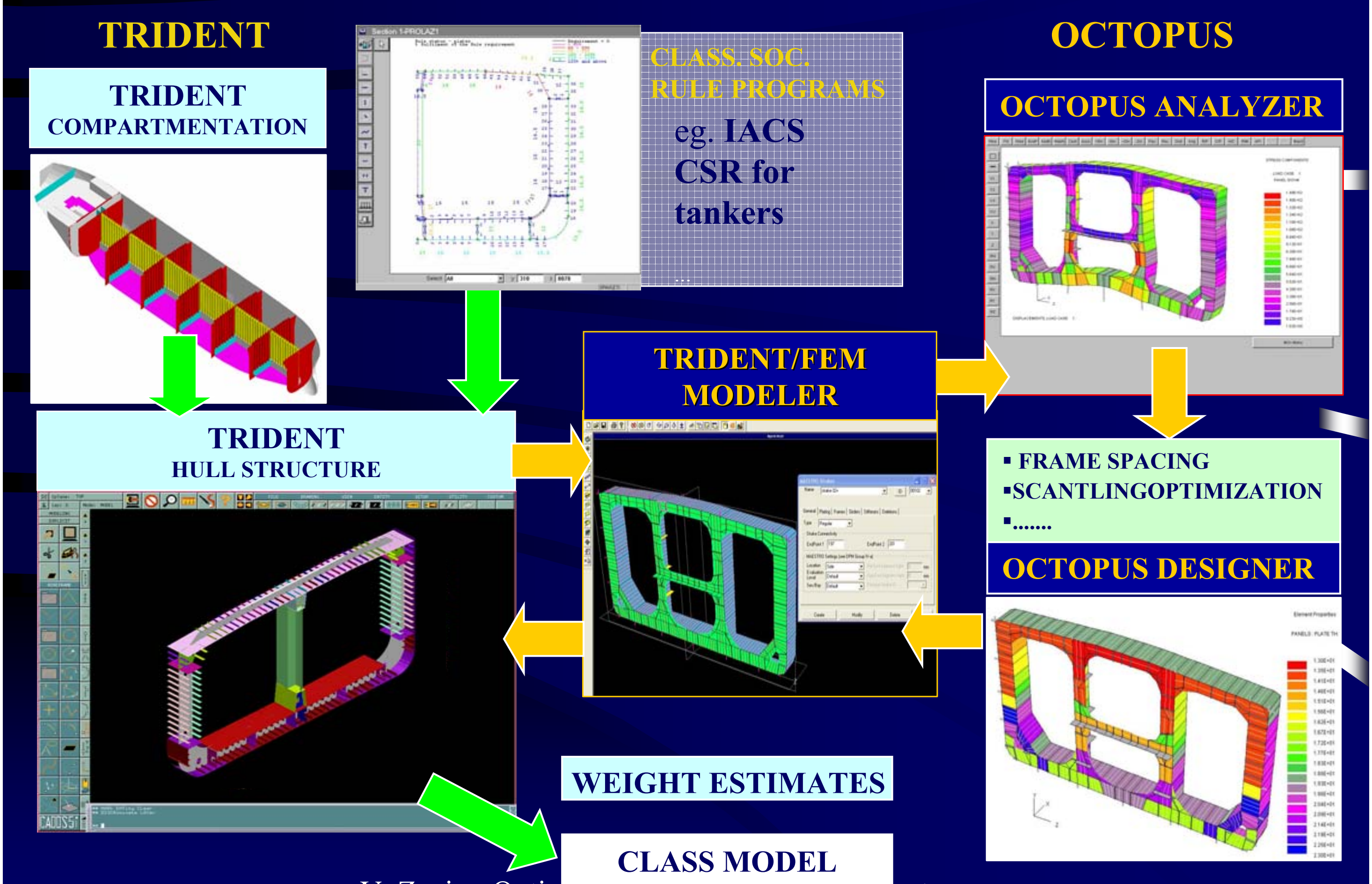
A / STRUCTURAL DESIGN



Concept design loop
OCTOPUS

Preliminary design loop
MAESTRO

CONCEPT DESIGN



TRIDENT

TRIDENT COMPARTMENTATION

CLASS. SOC. RULE PROGRAMS

eg. **IACS CSR for tankers**

...

OCTOPUS

OCTOPUS ANALYZER

TRIDENT/FEM MODELER

TRIDENT HULL STRUCTURE

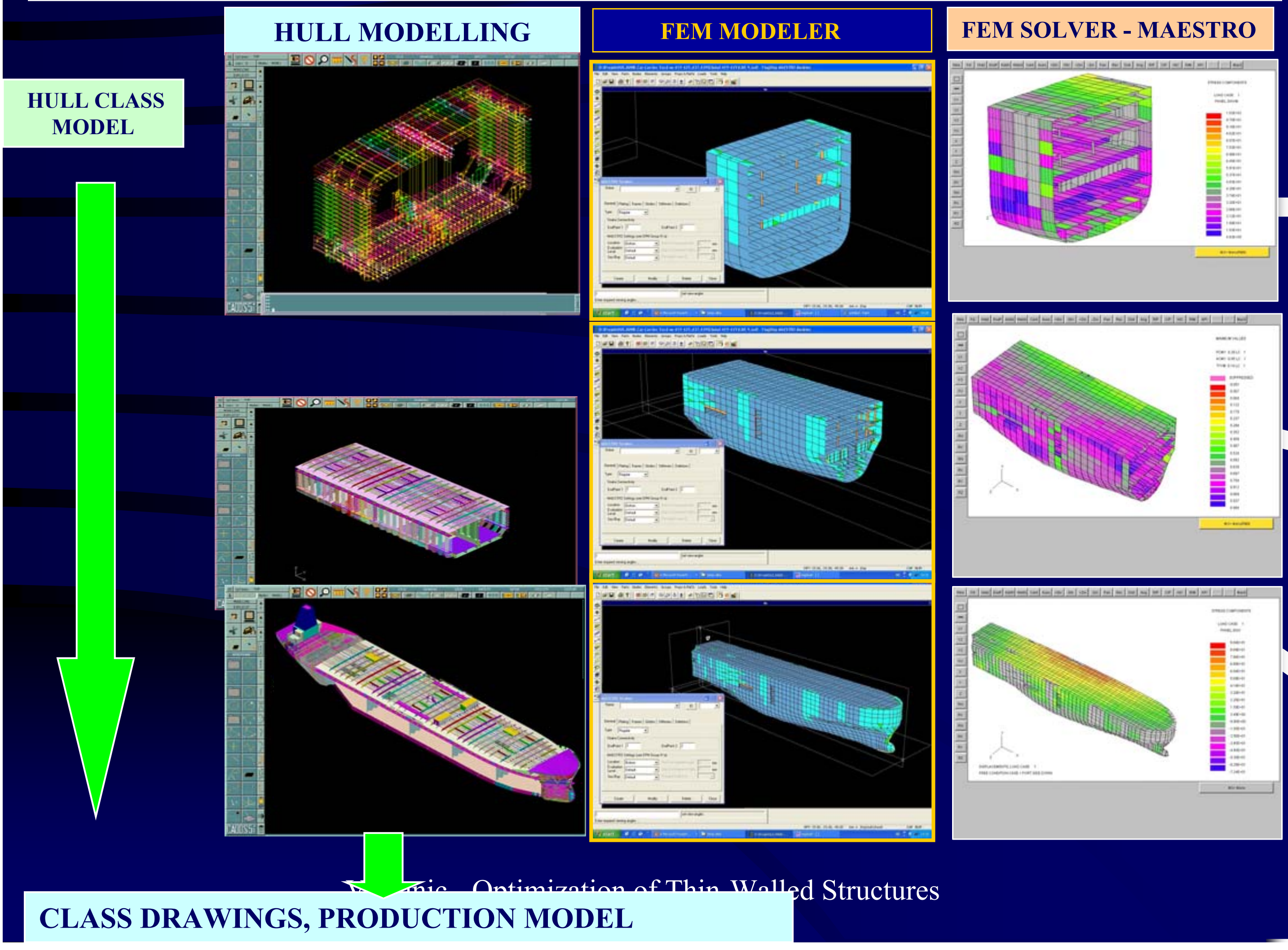
- FRAME SPACING
- SCANTLINGOPTIMIZATION
- ....

OCTOPUS DESIGNER

WEIGHT ESTIMATES

CLASS MODEL

PRELIMINARY DESIGN



HULL MODELLING

FEM MODELER

FEM SOLVER - MAESTRO

HULL CLASS MODEL

CLASS DRAWINGS, PRODUCTION MODEL

CONCEPT DESIGN ANALYSIS SYSTEM

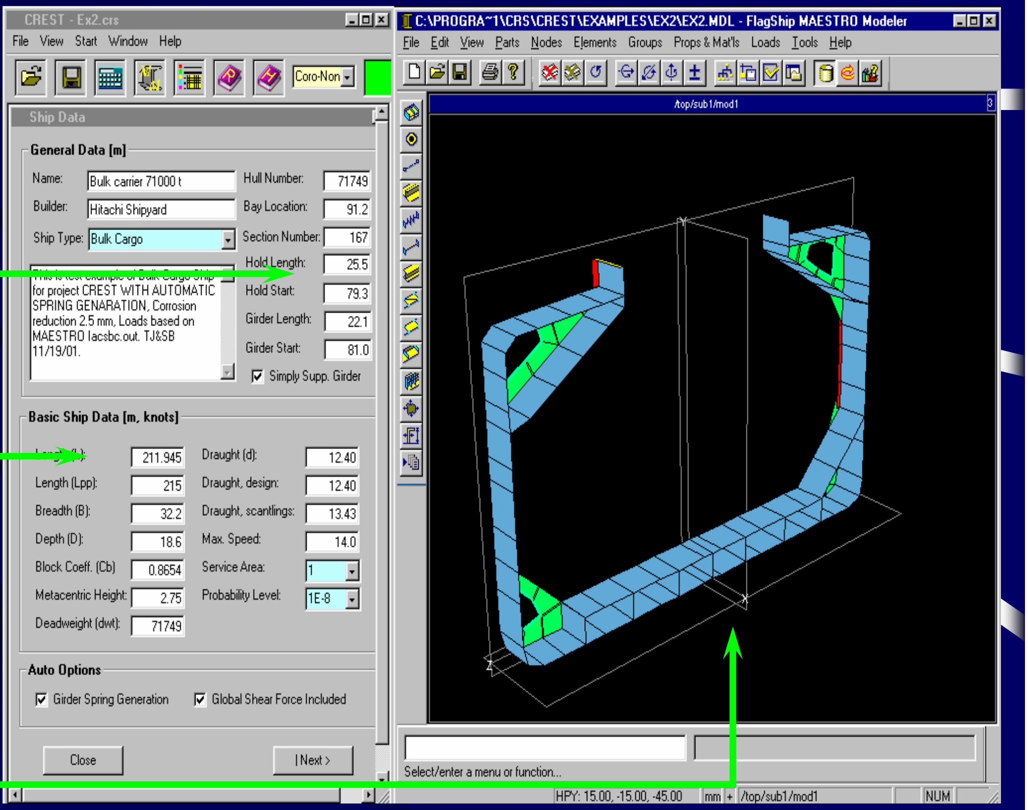
OCTOPUS ANALYZER:

Workspace

MODEL GENERAL DATA

BASIC SHIP DATA

MODEL FIGURE



Ship Data

General Data [m]

Name: Bulk carrier 71000 t
Builder: Hitachi Shipyard
Ship Type: Bulk Cargo

This is test example of Bulk Cargo Ship for project CREST WITH AUTOMATIC SPRING GENARATION, Corrosion reduction 2.5 mm, Loads based on MAESTRO lacsbc.out. TJ&SB 11/19/01.

Hull Number: 71749
Bay Location: 91.2
Section Number: 167
Hold Length: 25.5
Hold Start: 79.3
Girder Length: 22.1
Girder Start: 81.0
☑ Simply Supp. Girder

Basic Ship Data [m, knots]

Length (L): 211.945
Length (Lpp): 215
Breadth (B): 32.2
Depth (D): 18.6
Block Coeff. (Cb) 0.8654
Metacentric Height: 2.75
Deadweight (dwt): 71749
Draught (d): 12.40
Draught, design: 12.40
Draught, scantlings: 13.43
Max. Speed: 14.0
Service Area: 1
Probability Level: 1E-8

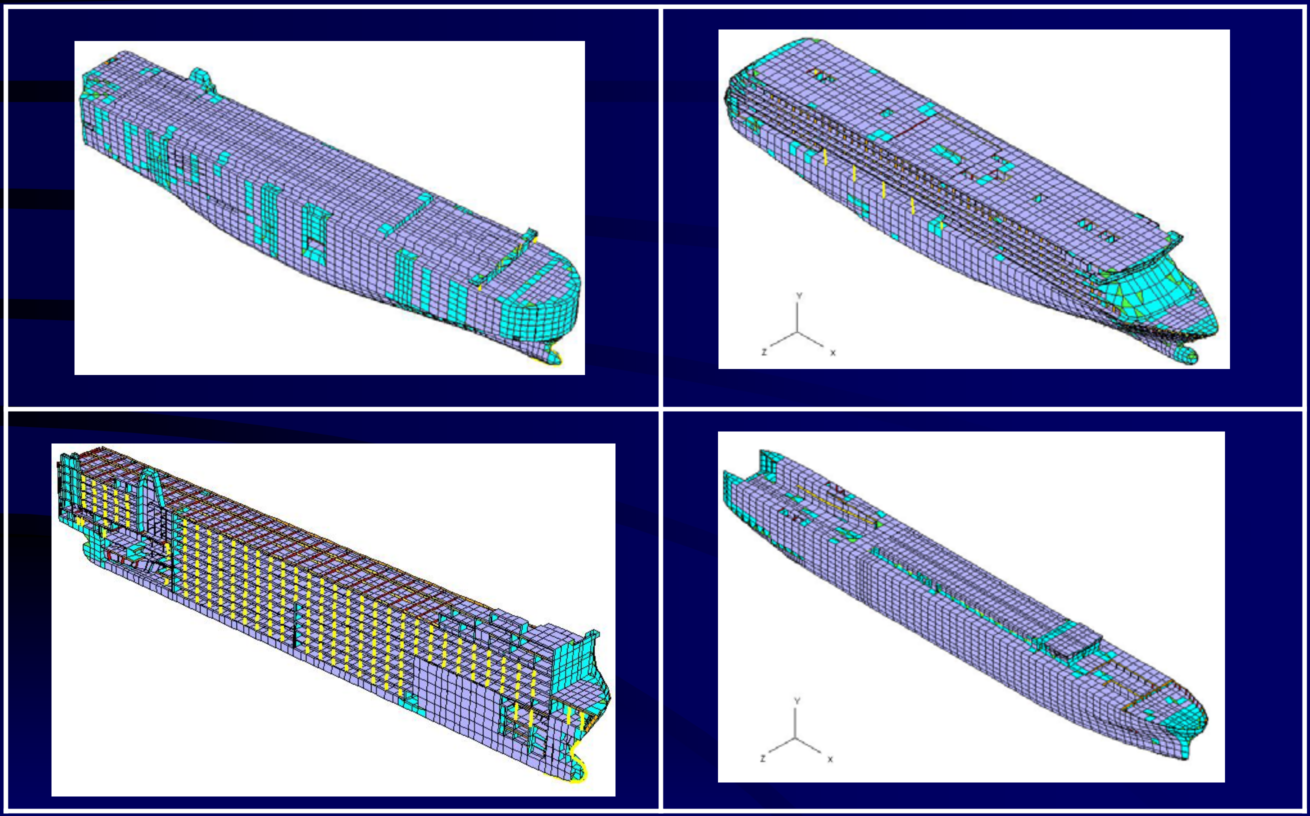
Auto Options

☑ Girder Spring Generation
☑ Global Shear Force Included

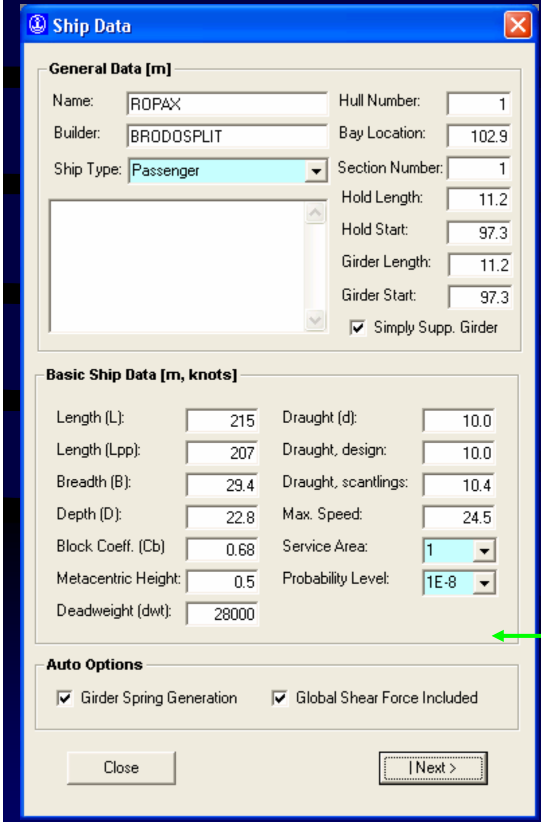
ANALISYS MODULES

ANALYSIS MODELS	**OCTOPUS ANALYZER MODULES**
Physical **(Φ)**	**FEM STRUCTURAL MODELER** **MIND – generator of minimal dimensions**
Environment **(ε)**	**OCTLOAD** - load model
Response **(ρ-1)**	**LTOR**- primary strength fields (warping displac.; normal/shear stresses)
Response **(ρ-2)**	**TOKV** -secondary strength fields: transverse and lateral displacements, stresses
Adequacy / feasibility **(α-1)**	**EPAN** – library of stiffened panel and girder ultimate strength & serviceability criteria. (FATCS – Rules fatigue calculation-Level 1)
Adequacy (α-2)	**LUSA** – Ultimate longitudinal strength module
Reliability **(π-1,2)**	**US-3** reliability calculation of element and system failure probability (level 1-3, mechan.) **SENCOR – sensitivity** to correlation.
Quality **(Ω-1 to 8)**	**WST / INC - cost/weight** **DCLV - ultimate vertical bending moment** **DCLT- ultimate racking load** **SSR / SCR - reliability measures** **ICM / TSN - robustness measures**

FMENA data base for calibration of mathematical models of thin-walled structures



PHYSICAL (Φ): - FEM STRUCTURAL MODELER, - MINIMAL DIMENSIONS MODULE



General Data [m]

Name: ROPAX

Builder: BRODOSPLIT

Ship Type: Passenger

Hull Number: 1

Bay Location: 102.9

Section Number: 1

Hold Length: 11.2

Hold Start: 97.3

Girder Length: 11.2

Girder Start: 97.3

☑ Simply Supp. Girder

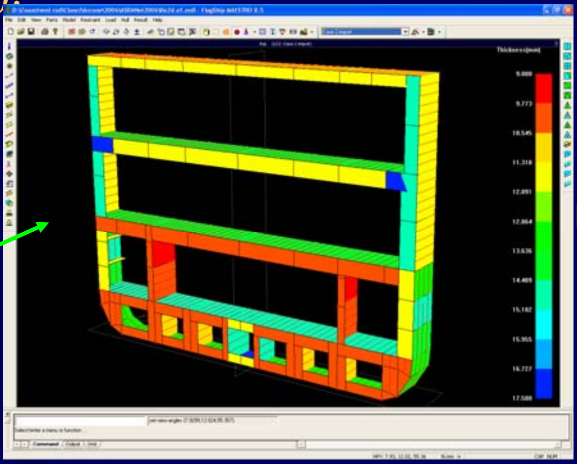
Basic Ship Data [m, knots]

Length (L):	215	Draught (d):	10.0
Length (Lpp):	207	Draught, design:	10.0
Breadth (B):	29.4	Draught, scantlings:	10.4
Depth (D):	22.8	Max. Speed:	24.5
Block Coeff. (Cb)	0.68	Service Area:	1
Metacentric Height:	0.5	Probability Level:	1E-8
Deadweight (dwt):	28000		

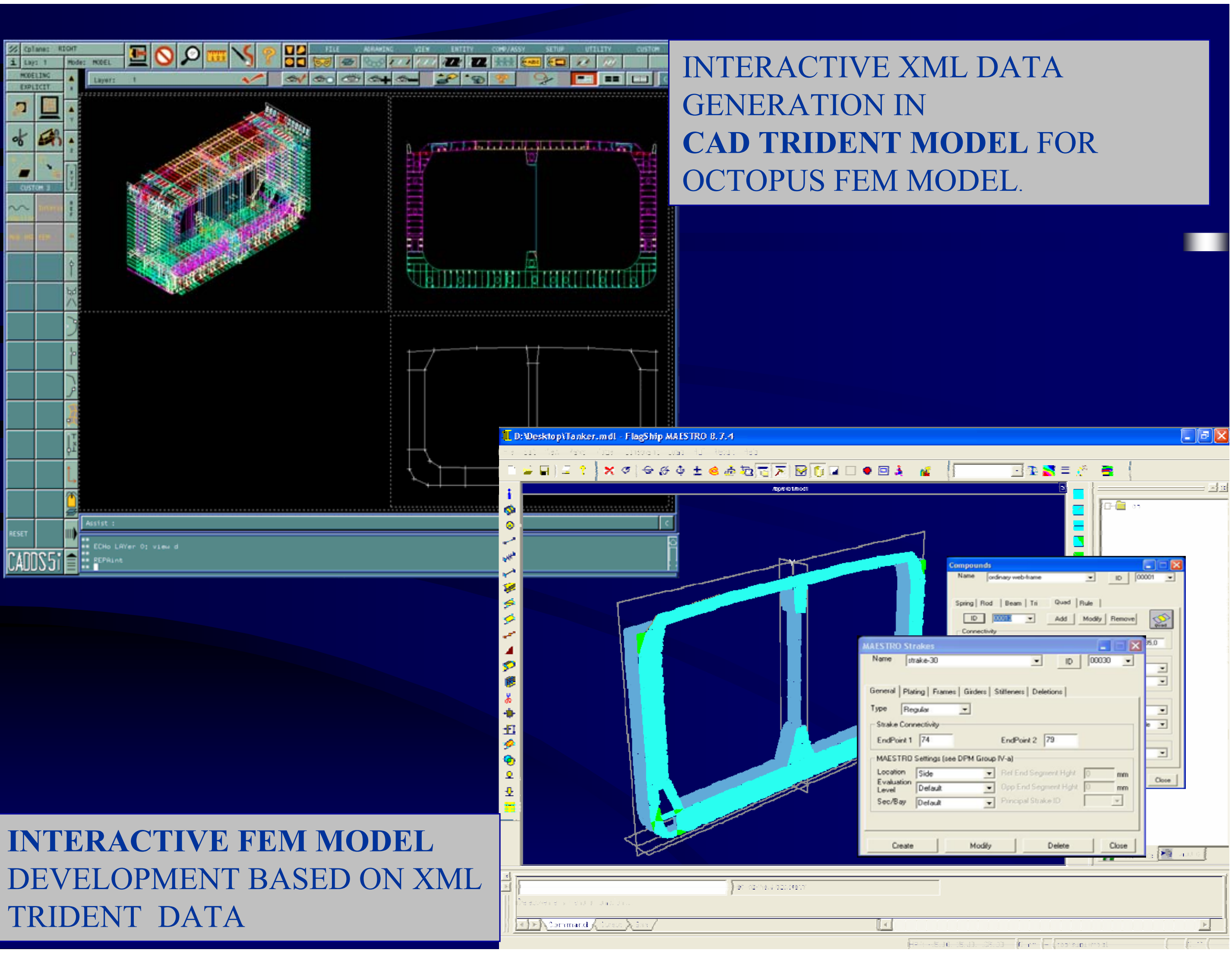
Auto Options

☑ Girder Spring Generation ☑ Global Shear Force Included

- MAESTRO MODELER used to define 2.5D FEM model with different cross-sections (web-frame, bulkhead).
- MIND (minimal dimensions definition from Class. Society Rules-eg. IACS CSR for tankers).



