Least Cost Structural Optimization of LNG Ship

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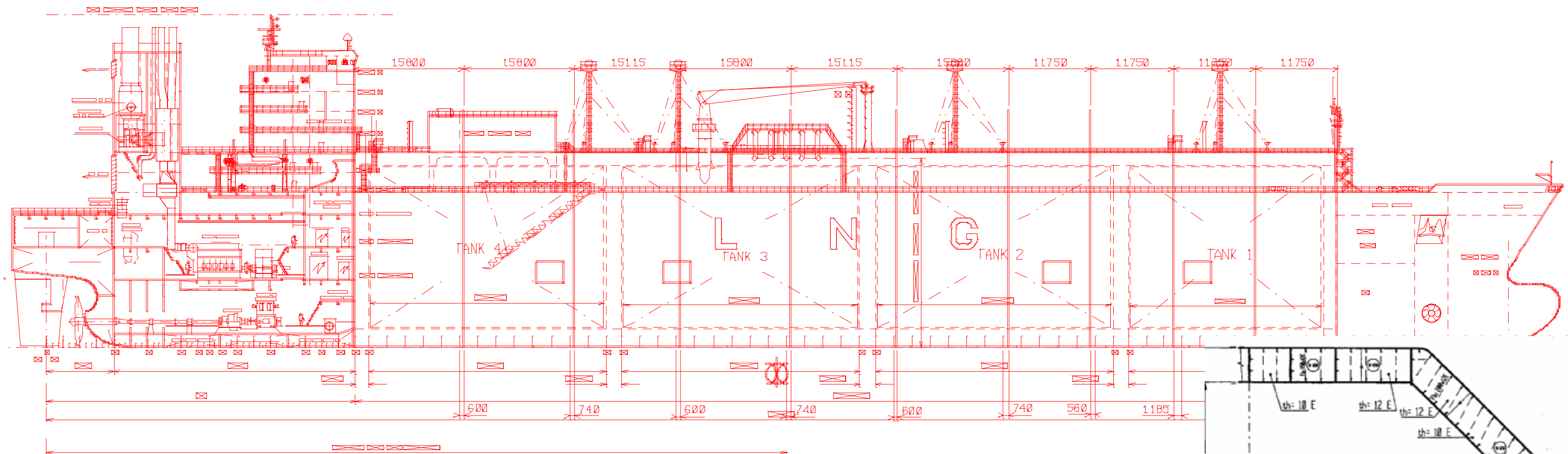