RoPax



Name: ordinary web-frame
ID: 00001

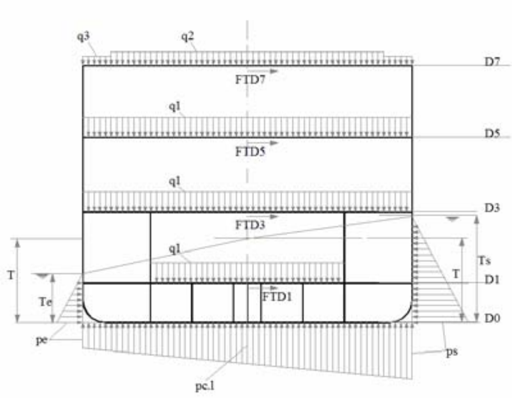
Name: strake-30
ID: 00030
Type: Regular
Strake Connectivity
EndPoint 1: 74
EndPoint 2: 79
MAESTRO Settings (see DPM Group IV-a)
Location: Side
Evaluation Level: Default
Sec/Bay: Default

INTERACTIVE XML DATA GENERATION IN **CAD TRIDENT MODEL** FOR OCTOPUS FEM MODEL.

INTERACTIVE FEM MODEL DEVELOPMENT BASED ON XML TRIDENT DATA

ENVIRONMENT (ε): - OCTLOAD

- Class. Society Loads - DNV (Note: CRS and IACS -CSR are generated automatically - CREST software).
- Designer given loads from seakeeping analysis (3D Hydro model) are optional input.



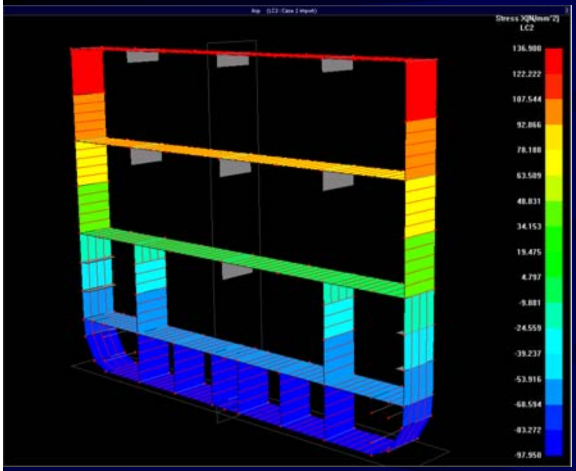
LC 6 and 7

RoPax

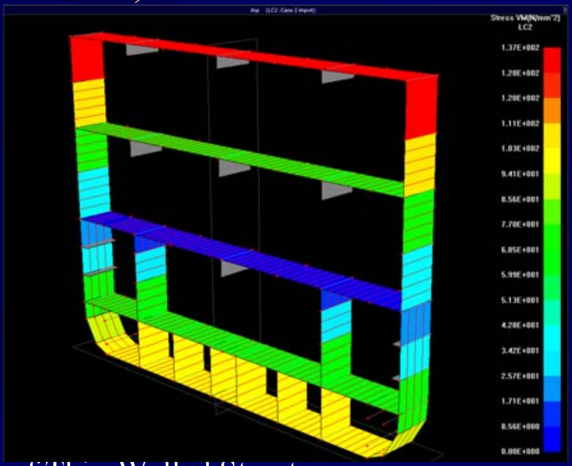
LC	DESCRIPTION
1-SAGG	Full load on decks + dyn. / Scantling draught
2-HOGG	Full load on decks + dyn. / Scantling draught
3-SAGG	Full load on decks except D1 + dyn. / T- scantling
4-HOGG	Full load on decks except D1 + dyn. / T- scantling
5-HOGG	Ballast condition /Draught 5.8 m
6-SAGG	Full load on decks + dyn. / Heeled condition
7-HOGG	Full load on decks + dyn. / Heeled condition

RESPONSE (ρ -1): - LTOR

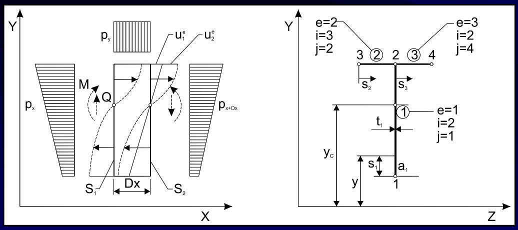
- Primary strength fields
  - Warping displ.; normal/shear stresses
  - Extended beam theory (cross section warping fields via FEM in vertical / horizontal bending and warping torsion)



LC 2 - σ_x

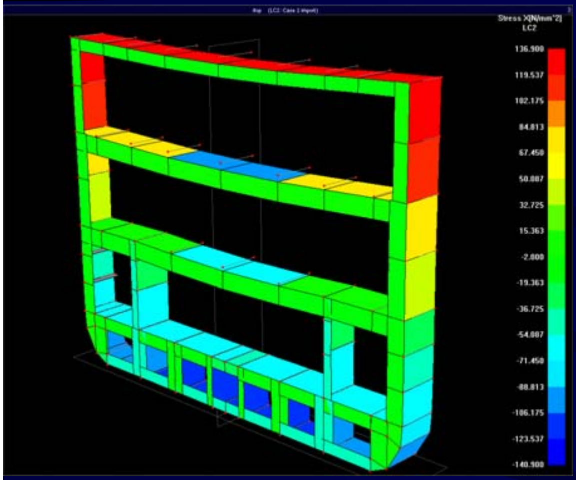


LC 2 - σ_{VM}

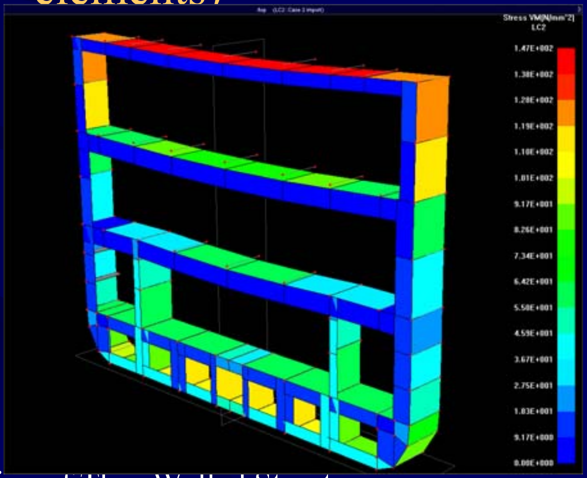


RESPONSE (ρ -2): - TOKV

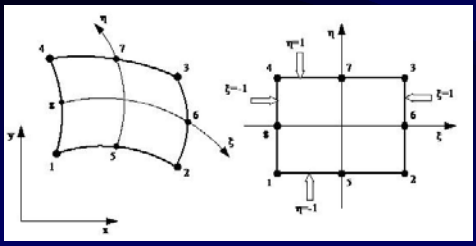
- Secondary strength fields:
  - transverse and lateral displ.; stresses
  - FEM analysis of web-frame and bulkhead (beam element with rigid ends; stiffened shell 8-node macro-elements)



LC 2 - σ_x

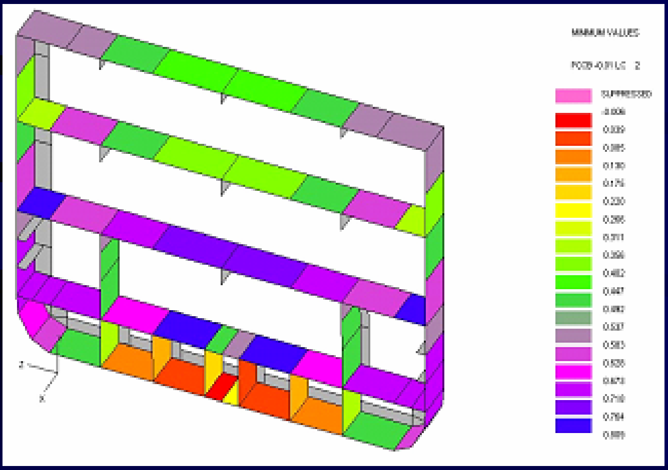


LC 2 - σ_{VM}



ADEQUACY (α -1): - EPAN / ELAN(IACS CSR)

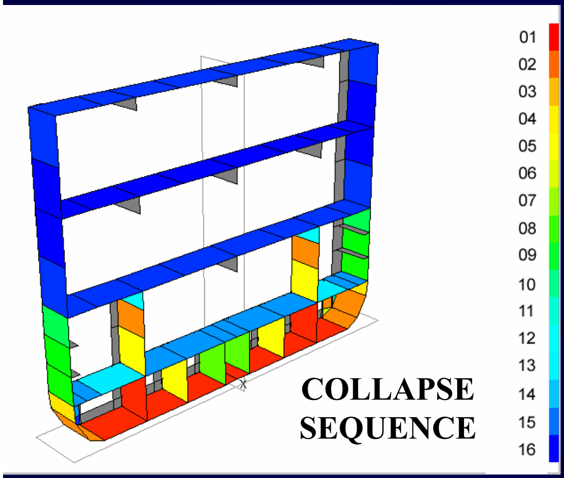
- Library of stiffened panel and girder ultimate strength & serviceability criteria
  - Calculation of macroelement feasibility based on super-position of response fields ρ-1, ρ-2 (FEM); ρ-3 (analytical) and using the library of analytical safety criteria



$$-1 \le g(x) = \frac{C - SF \cdot D}{C + SF \cdot D} \le 1,$$

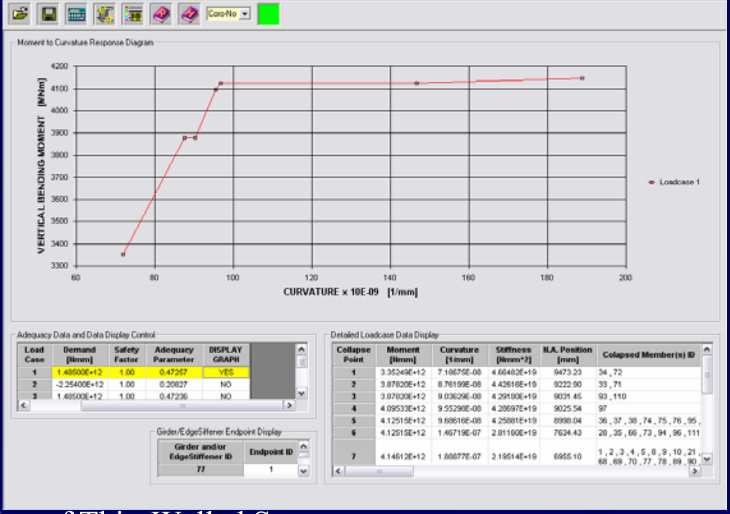
NAME	CRITERIA DESCRIPTION - PLATE
PCMY	**Panel Collapse Membrane Yield (Von Misses)**
PYLS	**Panel Yield Longitudinal Strength**
PCAPS	**Panel Collapse Arched Plate Yield**
PCAPT	**Panel Collapse Arched Plate Shear**
PFLB	**Panel Failure. Local Buckling**
PCES	**Panel Collapse Edge Shear**
S-UCS	**SLS, Uniaxial Compressive Stress**
U-UCS	**ULS, Uniaxial Compressive Stress**
S-ES	**SLS, Edge Shear**
U-ES	**ULS, Edge Shear**
S-ULL	**SLS, Uniform Lateral Load**
U-ULL	**ULS, Uniform Lateral Load**
....	**…………………………**

ADEQUACY (α-2) : - LUSA-1,2,3



COLLAPSE SEQUENCE

- Ultimate longitudinal strength
  - Incremental ultimate strength analysis of cross-section using IACS and extended Hughes/Adamchak procedures



Adequacy Data and Data Display Control

Load Case	Demand [Nmm]	Safety Factor	Adequacy Parameter	DISPLAY GRAPH
1	1.48500E+12	1.00	0.47257	YES
2	-2.25400E+12	1.00	0.20827	NO
3	1.48500E+12	1.00	0.47236	NO

Girder/EdgeSiffener Endpoint Display

Girder and/or EdgeStiffener ID	Endpoint ID
77	1

Detailed Loadcase Data Display

Collapse Point	Moment [Nmm]	Curvature [1/mm]	Stiffness [Nmm^2]	N.A. Position [mm]	Colapsed Member(s) ID
1	3.35249E+12	7.10675E-08	4.66482E+19	9473.23	34 , 72
2	3.87820E+12	8.76199E-08	4.42616E+19	9222.90	33 , 71
3	3.87820E+12	9.03629E-08	4.29100E+19	9031.45	93 , 110
4	4.09533E+12	9.55290E-08	4.28697E+19	9025.54	97
5	4.12515E+12	9.68616E-08	4.25881E+19	8998.04	36 , 37 , 38 , 74 , 75 , 76 , 95 ,
6	4.12515E+12	1.46719E-07	2.01160E+19	7634.43	20 , 35 , 66 , 73 , 94 , 96 , 111
7	4.14612E+12	1.80077E-07	2.19514E+19	6955.10	1 , 2 , 3 , 4 , 5 , 8 , 9 , 10 , 21 , 68 , 69 , 70 , 77 , 78 , 89 , 90 ,

RELIABILITY (π-1): - US3

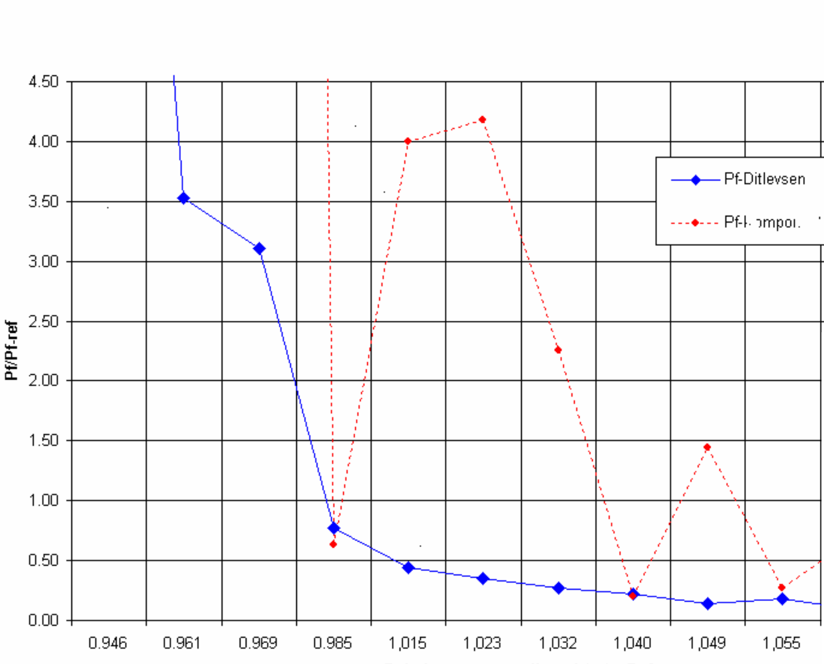
System failure probability based upon β -unzipping method for system probability of failure

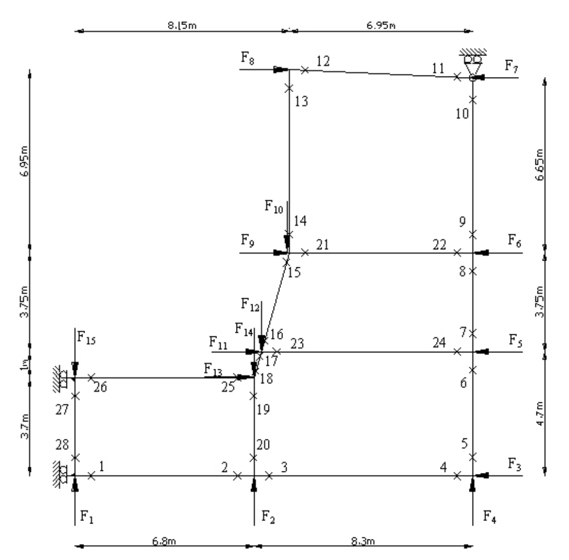
- Probabilistically dominant collapse scenarios are selected from the (large) set of potential collapse scenarios at the first, second, third and mechanism level.
- The system reliability measure at third level (RM-3) was found sufficient for the optimization (design) purpose.
- RM-3 is modeled as a series system of all identified, probabilistically dominant collapse scenarios.

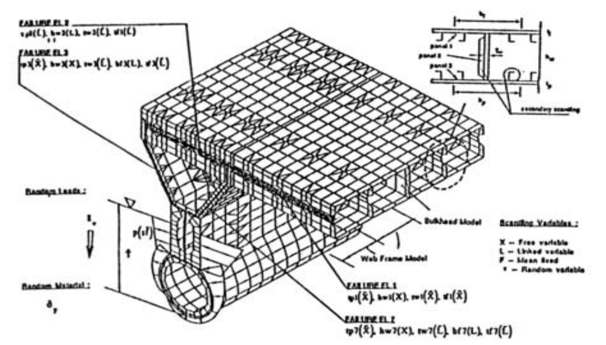
RELMOD

Pareto frontier :

normalised mass vs. normalised P_f







ROBEX

Robustness Analysis by Fractional Factorial Experiments

Robustness is the sensitivity to uncertain (uncontrolable) parametrs. A metric developed by Taguchi is the ratio of

- mean of the attribute value (μ), resulting from the values of design variables, to
- variation resulting from uncertain parameter values measured via standard deviation (σ).

$$SN_n = 20\log(\mu / \sigma) = 10\log(\mu^2 / \sigma^2) = 10[\log(\mu^2 / \sigma^2)]$$

It is the ratio of predictability versus unpredictability.

SN = robustness attribute in multi-criterial design

The most robust design coresponds to max SN.

QUALITY (Ω): DESIGN ATTRIBUTES

- INC - cost module
  - Minimal initial cost
- WST - weight module
  - Minimal structural weight = maximal DWT increase
- DCLV - ultimate vertical bending moment
  - Calculations using LUSA

- SSR / SCR - reliability measures (maintenance, risk analysis)
  - Upp. Ditlevsen bound of panel failure/ racking failure probab.
- ICM / TSN - robustness measures
  - (Information context measure / Taguchi S/N ratio via FFE).

CSMIND

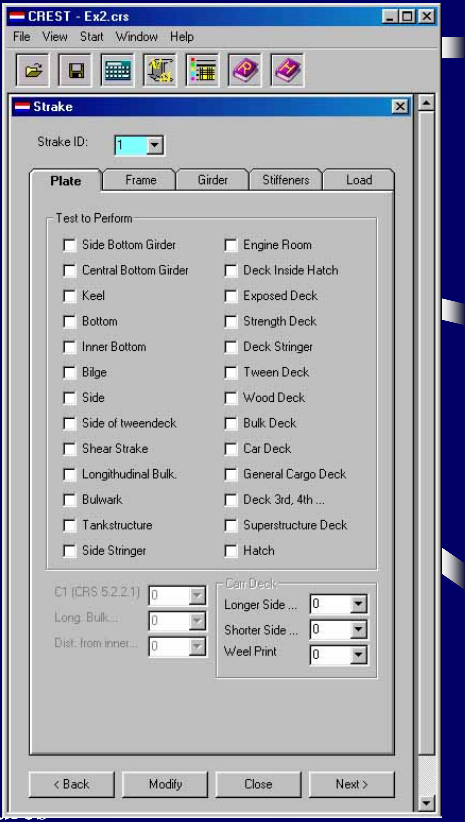
Minimal dimensions verification according to IACS Rules

- Calculation of minimal structural element dimensions according to CS descriptors

- Comparison of the as built and required dimensions

-Verification of a corroded element dimensions

Selection of CS tests for strake plating →



Strake ID: 1

Test to Perform

☐ Side Bottom Girder
☐ Central Bottom Girder
☐ Keel
☐ Bottom
☐ Inner Bottom
☐ Bilge
☐ Side
☐ Side of tweendeck
☐ Shear Strake
☐ Longithudinal Bulk.
☐ Bulwark
☐ Tankstructure
☐ Side Stringer
☐ Engine Room
☐ Deck Inside Hatch
☐ Exposed Deck
☐ Strength Deck
☐ Deck Stringer
☐ Tween Deck
☐ Wood Deck
☐ Bulk Deck
☐ Car Deck
☐ General Cargo Deck
☐ Deck 3rd, 4th ...
☐ Superstructure Deck
☐ Hatch

C1 (CRS 5.2.2.1) 0
Long. Bulk.... 0
Dist. from inner... 0

Carr Deck
Longer Side ... 0
Shorter Side ... 0
Weel Print 0

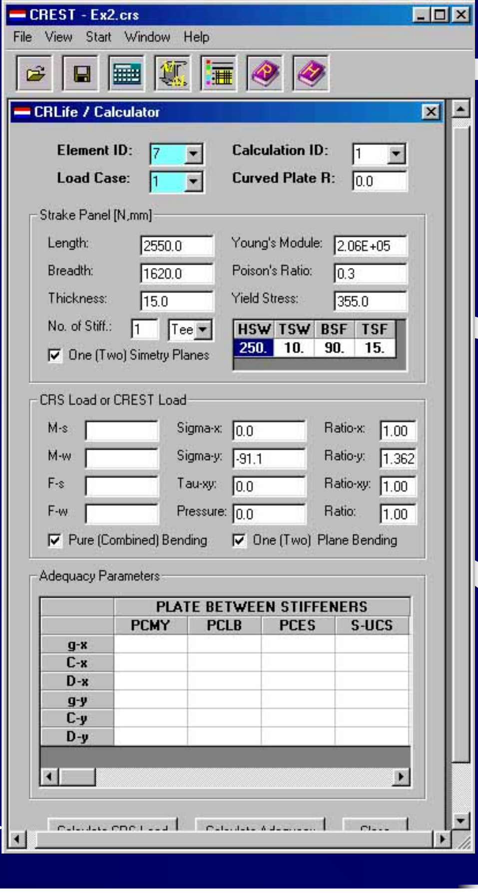
CALCULATOR

Criteria recalculation for new element dimensions

Automatic assesment of feasibility criteria for the selected strake using input from OCTOPUS solver

Calculates the feasibility criteria for the selected strake using user provided stresses and new scantlings

Independent safety criteria evaluation.



Element ID: 7
Calculation ID: 1
Load Case: 1
Curved Plate R: 0.0

Strake Panel [N,mm]
Length: 2550.0
Young's Module: 2.06E+05
Breadth: 1620.0
Poison's Ratio: 0.3
Thickness: 15.0
Yield Stress: 355.0
No. of Stiff.: 1 Tee

HSW	TSW	BSF	TSF
250.	10.	90.	15.

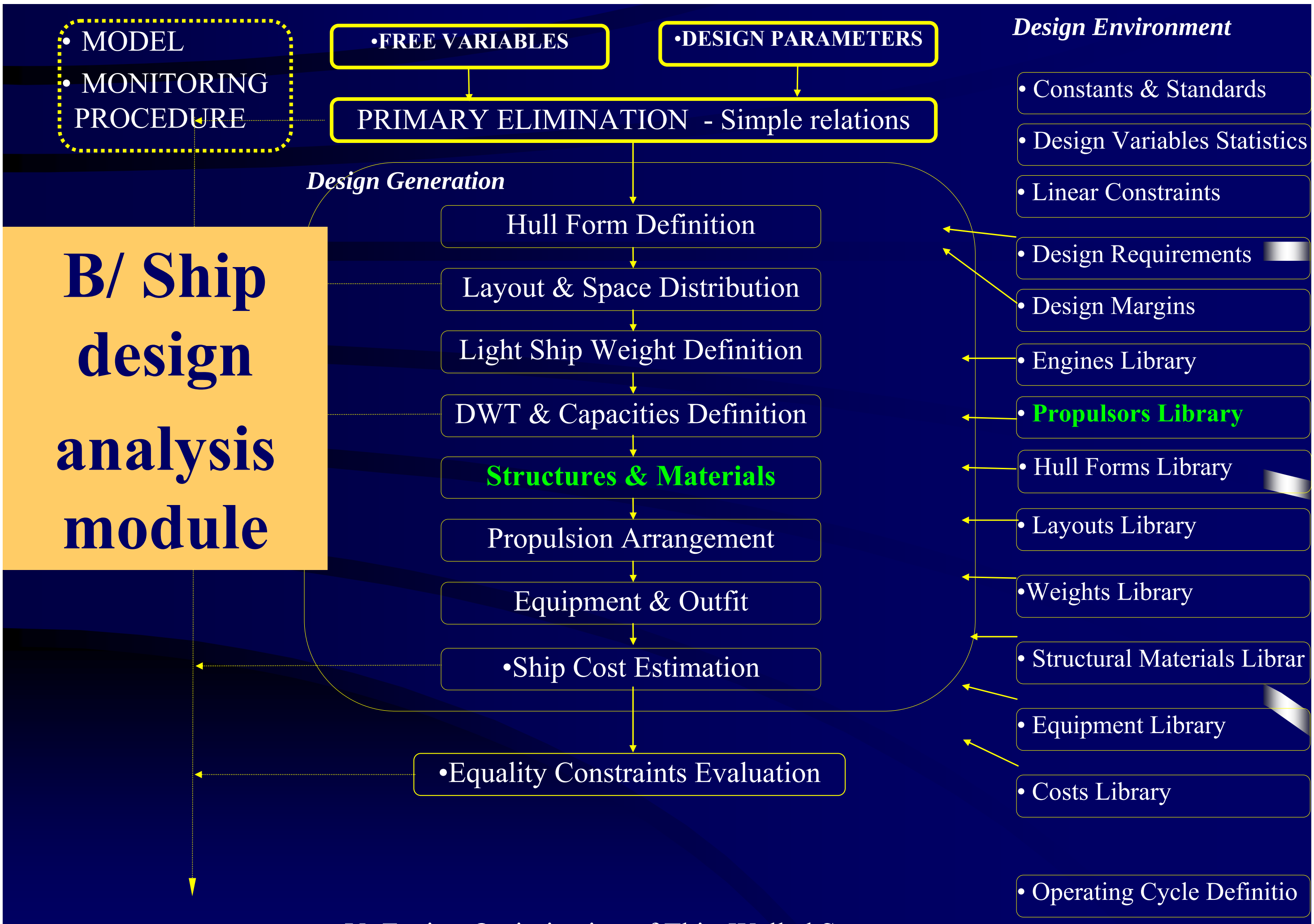
☑ One (Two) Simetry Planes

CRS Load or CREST Load
M-s
M-w
F-s
F-w
Sigma-x: 0.0
Sigma-y: -91.1
Tau-xy: 0.0
Pressure: 0.0
Ratio-x: 1.00
Ratio-y: 1.362
Ratio-xy: 1.00
Ratio: 1.00
☑ Pure (Combined) Bending
☑ One (Two) Plane Bending

Adequacy Parameters

	PLATE BETWEEN STIFFENERS			
	PCMY	PCLB	PCES	S-UCS
g-x				
C-x				
D-x				
g-y				
C-y				
D-y				

B/ Ship design analysis module



- MODEL
- MONITORING PROCEDURE

•FREE VARIABLES

•DESIGN PARAMETERS

PRIMARY ELIMINATION - Simple relations

Design Generation

Hull Form Definition

Layout & Space Distribution

Light Ship Weight Definition

DWT & Capacities Definition

Structures & Materials

Propulsion Arrangement

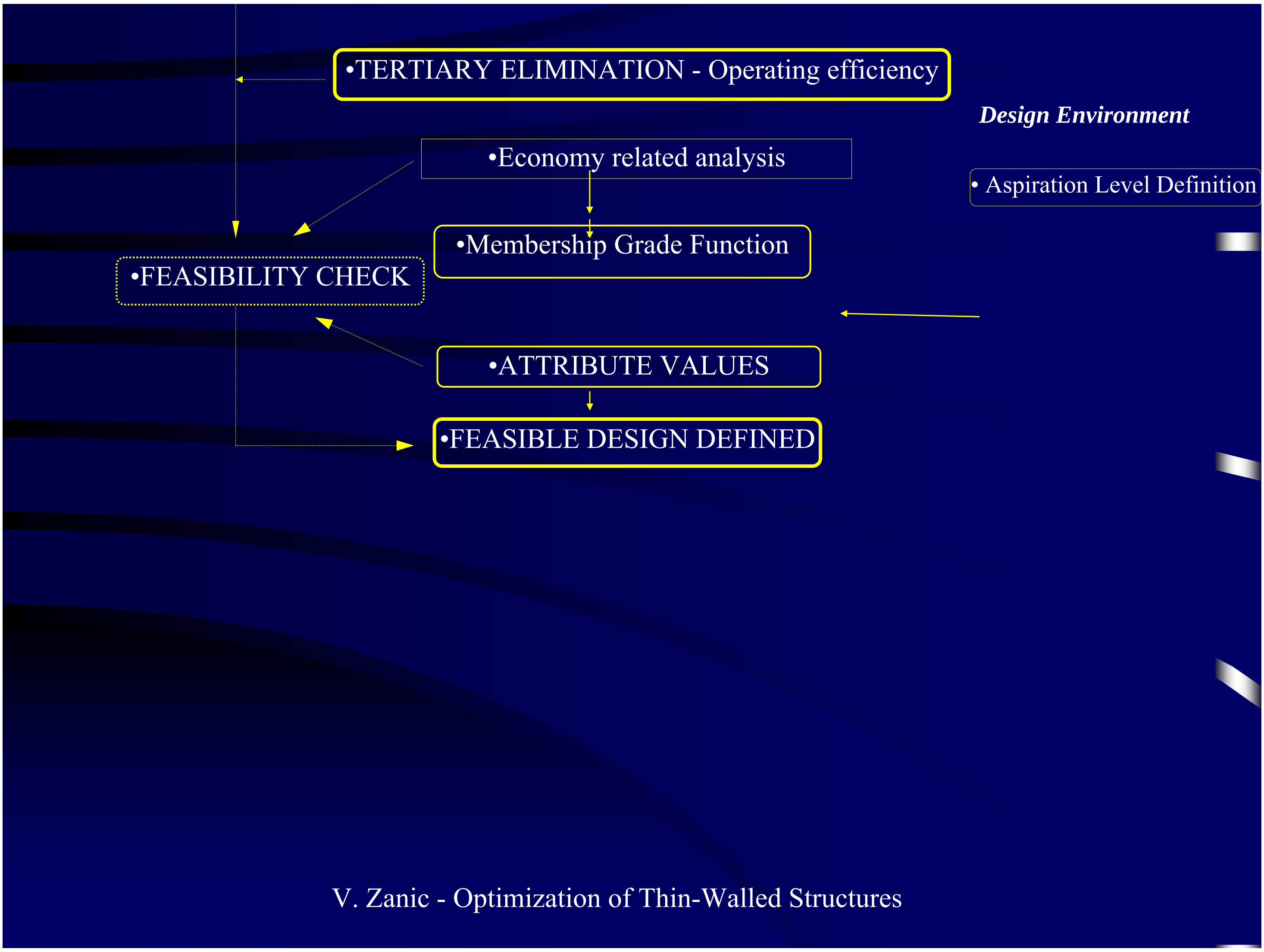
Equipment & Outfit

•Ship Cost Estimation

•Equality Constraints Evaluation

Design Environment

- Constants & Standards
- Design Variables Statistics
- Linear Constraints
- Design Requirements
- Design Margins
- Engines Library
- **Propulsors Library**
- Hull Forms Library
- Layouts Library
- Weights Library
- Structural Materials Librar
- Equipment Library
- Costs Library
- Operating Cycle Definitio



•TERTIARY ELIMINATION - Operating efficiency

•Economy related analysis

•Membership Grade Function

•FEASIBILITY CHECK

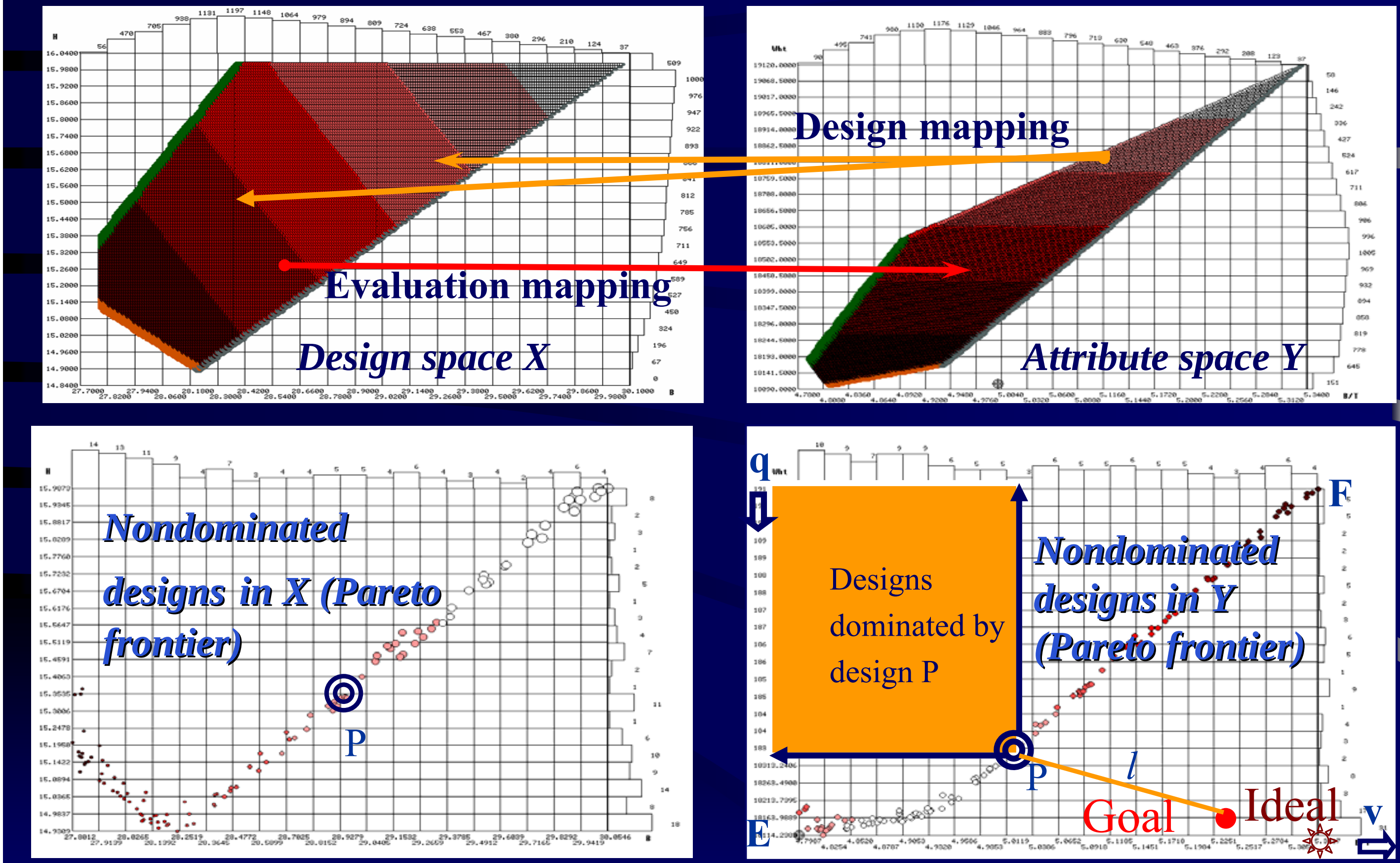
•ATTRIBUTE VALUES

•FEASIBLE DESIGN DEFINED

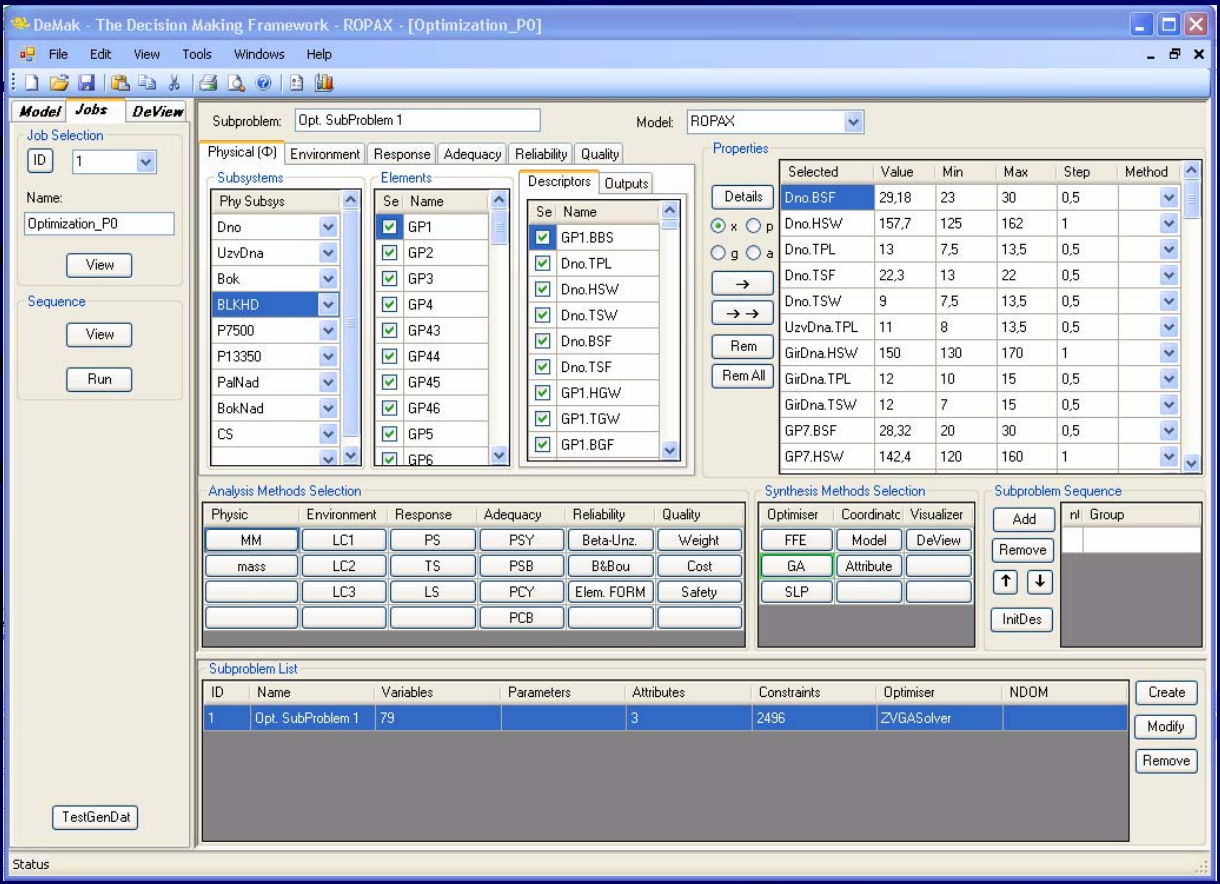
Design Environment

- Aspiration Level Definition

2. DESIGN PROBLEM SOLUTION



OCTOPUS - DECISION MAKING FRAMEWORK



ID: 1

Name: Optimization_P0

Subproblem: Opt. SubProblem 1

Model: ROPAX

Phy Subsys
Dno
UzvDna
Bok
BLKHD
P7500
P13350
PalNad
BokNad
CS

Se	Name
☑	GP1
☑	GP2
☑	GP3
☑	GP4
☑	GP43
☑	GP44
☑	GP45
☑	GP46
☑	GP5
☑	GP6

Se	Name
☑	GP1.BBS
☑	Dno.TPL
☑	Dno.HSW
☑	Dno.TSW
☑	Dno.BSF
☑	Dno.TSF
☑	GP1.HGW
☑	GP1.TGW
☑	GP1.BGF

Selected	Value	Min	Max	Step	Method
Dno.BSF	29,18	23	30	0,5	
Dno.HSW	157,7	125	162	1	
Dno.TPL	13	7,5	13,5	0,5	
Dno.TSF	22,3	13	22	0,5	
Dno.TSW	9	7,5	13,5	0,5	
UzvDna.TPL	11	8	13,5	0,5	
GirDna.HSW	150	130	170	1	
GirDna.TPL	12	10	15	0,5	
GirDna.TSW	12	7	15	0,5	
GP7.BSF	28,32	20	30	0,5	
GP7.HSW	142,4	120	160	1	

Physic	Environment	Response	Adequacy	Reliability	Quality
MM	LC1	PS	PSY	Beta-Unz.	Weight
mass	LC2	TS	PSB	B&Bou	Cost
	LC3	LS	PCY	Elem. FORM	Safety
			PCB		

Optimiser	Coordinatc	Visualizer
FFE	Model	DeView
GA	Attribute	
SLP		

ID	Name	Variables	Parameters	Attributes	Constraints	Optimiser	NDOM
1	Opt. SubProblem 1	79		3	2496	ZVGASolver	

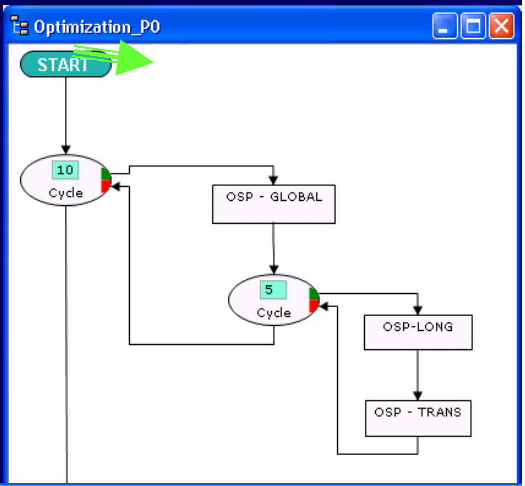
SYNTHESYS MODULES

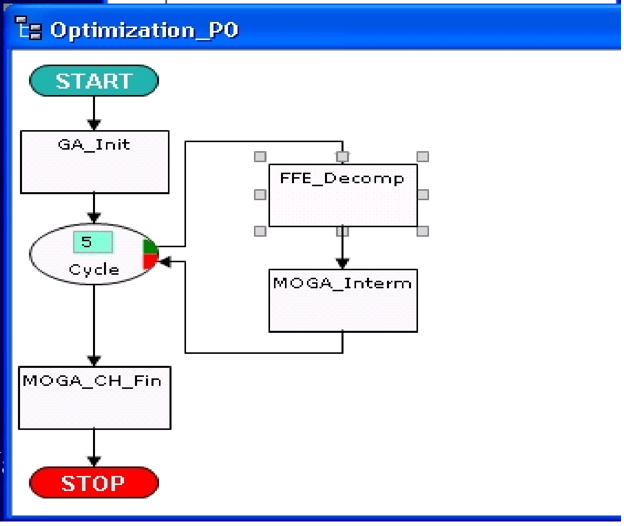
SYNTHESIS MODELS	OCTOPUS DESIGNER MODULES
Problem definition **(Δ)**	C# shell: **SYNCHRO** – decision support problem definition, selection of analysis and synthesis methods. **Auxiliary modules:** **CAPLAN – control of Pareto surface generation** **LINC – definition of feasible subspace based on subset of linear/linearized constraints**
Problem solution **(Σ)**	DeMak optimization solvers: **MONTE – multilevel multi criteria evolution strategy** **FFE – Fractional Factorial Experiments** **CALMOP - SLP cross section optimizer** **MOGA - Multi objective GA** **DOMINO – Pareto frontier filter** **MINIS – subspace size controller** **HYBRID – combination solver-sequencer**
Problem graphics and interactivity **(Γ)**	MAESTRO Graphic Environment De View C# Environment **Design selection modules in metric space:** **GOAL- interactive goal input** **SAATY - inter-attribute preferences** **FUZZY - intra-attribute preferences** **COREL - statistical analysis of results**

PROBLEM DEFINITION (Δ) MODULES

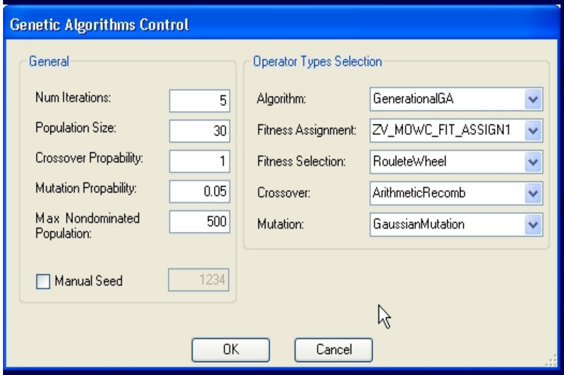
- Problem definition:
  - Objectives: Minimal weight; Minimal cost; Maximal safety measures, etc. from (Ω)
  - Variables - subset of prob. descriptors (Φ, ε)
  - Constraints:
    - Minimal dimensions (Φ_{min})
    - Library of criteria from (α-1,2)
- SYNCHRO – decision support problem definition, selection of analysis (load, response, probabilistic data for ε, ρ-1,2,3 and π) and synthesis methods, etc.
- AUXILIARY MODULES:
  - CAPLAN – control of Pareto surface generation
  - LINC – definition of feasible subspace based on subset of linear/linearized constraints

Synchro
(Sequencer)



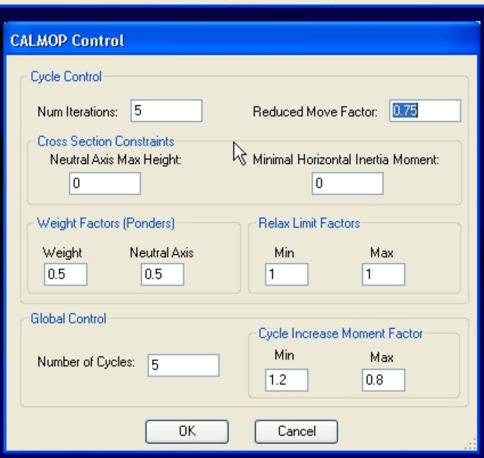


PROBLEM SOLUTION (Σ): - Optimization solvers



Num Iterations: 5
Population Size: 30
Crossover Propability: 1
Mutation Propability: 0.05
Max Nondominated Population: 500
☐ Manual Seed 1234

Algorithm: GeneralionalGA
Fitness Assignment: ZV_MOWC_FIT_ASSIGN1
Fitness Selection: RouleteWheel
Crossover: ArithmeticRecomb
Mutation: GaussianMutation



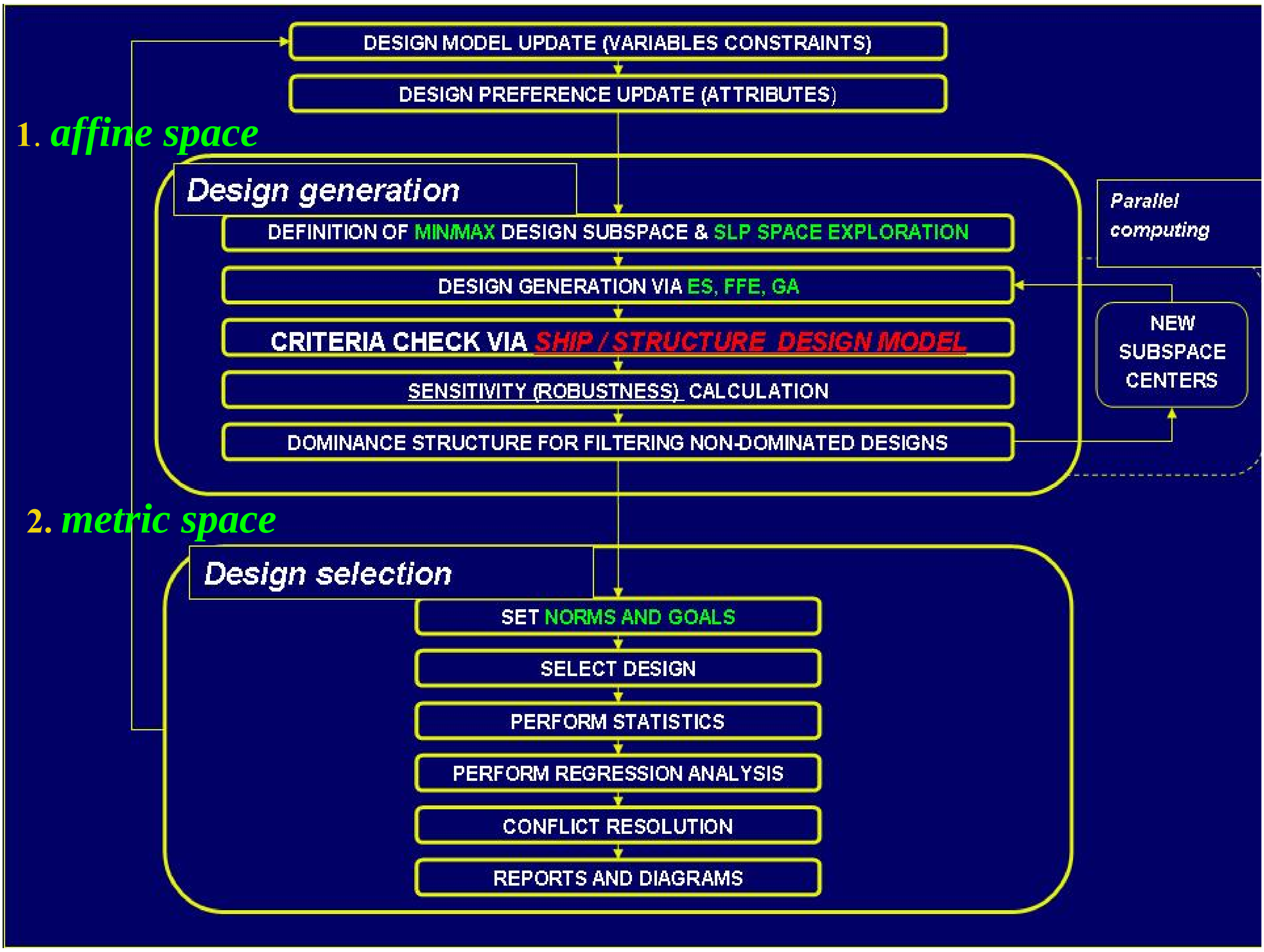
Num Iterations: 5
Reduced Move Factor: 0.75
Neutral Axis Max Height: 0
Minimal Horizontal Inertia Moment: 0
Weight: 0.5
Neutral Axis: 0.5
Relax Limit Factors Min: 1
Relax Limit Factors Max: 1
Number of Cycles: 5
Cycle Increase Moment Factor Min: 1.2
Cycle Increase Moment Factor Max: 0.8

Optimization solvers :

- ❑ MONTE - multilevel multi criteria evolution strategies using :
  - – Adaptive MC algorithm
  - – FFE – Fractional Factorial Experiments
- ❑ CALMOP - SLP cross section optimizer
- ❑ MOGA - Multi objective GA
- ❑ HYBRID – combination solver-sequencer

Utilities :

- – DOMINO – Pareto frontier filter
- – MINIS – subspace size controller



DESIGN MODEL UPDATE (VARIABLES CONSTRAINTS)

DESIGN PREFERENCE UPDATE (ATTRIBUTES)

1. *affine space*

Design generation

DEFINITION OF MIN/MAX DESIGN SUBSPACE & SLP SPACE EXPLORATION

DESIGN GENERATION VIA ES, FFE, GA

CRITERIA CHECK VIA SHIP / STRUCTURE DESIGN MODEL

SENSITIVITY (ROBUSTNESS) CALCULATION

DOMINANCE STRUCTURE FOR FILTERING NON-DOMINATED DESIGNS

Parallel computing

NEW SUBSPACE CENTERS

2. *metric space*

Design selection

SET NORMS AND GOALS

SELECT DESIGN

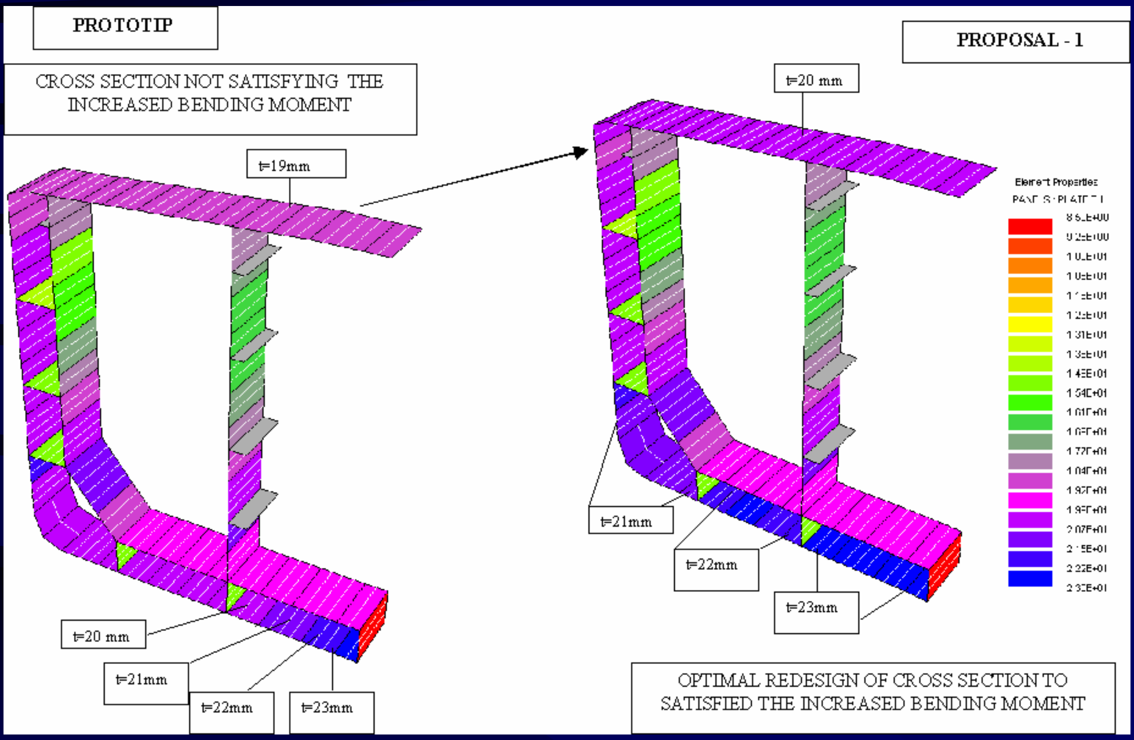
PERFORM STATISTICS

PERFORM REGRESSION ANALYSIS

CONFLICT RESOLUTION

REPORTS AND DIAGRAMS

(1) CALMOP GLOBAL OPTIMISATION OF CROSS SECTION USING SLP



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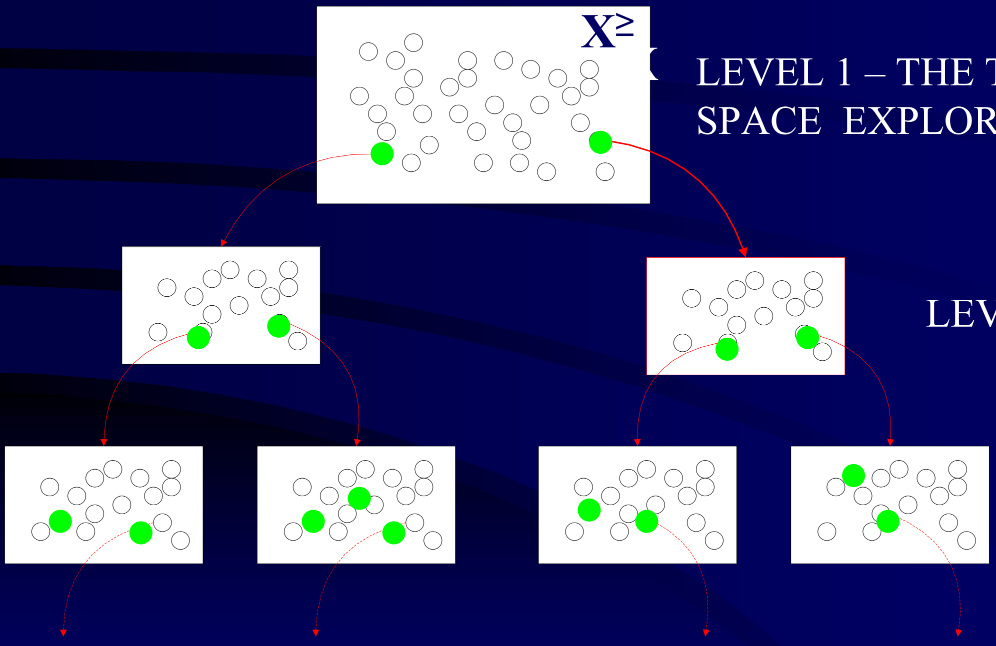
(2) EVOLUTIONARY STRATEGY FOR SUBSYSTEMS (SUB-SYSTEMS e.g. GROSS PANELS)



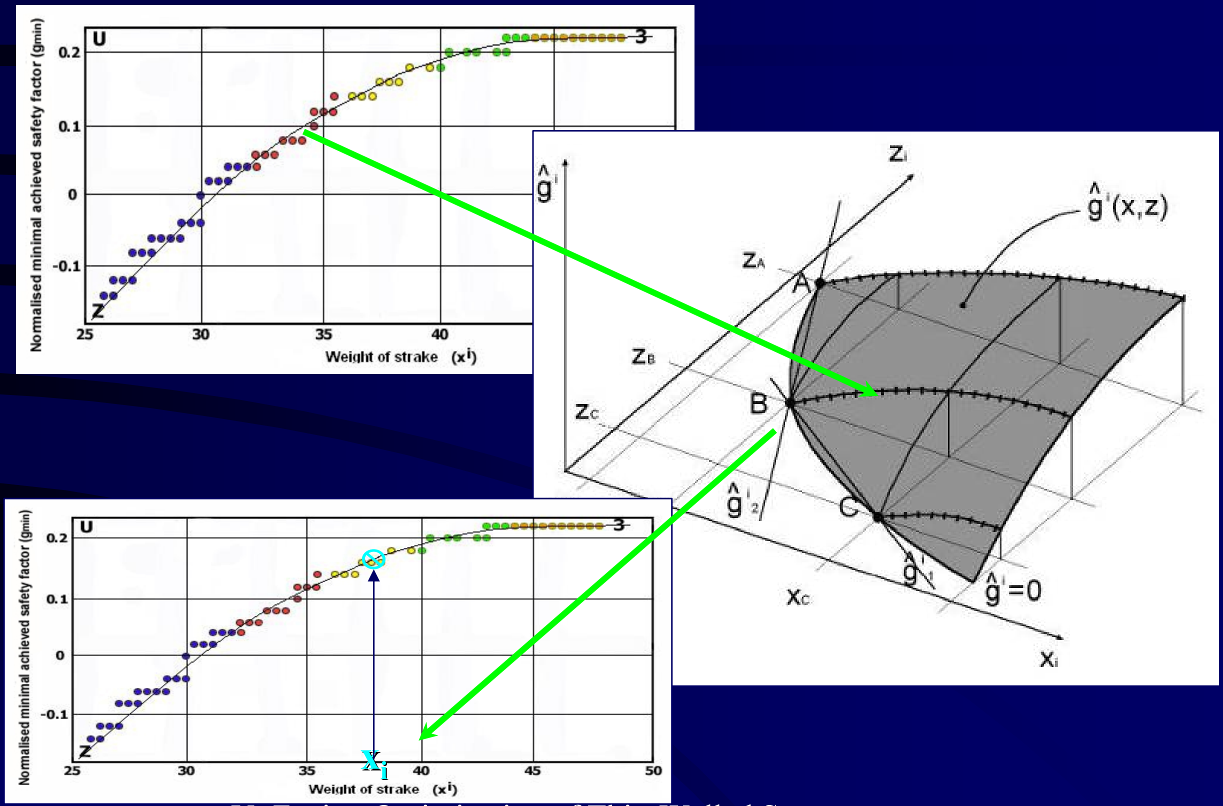
LEVEL 1 – THE TOTAL DESIGN SPACE EXPLORATION

LEVEL 2

LEVEL 3

LEVEL N...

(1) + (2): GLOBAL – LOCAL COORDINATION USING ENVELOPE OF LOCAL FAILURE SURFACES



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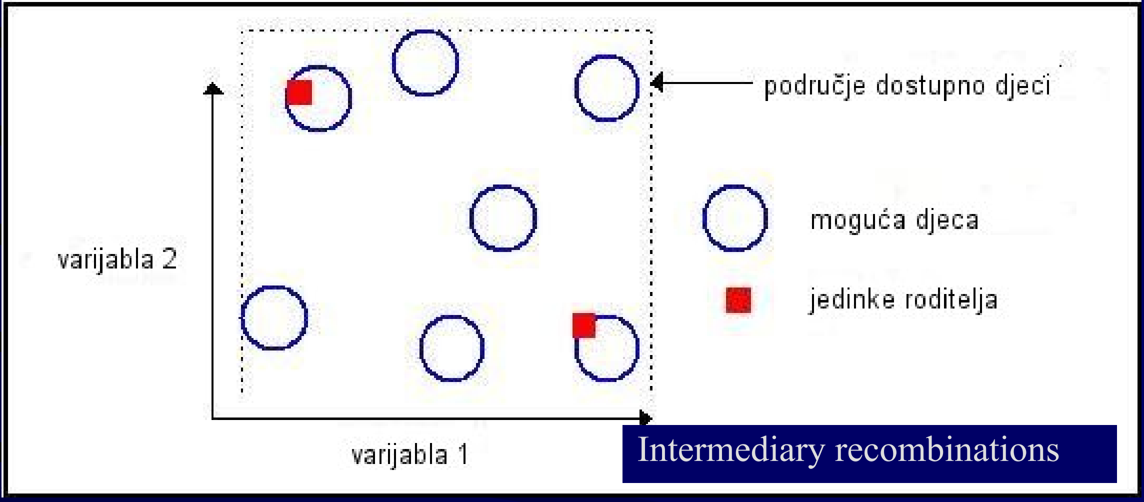
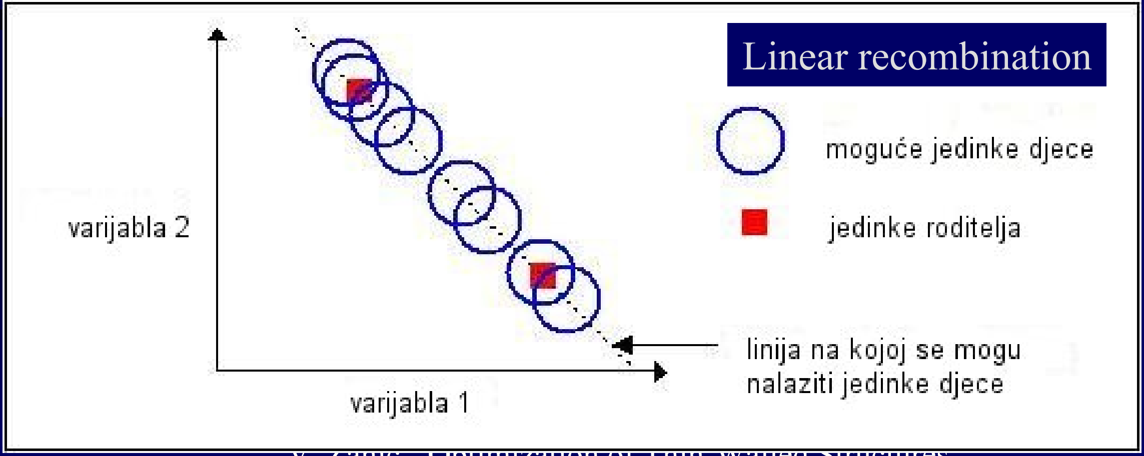
(3) APPLICATION OF MOGA

- Large problemS:
  - over 200 variables
  - more that 2.500 constraints
  - 3 objective functions
- Solved with standard generational and steady-state genetic algorithms
- Modification of fitness assignment operator was required
  - fitness value based on Pareto dominance
  - penalty for constraint violation
  - use of technique of fitness sharing for achieving better spread of Pareto front

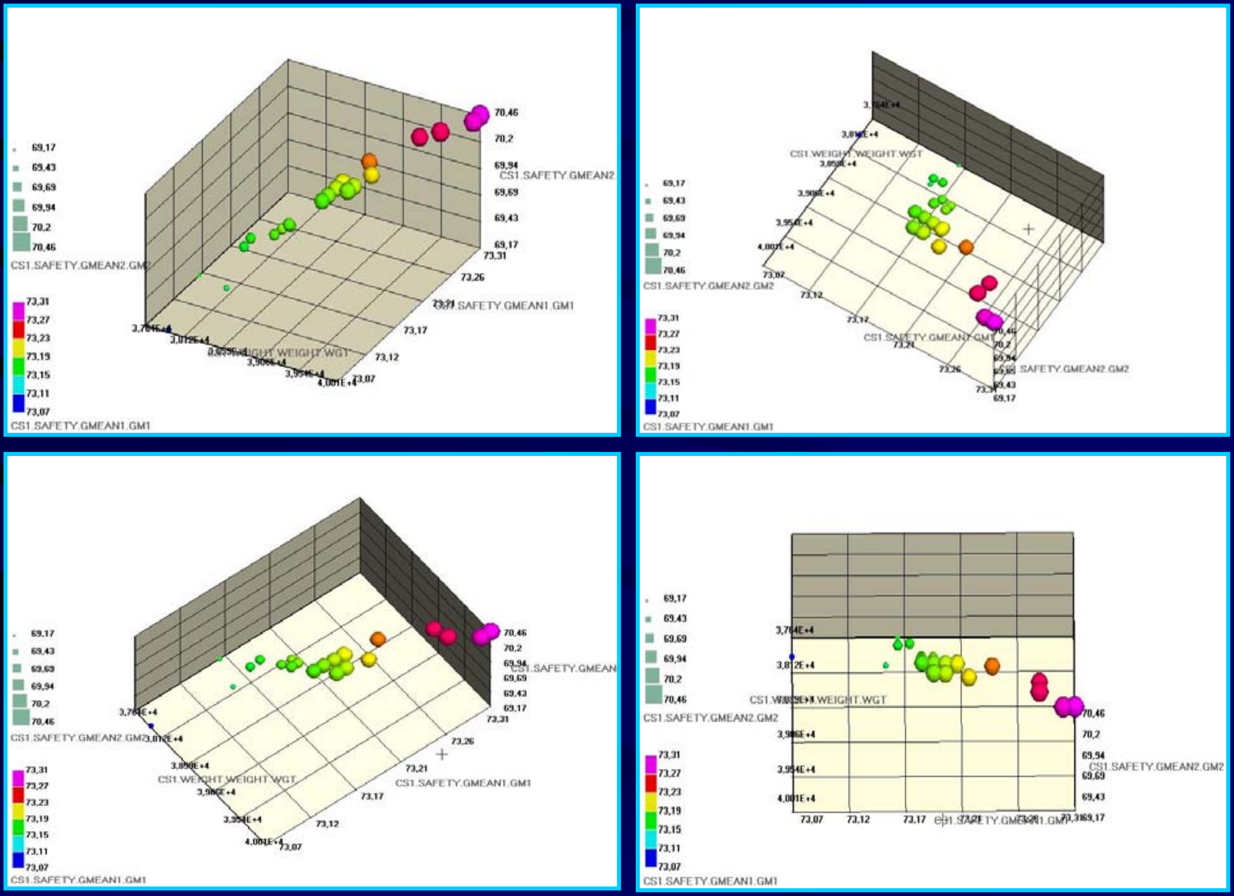


Intermediary recombinations



Linear recombination

GRAPHICS MODULES (Γ): PARETO FRONTIER

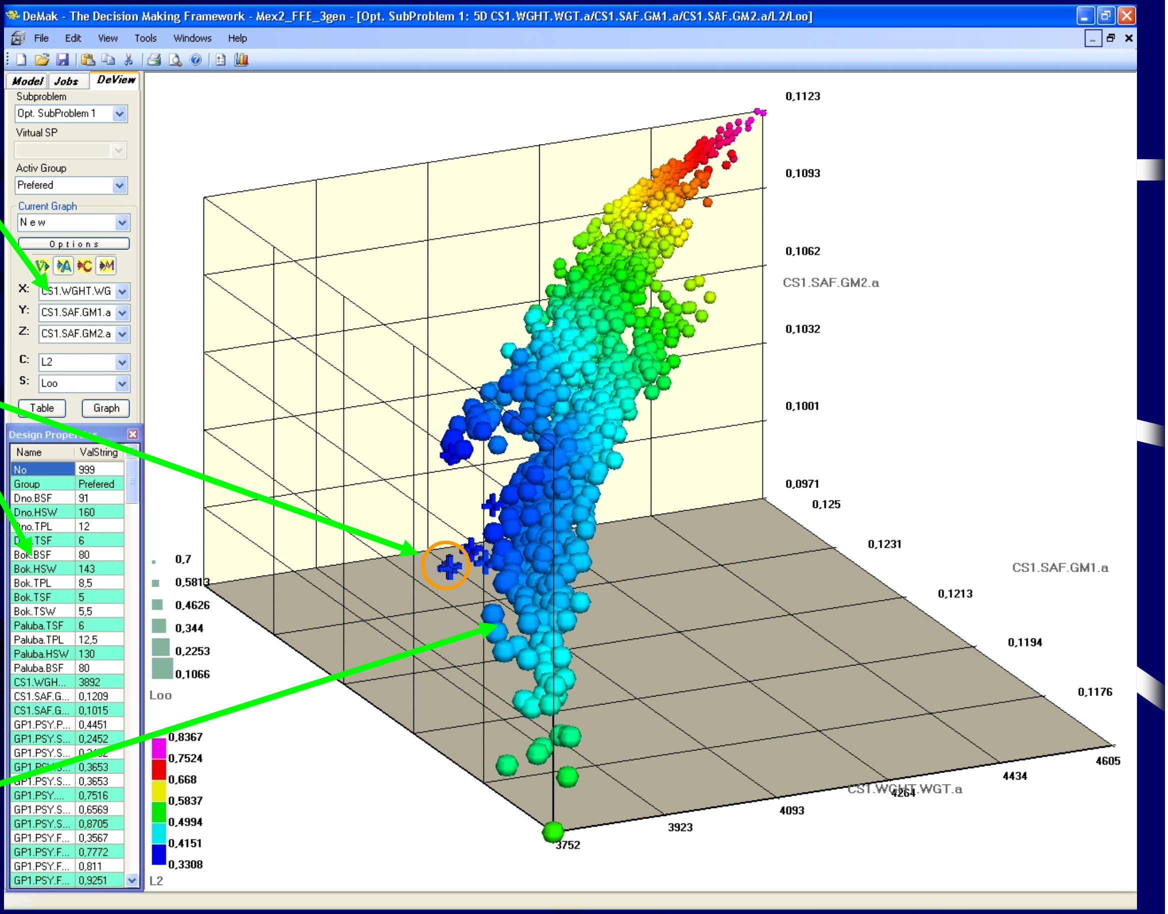


DeView – PARETO SURFACE IN 5D SPACE

Visualization control for Graphs and Tables

Properties of the Currently Selected Design

Graphical Representation of Pareto surface



Subproblem: Opt. SubProblem 1
Virtual SP:
Activ Group: Prefered
Current Graph: N e w
X: CS1.WGHT.WG
Y: CS1.SAF.GM1.a
Z: CS1.SAF.GM2.a
C: L2
S: Loo

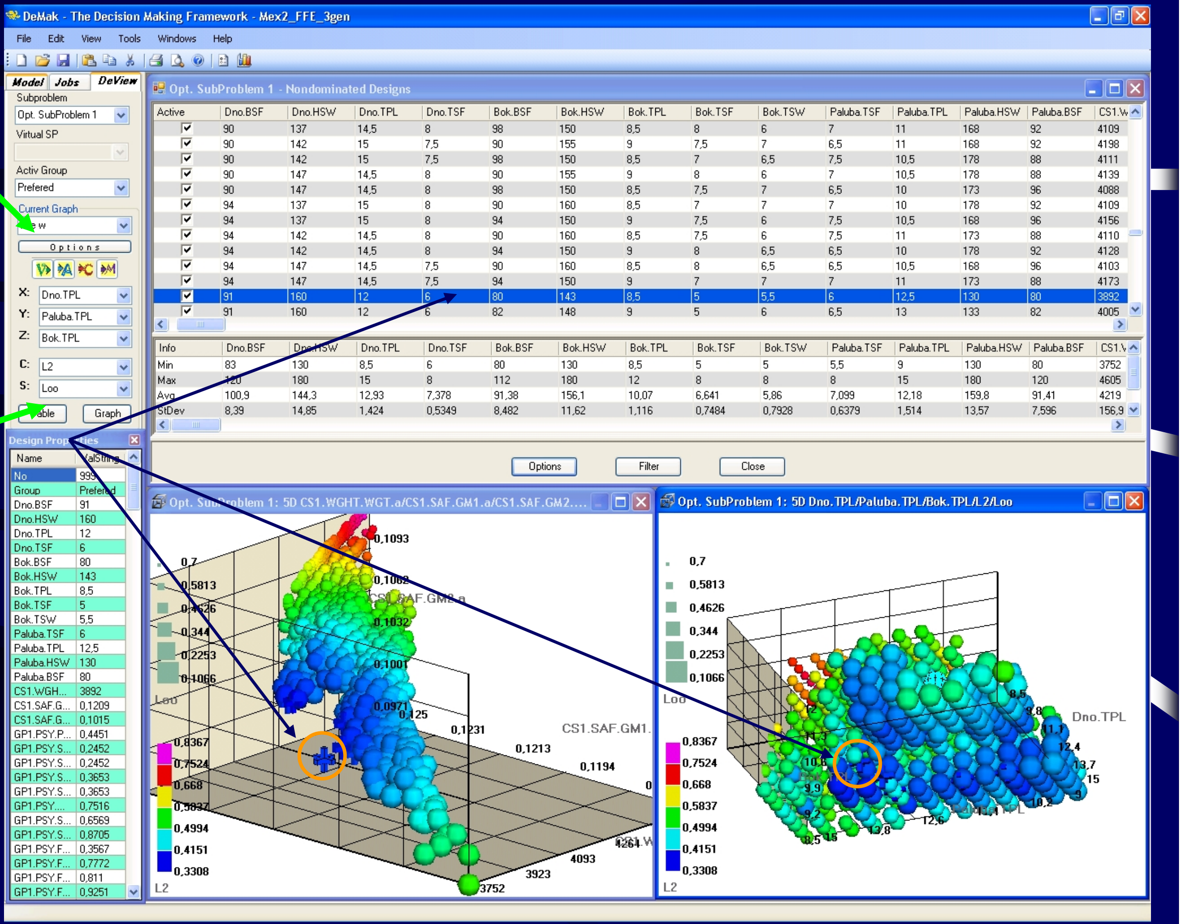
Name	ValString
No	999
Group	Prefered
Dno.BSF	91
Dno.HSW	160
Dno.TPL	12
Dno.TSF	6
Bok.BSF	80
Bok.HSW	143
Bok.TPL	8,5
Bok.TSF	5
Bok.TSW	5,5
Paluba.TSF	6
Paluba.TPL	12,5
Paluba.HSW	130
Paluba.BSF	80
CS1.WGH...	3892
CS1.SAF.G...	0,1209
CS1.SAF.G...	0,1015
GP1.PSY.P...	0,4451
GP1.PSY.S...	0,2452
GP1.PSY.S...	0,2452
GP1.PSY.S...	0,3653
GP1.PSY.S...	0,3653
GP1.PSY....	0,7516
GP1.PSY.S...	0,6569
GP1.PSY.S...	0,8705
GP1.PSY.F...	0,3567
GP1.PSY.F...	0,7772
GP1.PSY.F...	0,811
GP1.PSY.F...	0,9251

DeView SNAPSHOT OF THE SELECTED DESIGN

Visualization control for Graphs and Tables

Properties of the Currently Selected Design (marked cross)

Multiple views of X+Y spaces (selection of the 5-axis views)



Subproblem: Opt. SubProblem 1
Virtual SP:
Activ Group: Prefered
Current Graph: New
X: Dno.TPL
Y: Paluba.TPL
Z: Bok.TPL
C: L2
S: Loo

Active	Dno.BSF	Dno.HSW	Dno.TPL	Dno.TSF	Bok.BSF	Bok.HSW	Bok.TPL	Bok.TSF	Bok.TSW	Paluba.TSF	Paluba.TPL	Paluba.HSW	Paluba.BSF	CS1.W
☑	90	137	14,5	8	98	150	8,5	8	6	7	11	168	92	4109
☑	90	142	15	7,5	90	155	9	7,5	7	6,5	11	168	92	4198
☑	90	142	15	7,5	98	150	8,5	7	6,5	7,5	10,5	178	88	4111
☑	90	147	14,5	8	90	155	9	8	6	7	10,5	178	88	4139
☑	90	147	14,5	8	98	150	8,5	7,5	7	6,5	10	173	96	4088
☑	94	137	15	8	90	160	8,5	7	7	7	10	178	92	4109
☑	94	137	15	8	94	150	9	7,5	6	7,5	10,5	168	96	4156
☑	94	142	14,5	8	90	160	8,5	7,5	6	7,5	11	173	88	4110
☑	94	142	14,5	8	94	150	9	8	6,5	6,5	10	178	92	4128
☑	94	147	14,5	7,5	90	160	8,5	8	6,5	6,5	10,5	168	96	4103
☑	94	147	14,5	7,5	94	150	9	7	7	7	11	173	88	4173
☑	91	160	12	6	80	143	8,5	5	5,5	6	12,5	130	80	3892
☑	91	160	12	6	82	148	9	5	6	6,5	13	133	82	4005

Info	Dno.BSF	Dno.HSW	Dno.TPL	Dno.TSF	Bok.BSF	Bok.HSW	Bok.TPL	Bok.TSF	Bok.TSW	Paluba.TSF	Paluba.TPL	Paluba.HSW	Paluba.BSF	CS1.W
Min	83	130	8,5	6	80	130	8,5	5	5	5,5	9	130	80	3752
Max	120	180	15	8	112	180	12	8	8	8	15	180	120	4605
Avg	100,9	144,3	12,93	7,378	91,38	156,1	10,07	6,641	5,86	7,099	12,18	159,8	91,41	4219
StDev	8,39	14,85	1,424	0,5349	8,482	11,62	1,116	0,7484	0,7928	0,6379	1,514	13,57	7,596	156,9

Name	ValString
No	999
Group	Prefered
Dno.BSF	91
Dno.HSW	160
Dno.TPL	12
Dno.TSF	6
Bok.BSF	80
Bok.HSW	143
Bok.TPL	8,5
Bok.TSF	5
Bok.TSW	5,5
Paluba.TSF	6
Paluba.TPL	12,5
Paluba.HSW	130
Paluba.BSF	80
CS1.WGH...	3892
CS1.SAF.G...	0,1209
CS1.SAF.G...	0,1015
GP1.PSY.P...	0,4451
GP1.PSY.S...	0,2452
GP1.PSY.S...	0,2452
GP1.PSY.S...	0,3653
GP1.PSY.S...	0,3653
GP1.PSY....	0,7516
GP1.PSY.S...	0,6569
GP1.PSY.S...	0,8705
GP1.PSY.F...	0,3567
GP1.PSY.F...	0,7772
GP1.PSY.F...	0,811
GP1.PSY.F...	0,9251

DeMak – DEFINITION OF INTER / INTRA ATTRIBUTE PREFERENCES

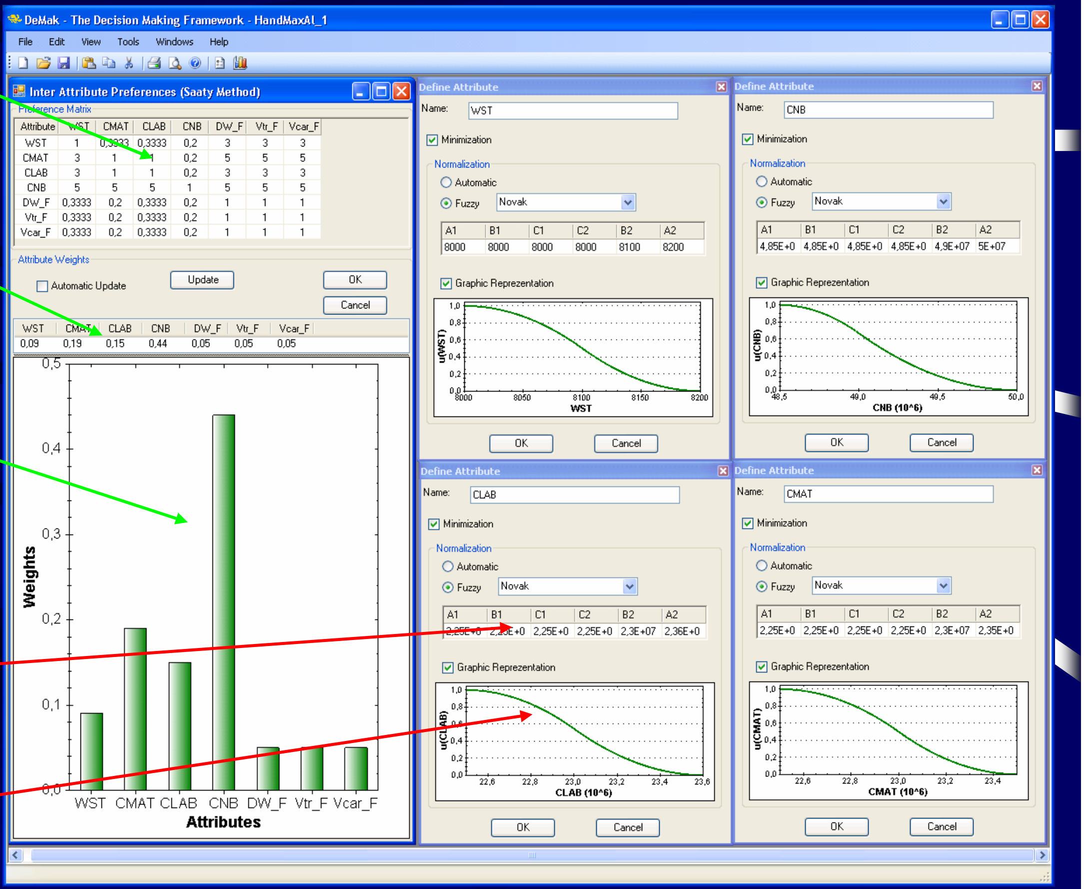
Inter Attribute Preference Matrix

Weights Calculated by Saaty Method

Weights Graphical Visualization

Fuzzy Functions Definition

Graphical Visualization of Fuzzy Functions



Attribute	WST	CMAT	CLAB	CNB	DW_F	Vtr_F	Vcar_F
WST	1	0,3333	0,3333	0,2	3	3	3
CMAT	3	1	1	0,2	5	5	5
CLAB	3	1	1	0,2	3	3	3
CNB	5	5	5	1	5	5	5
DW_F	0,3333	0,2	0,3333	0,2	1	1	1
Vtr_F	0,3333	0,2	0,3333	0,2	1	1	1
Vcar_F	0,3333	0,2	0,3333	0,2	1	1	1

☐ Automatic Update

WST	CMAT	CLAB	CNB	DW_F	Vtr_F	Vcar_F
0,09	0,19	0,15	0,44	0,05	0,05	0,05

Name: WST

☑ Minimization

○ Automatic
● Fuzzy Novak

A1	B1	C1	C2	B2	A2
8000	8000	8000	8000	8100	8200

☑ Graphic Reprezentation

Name: CNB

☑ Minimization

○ Automatic
● Fuzzy Novak

A1	B1	C1	C2	B2	A2
4,85E+0	4,85E+0	4,85E+0	4,85E+0	4,9E+07	5E+07

☑ Graphic Reprezentation

Name: CLAB

☑ Minimization

○ Automatic
● Fuzzy Novak

A1	B1	C1	C2	B2	A2
2,25E+0	2,25E+0	2,25E+0	2,25E+0	2,3E+07	2,36E+0

☑ Graphic Reprezentation

Name: CMAT

☑ Minimization

○ Automatic
● Fuzzy Novak

A1	B1	C1	C2	B2	A2
2,25E+0	2,25E+0	2,25E+0	2,25E+0	2,3E+07	2,35E+0

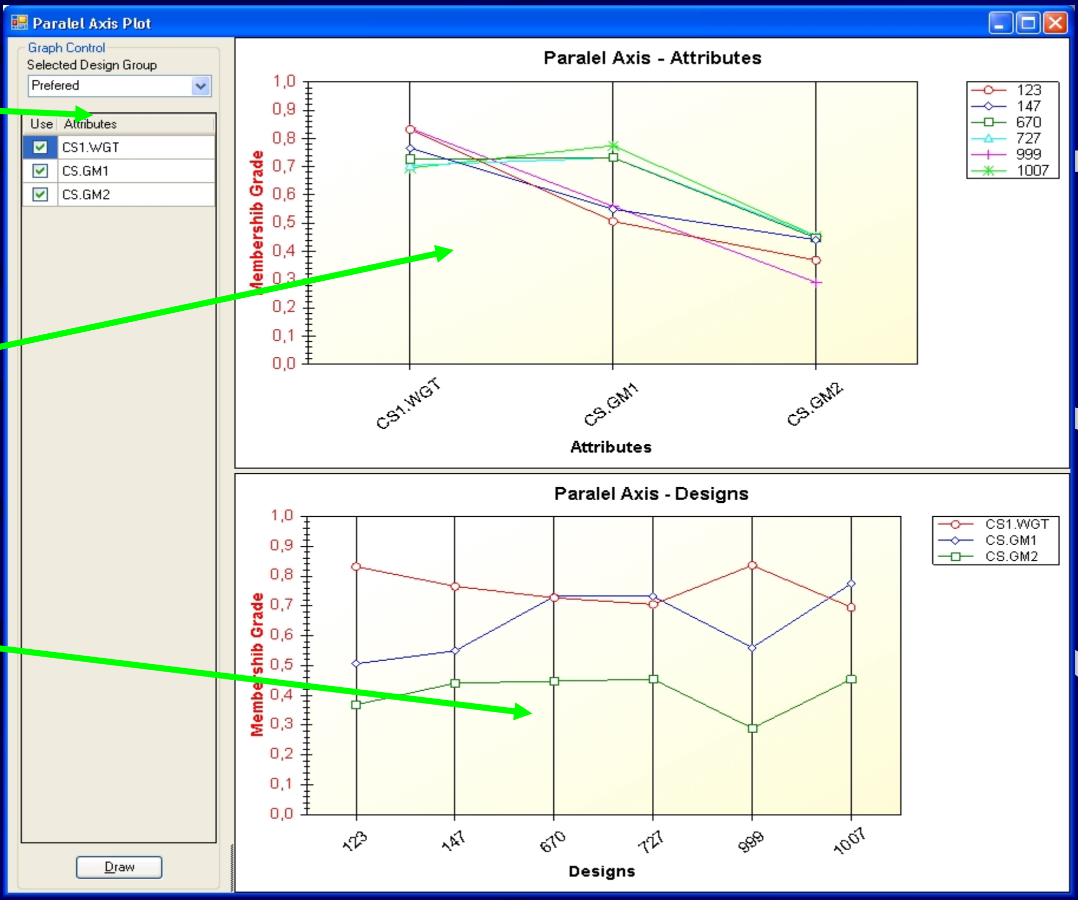
☑ Graphic Reprezentation

DeView – PARALEL AXIS PLOT

Group and Attribute Selection

Attributes on X axis

Designs on X axis

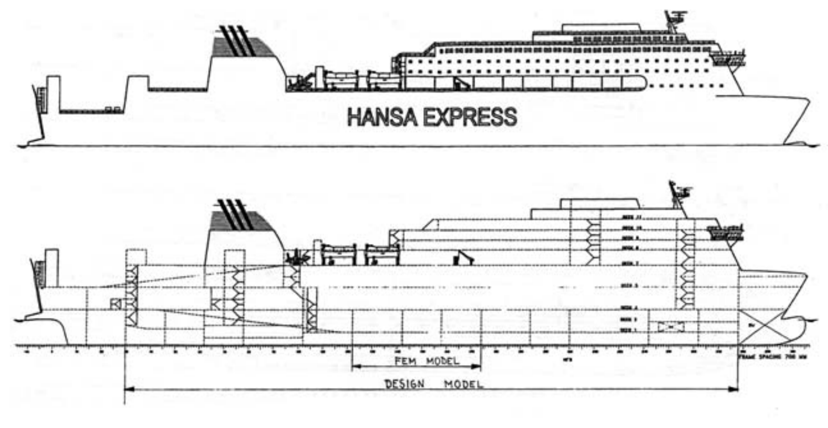


Selected Design Group: Prefered

Use	Attributes
☑	CS1.WGT
☑	CS.GM1
☑	CS.GM2

3. APPLICATIONS

CASE STUDY A 1: Structural Design, Analysis and Optimization of Large RoPax (3500 lanemeters),



PRINCIPAL DIMENSIONS	
Length overall	221.2 m
Length between perpendiculars	207.0 m
Breadth max. o.f	29.0 m
Depth to bulkhead deck	9.8 m
Depth to deck 5	16.4 m
Design draft	7.0 m
Scantling draft	7.4 m
Lanemeters	3500 m
Speed at design draft with 4 engines at 85%	24.5 Kn

DeMak inbuilt into MAESTRO

☐ Design Problem Identification:

Design objectives $a_{1-3}(.)$: min. weight, min. cost, max. safety

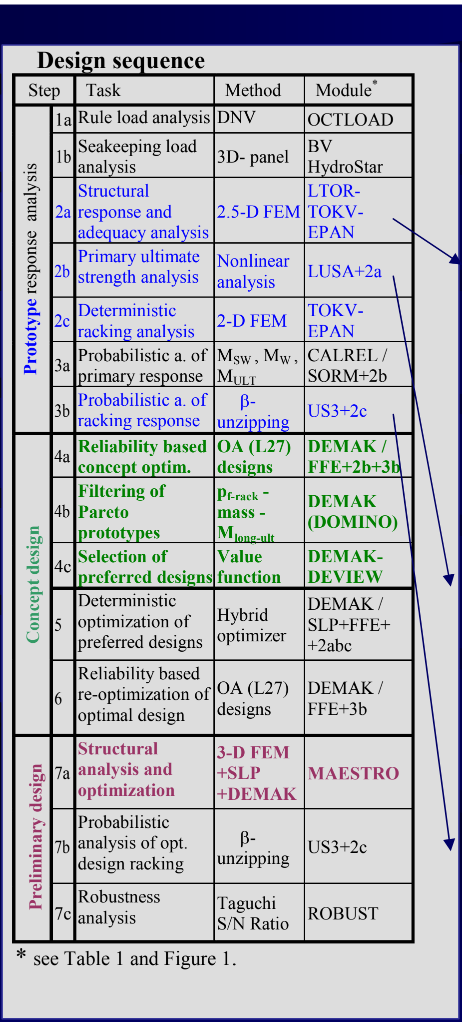
Free design variables $\underline{X} = \{\underline{x}^1,..,\underline{x}^{NS}\}$ are scantlings; nv =264

Constraints $g(\underline{X}) \geq 0$;ng ≈ 49000 from DnV Rules

Prototype P^0 scantlings from Yard documentation

Frame spacing and topology fixed to P^0 design values.

PROTOTYPE:SAFETY ANALYSIS



Design sequence

	Step	Task	Method	Module*
Prototype response analysis	1a	Rule load analysis	DNV	OCTLOAD
	1b	Seakeeping load analysis	3D- panel	BV HydroStar
	2a	Structural response and adequacy analysis	2.5-D FEM	LTOR-TOKV-EPAN
	2b	Primary ultimate strength analysis	Nonlinear analysis	LUSA+2a
	2c	Deterministic racking analysis	2-D FEM	TOKV-EPAN
	3a	Probabilistic a. of primary response	M_{SW} , M_W , M_{ULT}	CALREL / SORM+2b
	3b	Probabilistic a. of racking response	β-unzipping	US3+2c
Concept design	4a	**Reliability based concept optim.**	**OA (L27) designs**	**DEMAK / FFE+2b+3b**
	4b	**Filtering of Pareto prototypes**	**$p_{f\text{-rack}}$ - mass - $M_{long\text{-}ult}$**	**DEMAK (DOMINO)**
	4c	**Selection of preferred designs**	**Value function**	**DEMAK-DEVIEW**
	5	Deterministic optimization of preferred designs	Hybrid optimizer	DEMAK / SLP+FFE+ +2abc
	6	Reliability based re-optimization of optimal design	OA (L27) designs	DEMAK / FFE+3b
Preliminary design	7a	**Structural analysis and optimization**	**3-D FEM +SLP +DEMAK**	**MAESTRO**
	7b	Probabilistic analysis of opt. design racking	β-unzipping	US3+2c
	7c	Robustness analysis	Taguchi S/N Ratio	ROBUST

* see Table 1 and Figure 1.

Prototype deterministic safety analysis showed that prototype failed in 35 criteria w.r.t DNV Rules (out of 8820 checks for 7 LCs) in:

- ❑ double bottom (stiff. panels/ frames $g_{FCPB,} = -0.268$)
- ❑ tank-side (st. panels e.g. $g_{U\text{-}BCAES,min} = -0.172$)
- ❑ deck5-middle (st. panel e.g. $g_{PFLB,min} = -0.243$)

- ❑ Ultimate bending moment-LC1(sagg)=3.93 106 kNm LC2 (hogg)=3.18 106 kNm (bottom collapse in compression-see above).
- ❑ Identified failed elements were non-optimally strengthened (mass increased 1.2%; strong prototype ▪)

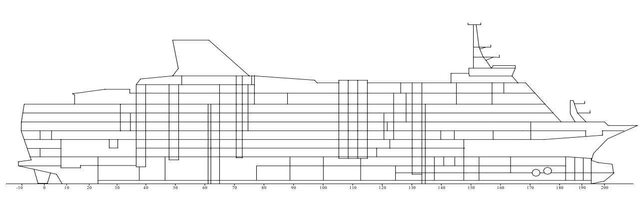
- ❑ System failure probability (Ditlevsen upper bound) for the 45 identified relevant (level-3) failure scenarios was: $p_f=0.101 \cdot 10^{-6}$; $\beta_G=5.198$ showing the existence of considerable safety margin

---

Optimization results

MODEL	Geometry s_w L_{FEM} (mm)	Weight of optimization model (t) W_{start} W_{opt}	Weight per length W_{opt} / L_{FEM} (t / m)	Savings before final standard. $\frac{(W_{start} - W_{opt})}{W_{start}}$	Global safety (adequacy) measure	Weight of design model $W=L*k*w_L$ (t)	Increased deadweihgt = decreased steel weight
PROTOTYPE	**2800** **33600**	**1355** **-**	**40.33**	**-**	**0.9622**	**5646**	-
PROPOSAL 1	**2800** **33600**	**1355** **1220**	**36.31**	**9.97%**	**0.9905**	**5083**	**563 t**
PROPOSAL 2	**2400** **28800**	**1202** **1046**	**36.32**	**9.94%**	**0.9889**	**5085**	**561 t**
PROPOSAL 3	**3000** **36000**	**1416** **1282**	**35.61**	**(11.70 %)**	**0.9719**	**4985**	**661 t**
PROPOSAL 4	**2800** **33600**	**1382** **1139**	**33.90**	**experiment**	**0.9683**	**/**	**/**

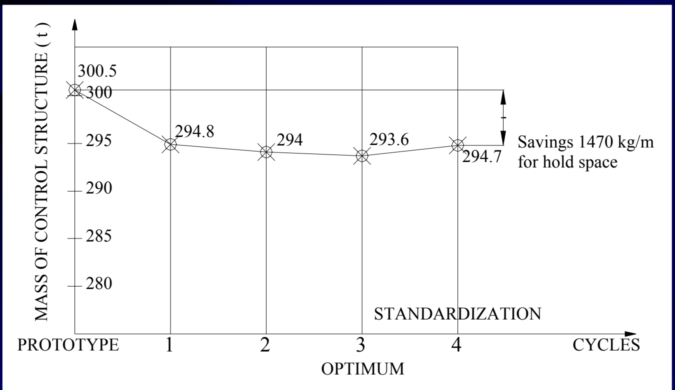
CASE STUDY 2: Structural Design, Analysis and Optimization of **Passenger/Car Ferry (L=169 m, 11 decks)**



MAIN PARTICULARS:

LOA = 176,0 m
LPP = 169,0 m
B = 32,0 m
T = 10,0 m
Speed trial =22 Kn
2200 passengers
600 cars

OPTIMIZATION PROCEDURE



The four ships of this type have been built in Croatia and they operate in the Baltic.

The optimization was performed due to the owner's conflicting requirements on ship weight and vibration criteria.

Cost sensitivity study with respect to frame spacing (800, 850 and 900 mm)was performed for the third and fourth ship.

Design process is divided into two parts :

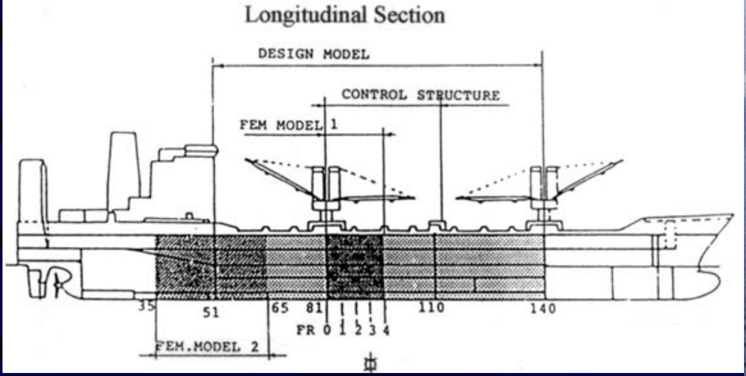
optimization for weight critical design
cost sensitivity study with respect to frame spacing.

The optimization model included : 492 scantlings of design variables

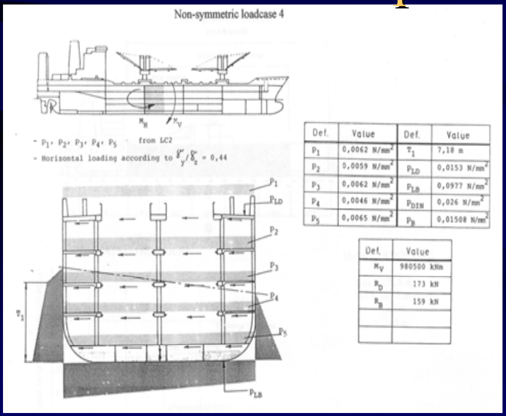
Results

- ❑Problem of structural adequacy is solved by simultaneously resolving 49 unsatisfied failure criteria of the very sophisticated prototype.
- ❑Weight decrease of 600 kg/m has been achieved for critical weight constrained design, as compared to the minimal weight prototype, giving 60 tons of weight reserve to the designer to be used in satisfying vibration criteria.
- ❑Sensitivity study shows that the cost of structure per meter is rather insensitive to frame spacing, in given interval, due to cancellation of the effects of structural modifications and smaller number of web frames.

CASE STUDY 3: Structural Design, Analysis and Optimization of **Reefer/Ro-Ro Ship (470000 cbft)**



Loadcase description

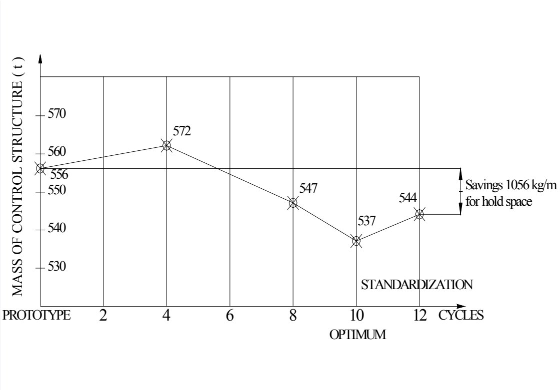


- P_1, P_2, P_3, P_4, P_5 from LC2
- Horizontal loading according to $\gamma_y/\gamma_z = 0{,}44$

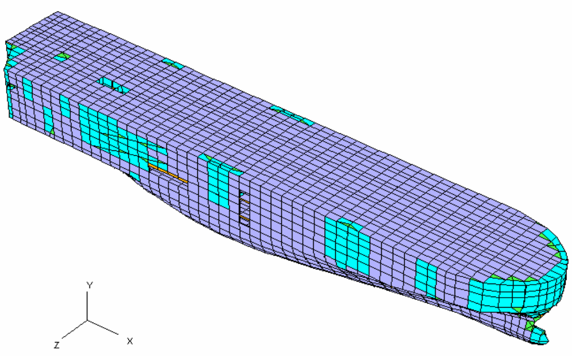
Def.	Value	Def.	Value
P_1	0,0062 N/mm^2	T_1	7,18 m
P_2	0,0059 N/mm^2	P_{LD}	0,0153 N/mm^2
P_3	0,0062 N/mm^2	P_{LB}	0,0977 N/mm^2
P_4	0,0046 N/mm^2	P_{DIN}	0,026 N/mm^2
P_5	0,0065 N/mm^2	P_B	0,01508 N/mm^2

Def.	Value
M_V	980500 kNm
R_D	173 kN
R_B	159 kN

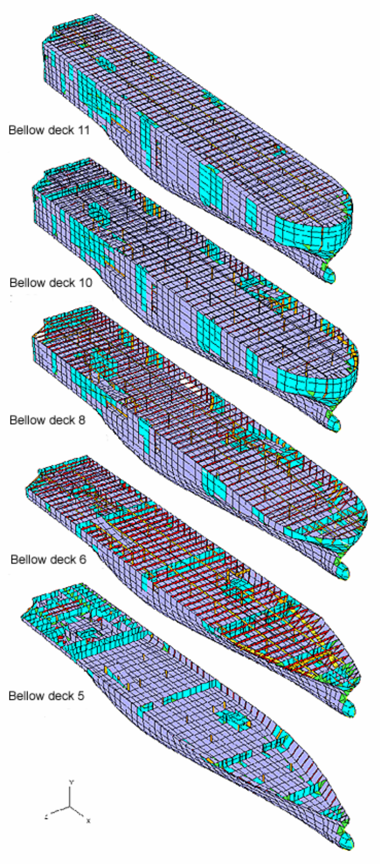
Optimization Procedure

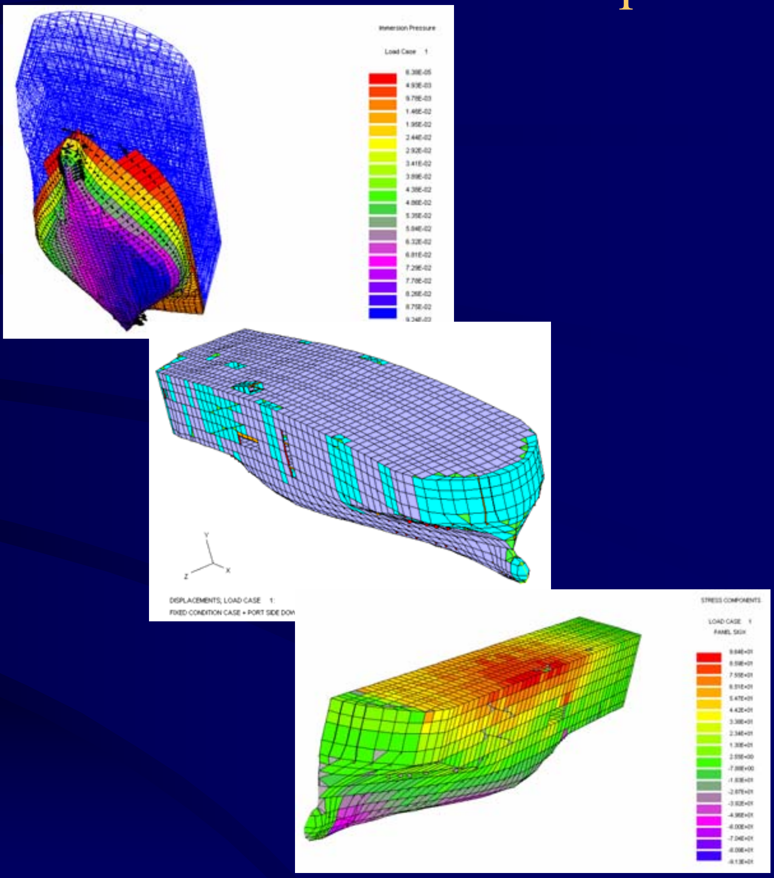


CASE STUDY 4: Structural Design, Analysis and redesign of **Car-Truck Carrier LOA = 176.7 m, 5300 cars**



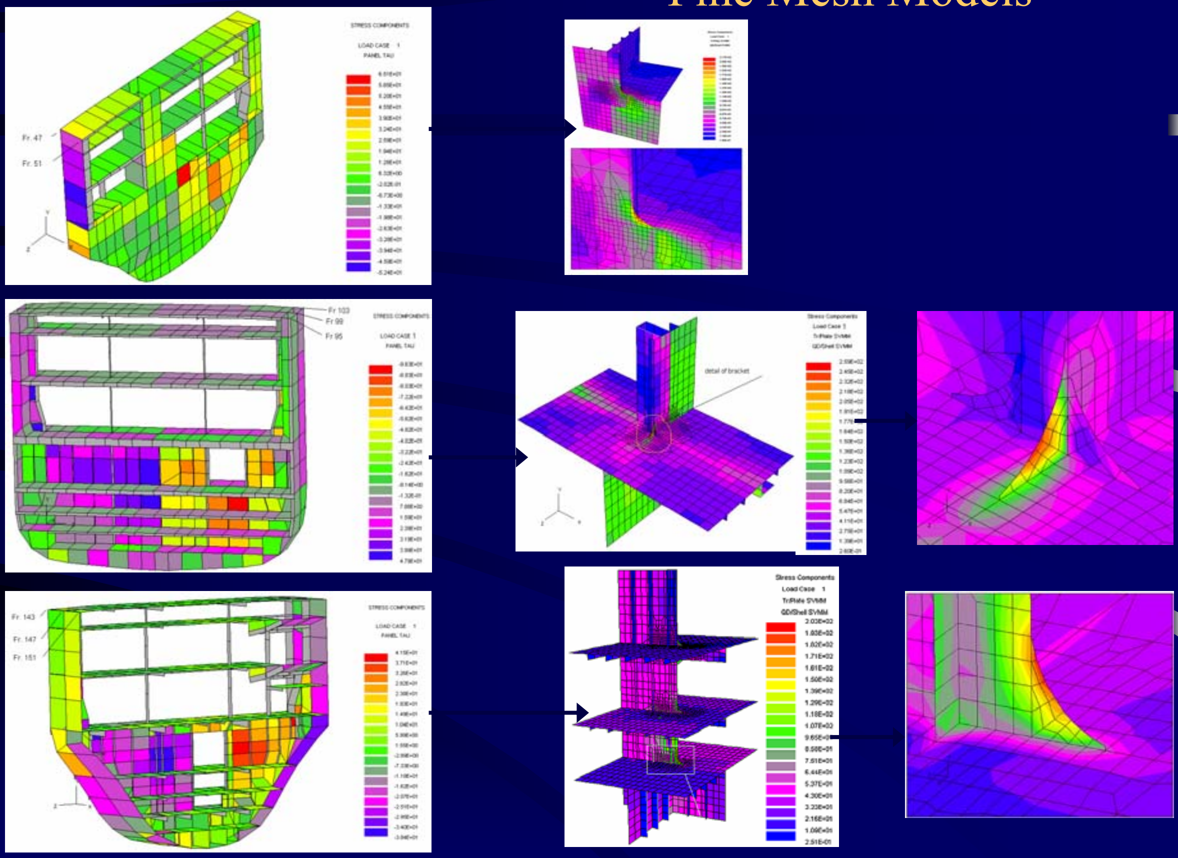
Full Ship F.E.M Model, Immersion Load and Global Response





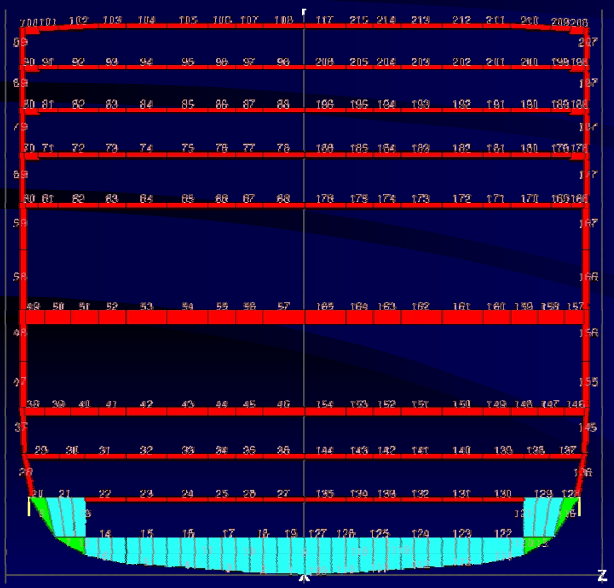
Global Respons

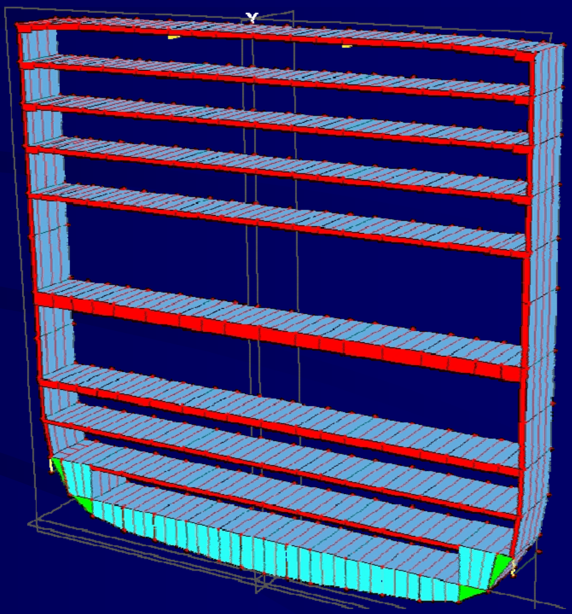
von Mises Stresses for Fine Mesh Models



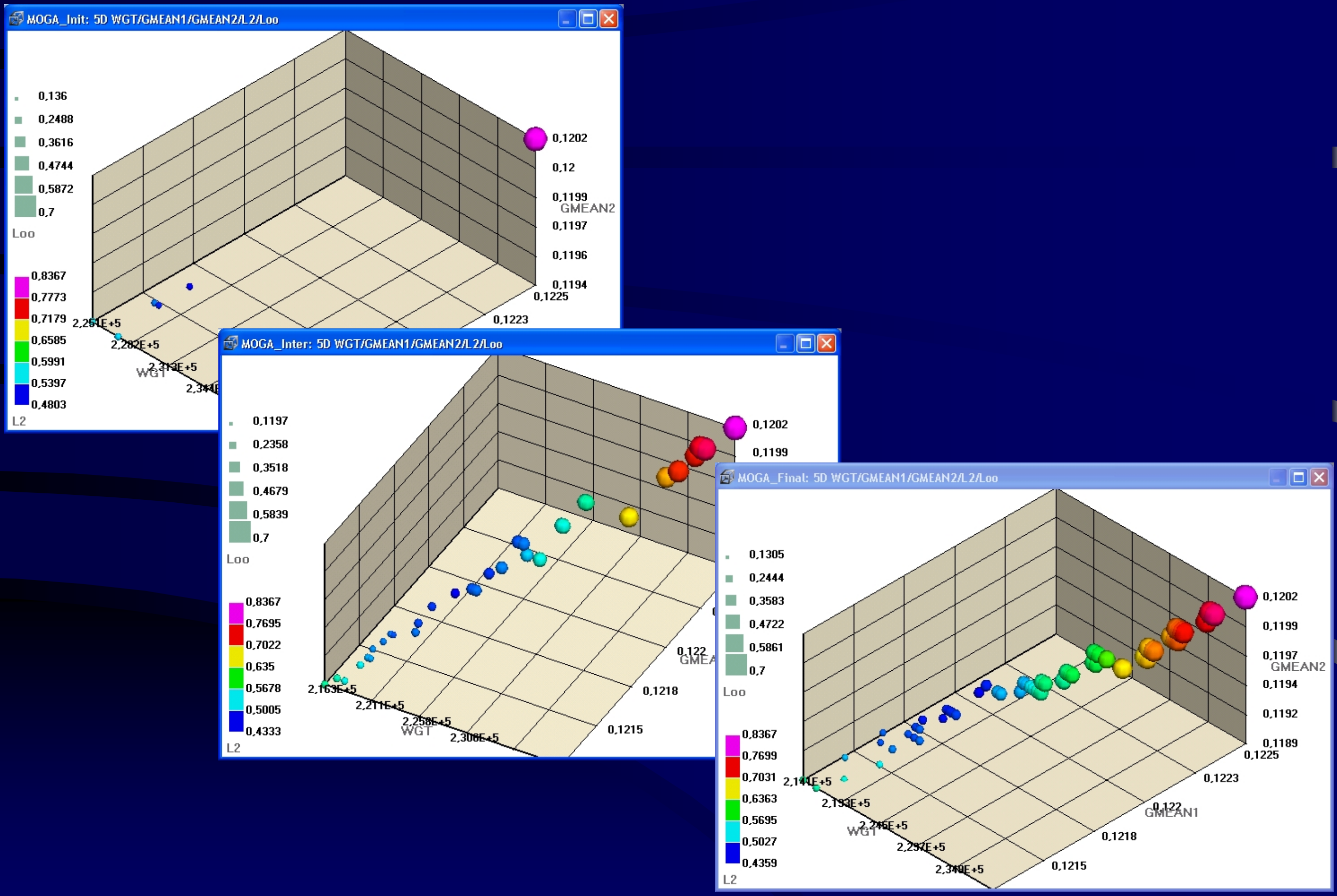
MOGA optimisation of CAR CARRIER

	Number
Design Variables:	635
Constraints:	2469
Objectives:	3

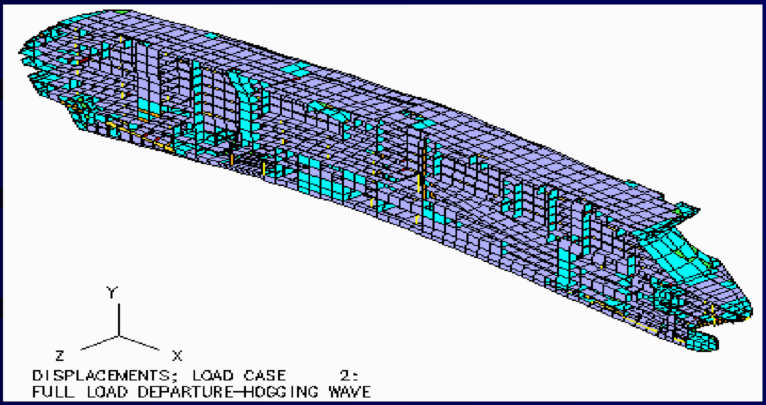


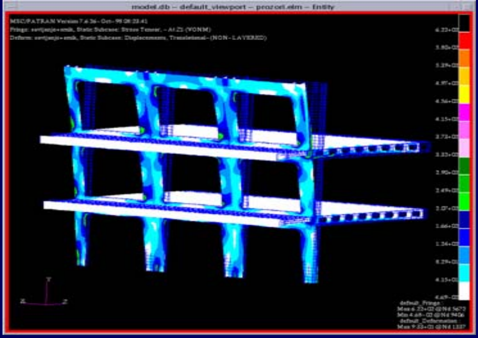


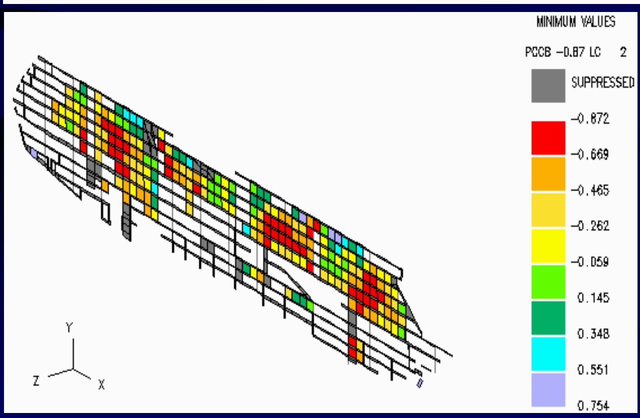
PROGRESS OF PARETO FRONTIER

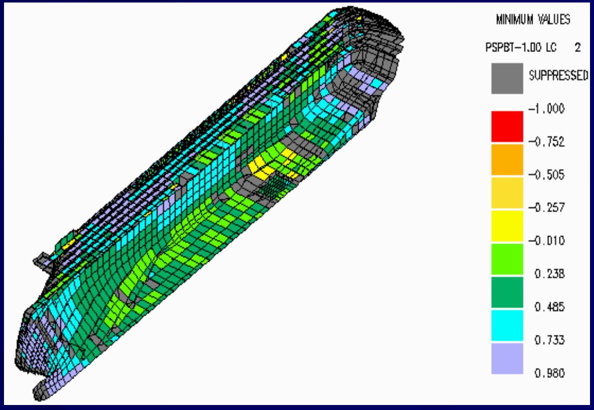


CASE STUDY 5: First class passenger ship (800 passengers)
Redesign for Cantieri Nuovi di Apuania, Navis Consult–Rijeka

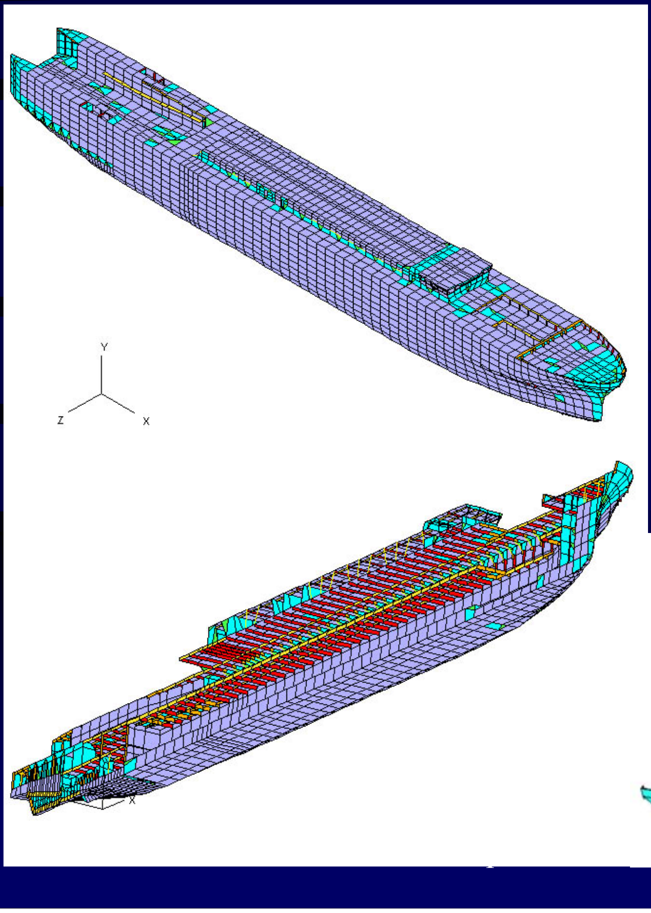






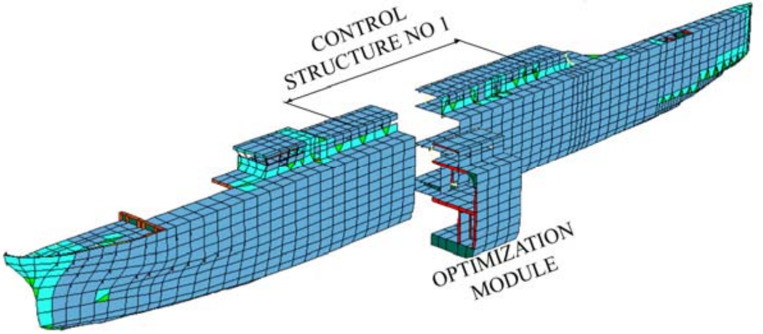


CASE STUDY 6: Structural Design, Analysis and Optimization of **Tank car carrier (L=52 tank cars)**

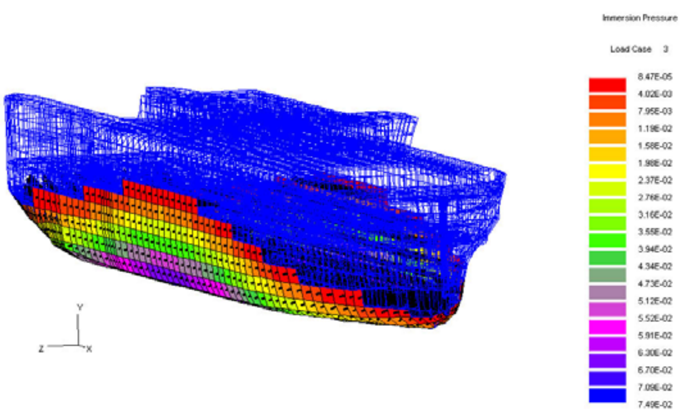


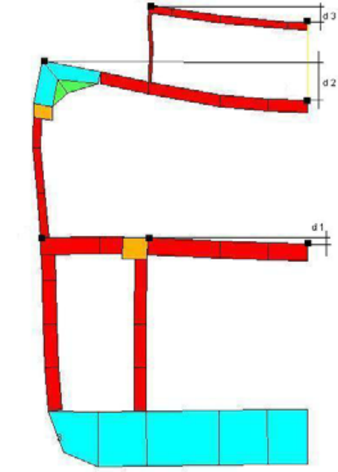
Principal dimensions:

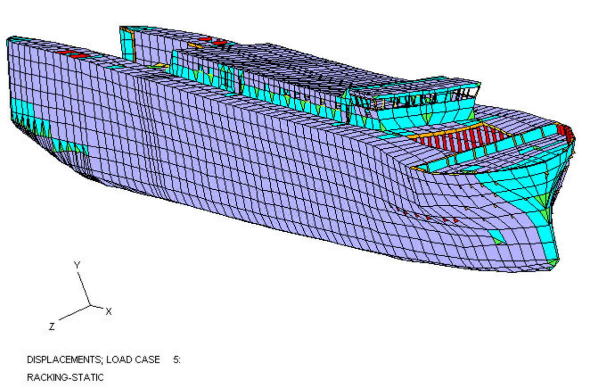
Length overall	154.50 m
Length between perpendiculars	147.00 m
Breadth moulded	17.50 m
Breadth max.	18.30 m
Depth to upper deck	7.50 m
Depth to accommodation deck	13.35 m
Draught	7.70 m
Deadweight	5000 t
Main engines	2 X 2000 kW
Speed trial (80% MCR)	14.0 knots
Wagons	52



Loads and Response

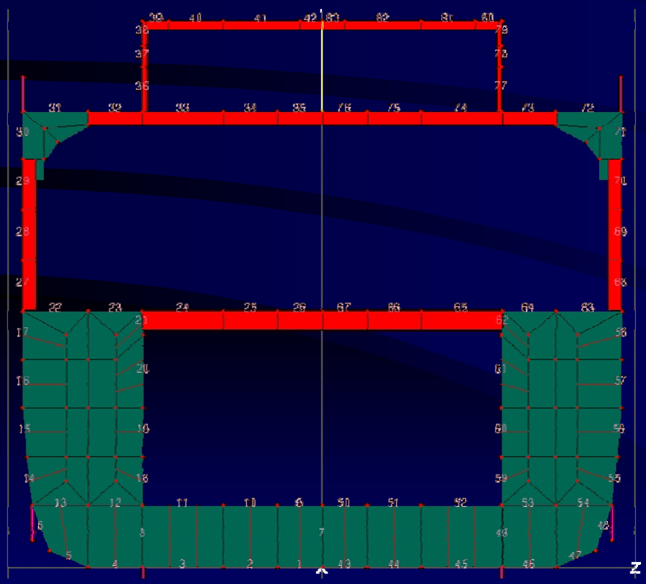


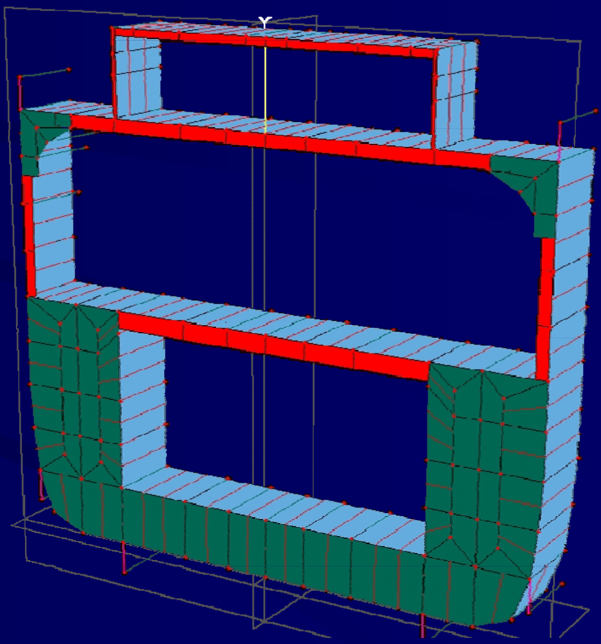




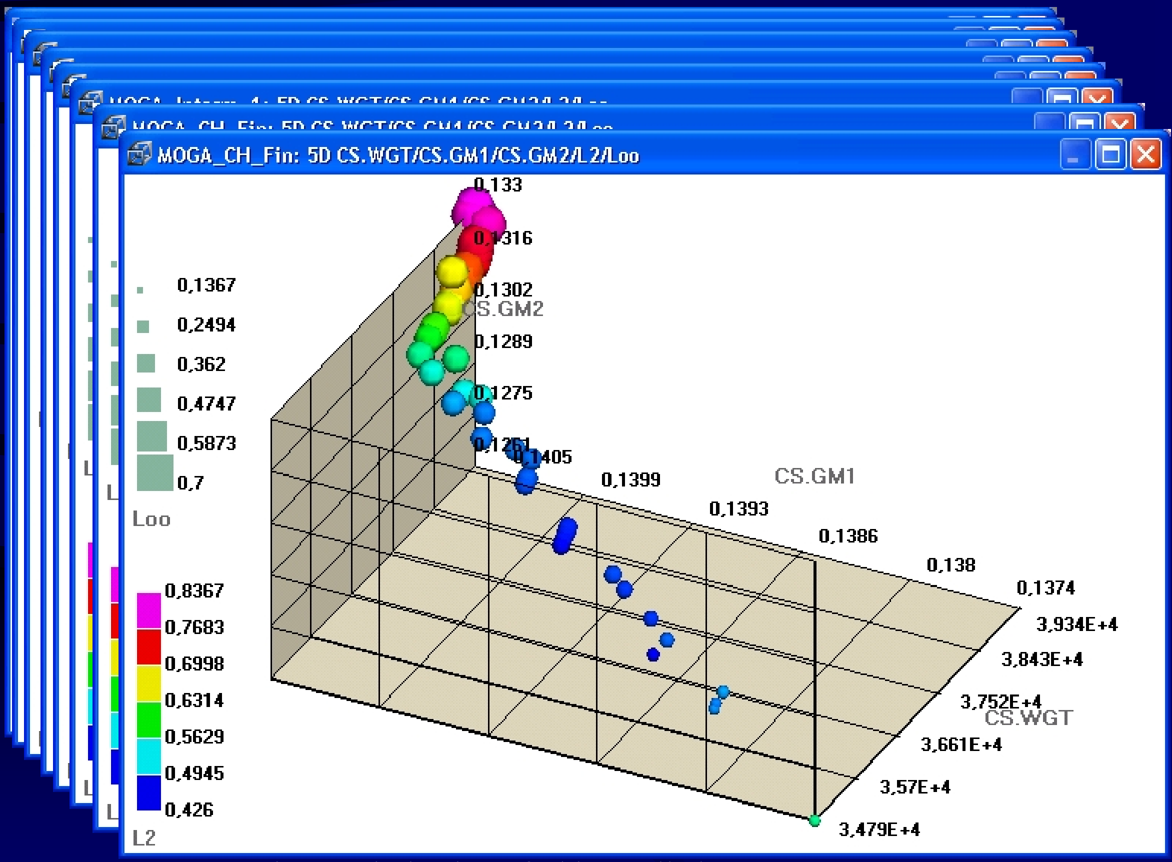
CONCEPT STRUCTURAL DESIGN OF THE TANK CAR CARRIER (MOGA)

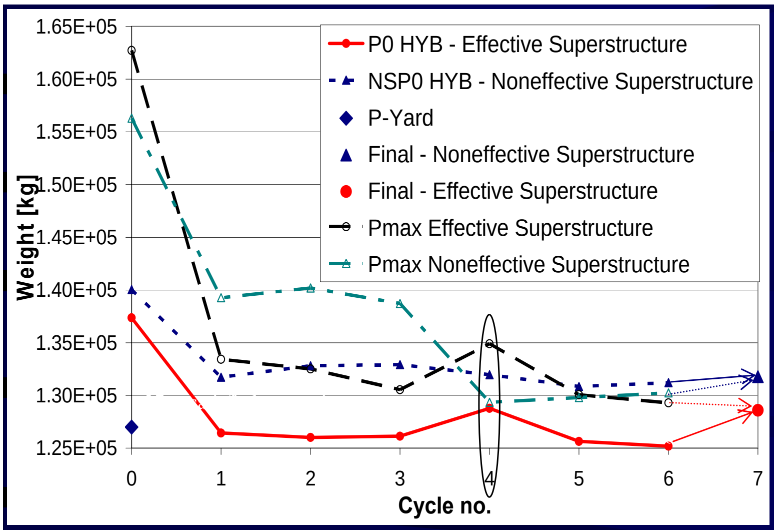
	Number
Design Variables:	79
Constraints:	2496
Objectives:	3





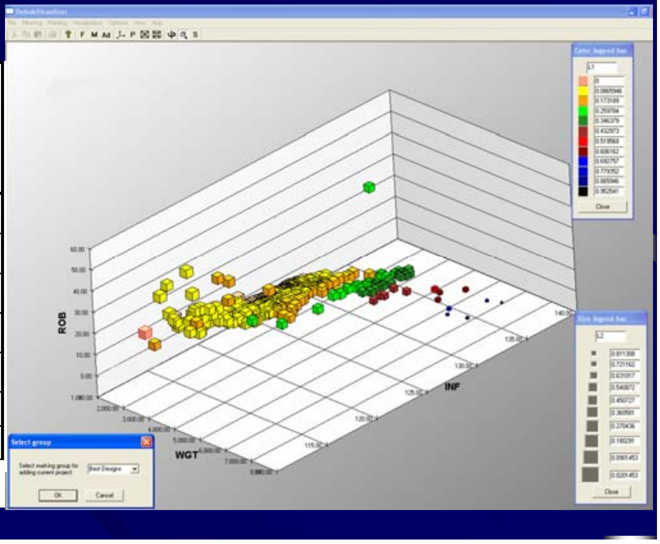
PROGRES OF PARETO FRONTIER





PRELIMINARY STRUCTURAL DESIGN OF THE TANK CAR CARRIER (DeMak Hybrid solver incorporated in MAESTRO)

Model		Mass Opt. Module (t)	Mass Control Structure (t)	Unsatisfied Criteria		Weight Savings W.R.T. P0	Weight Diff. W.R.T. Final D.
				num	Min.val.		
p^{ms}		127.1	699.05	-37	-0.25	/	
Effective SS	$P_1{}^0$	136.4	750.2	0	/		
	$O_1{}^2$	125.2	688.6	-5	-0.08	8.2%	
	$D_1{}^2$	128.6	707.3	0	/	5.7%	2.4%
Nonefective SS	$P_2{}^0$	141.6	778.8	0	/		
	$O_2{}^2$	131.2	721.6	-3	-0.05	7.3%	
	$D_2{}^2$	131.7	724.3	0	/	7.0%	

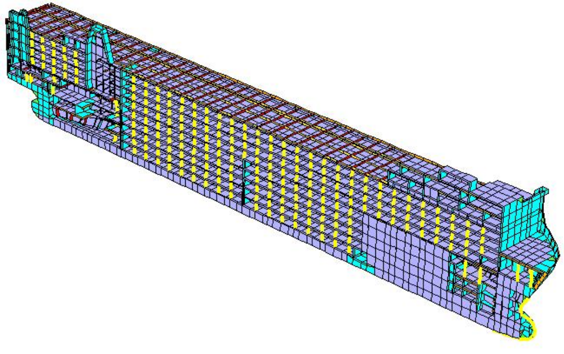


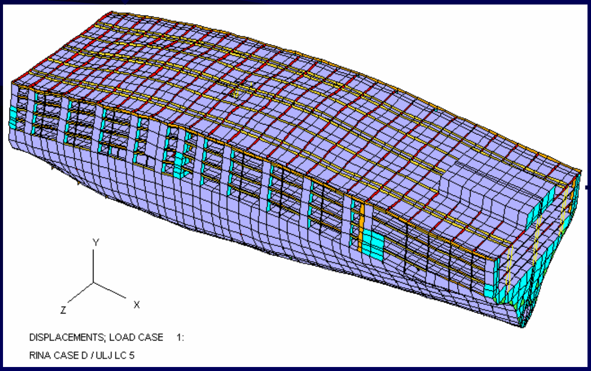
CASE STUDY 7: Livestock Carrier (LOA = 176.7 m, 24 000 sq.meters) Yard no. 428 for ULJANIK Shipyard.

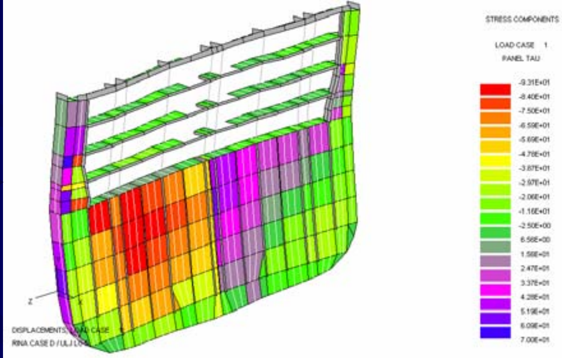
Objective of case study was to demonstrate:

- The structural analysis and redesign **of the FEM model of livestock carrier according to R.I.N.A Rules.**
- Racking analysis **to identify relevant critical areas in the transverse structure.**
- Detail design **: Feasibility of additional openings in principal structural members through the fine mesh models**

Longitudinal Section and Global Respons





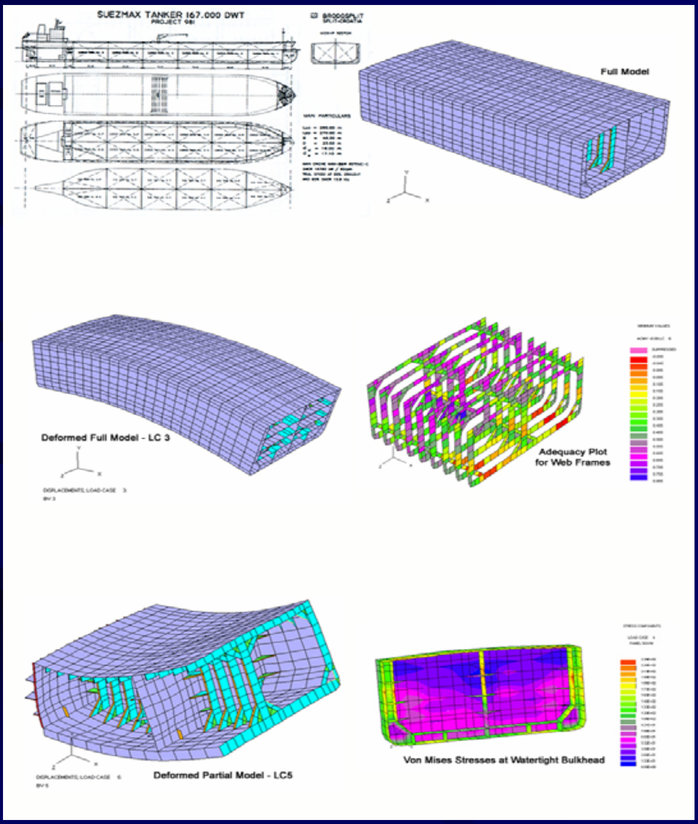


CASE STUDY 8A: Suezmax Tanker (LOA = 280.0 m, 166 300 TDW) Yard no. 433-434, for BRODOSPLIT Shipyard.

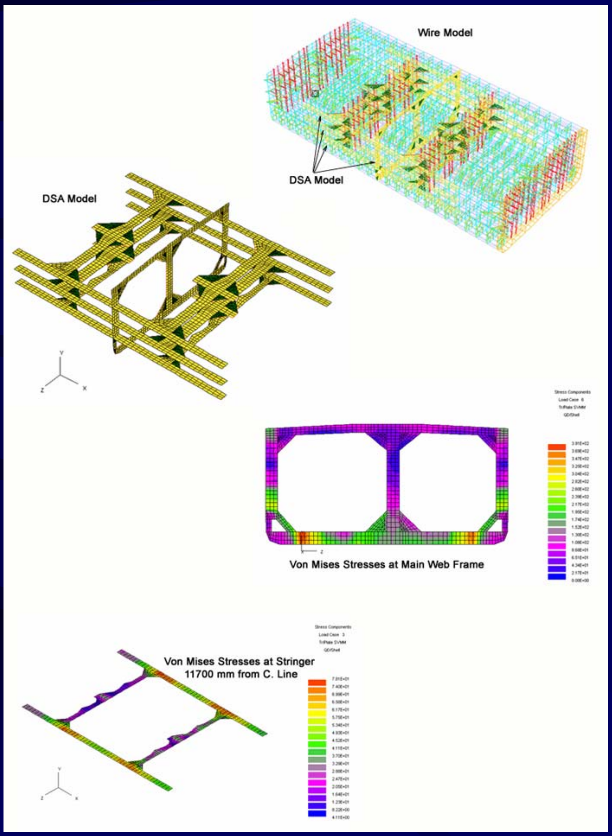
Objective of case study was to demonstrate:

- **-The** optimization process **for 3 prototypes of SUEZMAX tanker with web frame spacing of 3940, 4410 and 5065 mm.**
- **-Structural optimization for** minimal structural weight **under class.soc. requirements.**
- -Sensitivity analysis **of ship structural weight with respect to web frame spacing.**
- -Fine mesh stress analysis **(DSA) of final PROTOTYPE under BV requirements as decision support problem for final scantlings determination.**

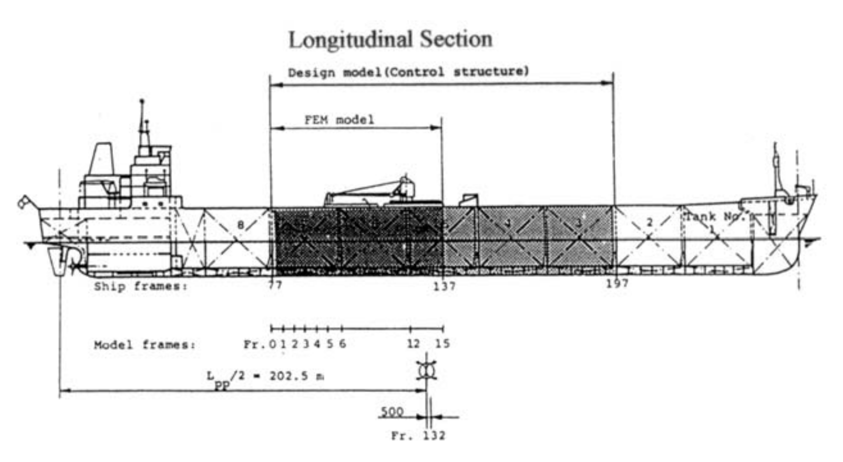
Longitudinal Section, F.E.M Model and Global Respons

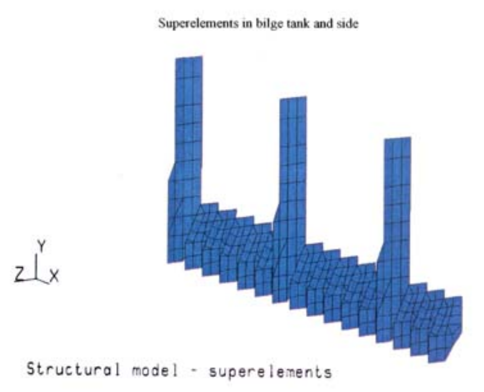


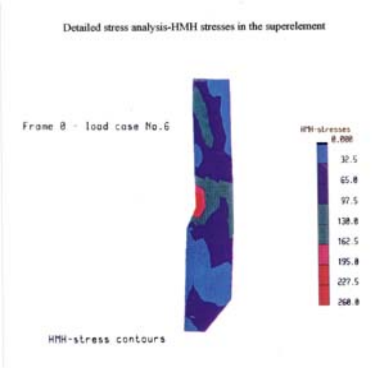
DSA/Fine Mesh Model – Maximum Principle Stresses



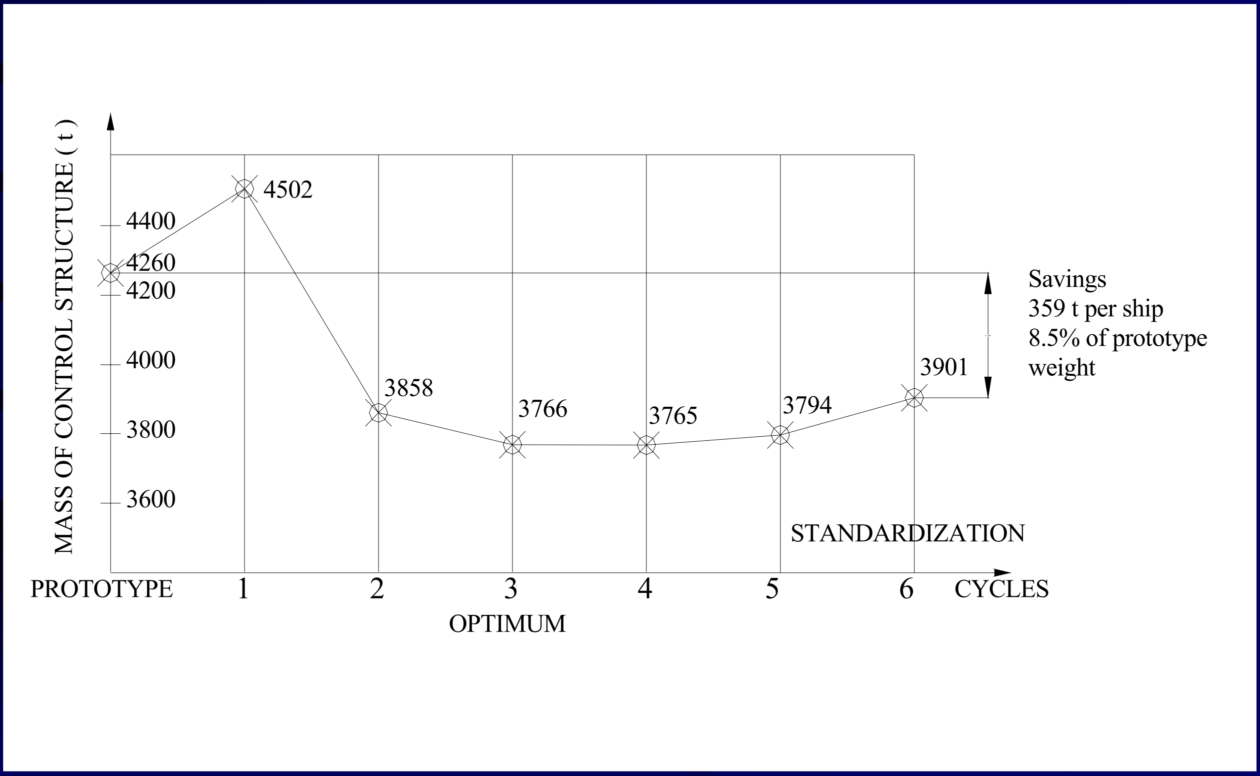
CASE STUDY 8B: Structural Design, Analysis and Optimization of **Tanker for oil** (70000 TDW)





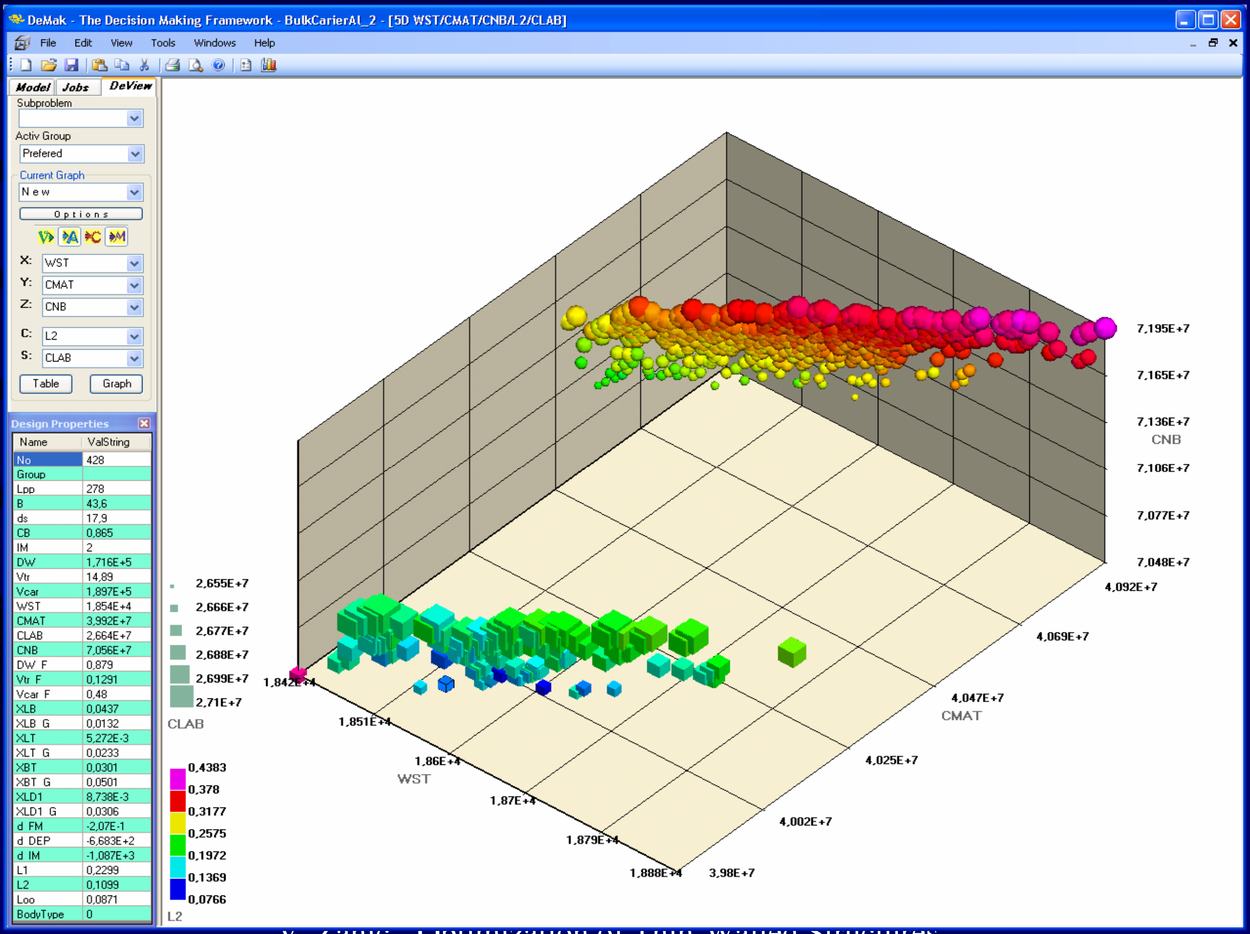


Optimization Procedure



Savings
359 t per ship
8.5% of prototype
weight

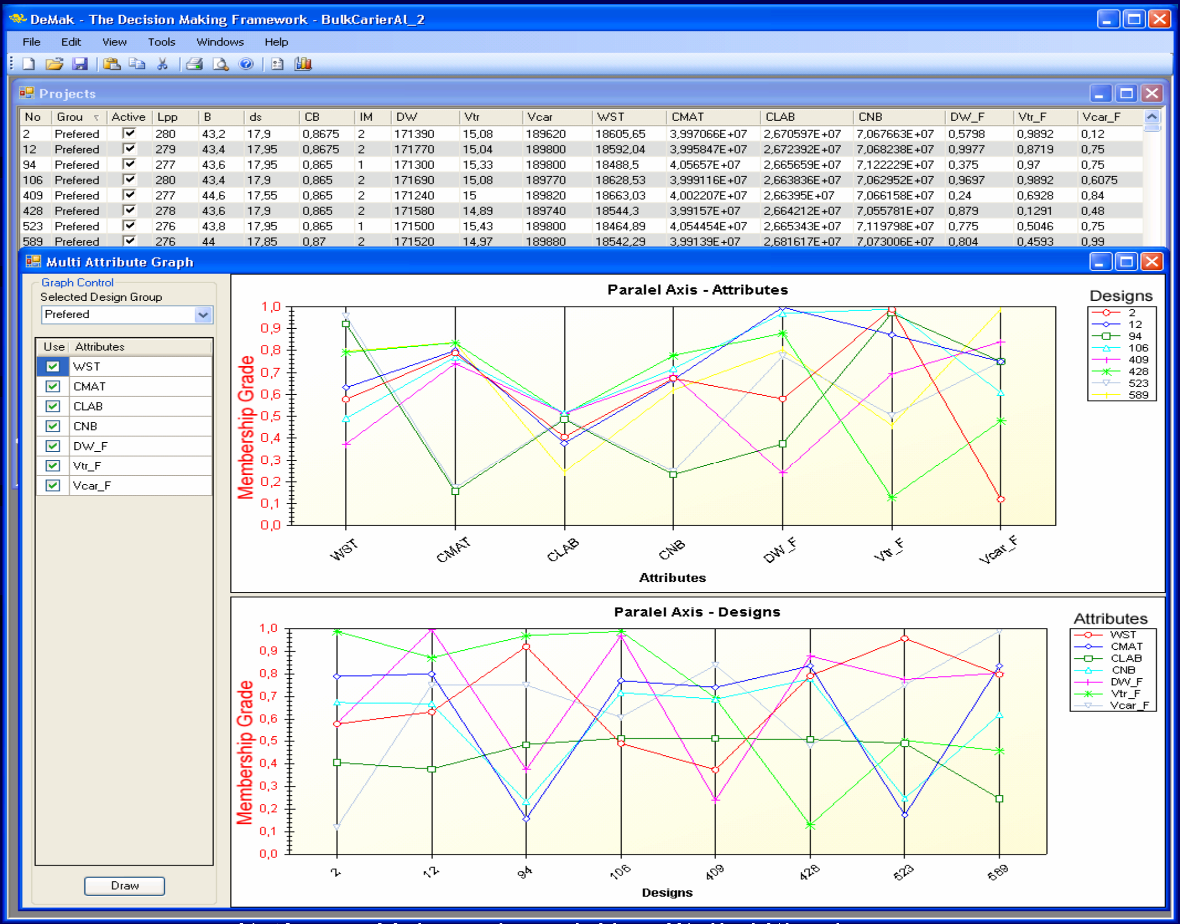
CASE STUDY in *SHIP CONCEPT DESIGN*
OF HANDYMAX PRODUCT TANKER



Design Properties

Name	ValString
No	428
Group	
Lpp	278
B	43,6
ds	17,9
CB	0,865
IM	2
DW	1,716E+5
Vtr	14,89
Vcar	1,897E+5
WST	1,854E+4
CMAT	3,992E+7
CLAB	2,664E+7
CNB	7,056E+7
DW F	0,879
Vtr F	0,1291
Vcar F	0,48
XLB	0,0437
XLB G	0,0132
XLT	5,272E-3
XLT G	0,0233
XBT	0,0301
XBT G	0,0501
XLD1	8,738E-3
XLD1 G	0,0306
d FM	-2,07E-1
d DEP	-6,683E+2
d IM	-1,087E+3
L1	0,2299
L2	0,1099
Loo	0,0871
BodyType	0

Subjective decision making using paralel axes



Projects

No	Grou	Active	Lpp	B	ds	CB	IM	DW	Vtr	Vcar	WST	CMAT	CLAB	CNB	DW_F	Vtr_F	Vcar_F
2	Prefered	☑	280	43,2	17,9	0,8675	2	171390	15,08	189620	18605,65	3,997066E+07	2,670597E+07	7,067663E+07	0,5798	0,9892	0,12
12	Prefered	☑	279	43,4	17,95	0,8675	2	171770	15,04	189800	18592,04	3,995847E+07	2,672392E+07	7,068238E+07	0,9977	0,8719	0,75
94	Prefered	☑	277	43,6	17,95	0,865	1	171300	15,33	189800	18488,5	4,05657E+07	2,665659E+07	7,122229E+07	0,375	0,97	0,75
106	Prefered	☑	280	43,4	17,9	0,865	2	171690	15,08	189770	18628,53	3,999116E+07	2,663836E+07	7,062952E+07	0,9697	0,9892	0,6075
409	Prefered	☑	277	44,6	17,55	0,865	2	171240	15	189820	18663,03	4,002207E+07	2,66395E+07	7,066158E+07	0,24	0,6928	0,84
428	Prefered	☑	278	43,6	17,9	0,865	2	171580	14,89	189740	18544,3	3,99157E+07	2,664212E+07	7,055781E+07	0,879	0,1291	0,48
523	Prefered	☑	276	43,8	17,95	0,865	1	171500	15,43	189800	18464,89	4,054454E+07	2,665343E+07	7,119798E+07	0,775	0,5046	0,75
589	Prefered	☑	276	44	17,85	0,87	2	171520	14,97	189880	18542,29	3,99139E+07	2,681617E+07	7,073006E+07	0,804	0,4593	0,99

CONCLUSIONS

The case studies have proved the following points:

- **Increased deadweight + decreased cost of mat. & work**
- **Increased safety due to rational material distribution**
- **Considerable modifications** are **quickly performed** following the head designer's requests.
- **Cost sensitivity study** can be produced **even during negotiations** with ship owner.
- **Full ship analysis** avoids **gross-errors** due to unknown normal and shear stress distribution.

- The **complex full ship macroelement model** can be generated simultaneously with class. documentation **starting from general arrangement.**
- Structural modeling and loadcase selection should **start as soon as possible** and **follow, support and simplify the decision making** to the designer.

Modern design procedure is a necessity rather then an option and FMENA is interested in participating in projects on

development of advanced software for ship design
and
its application to inovative ship types.

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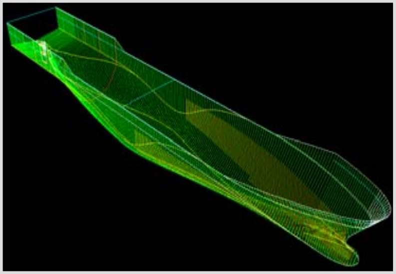

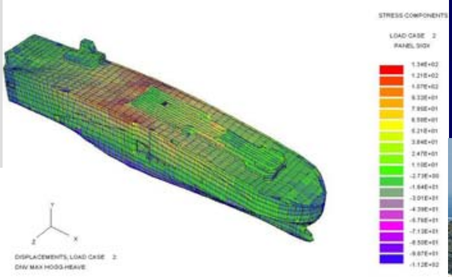

www.fsb.hr/octopus

FMENA-Zagreb: V.Žanić, T. Jančijev, J. Andrić, S. Kitarović, M.Stipčević, P. Prebeg

USCS Pula : E. Vitasović, B. Čupić, M. Šimunec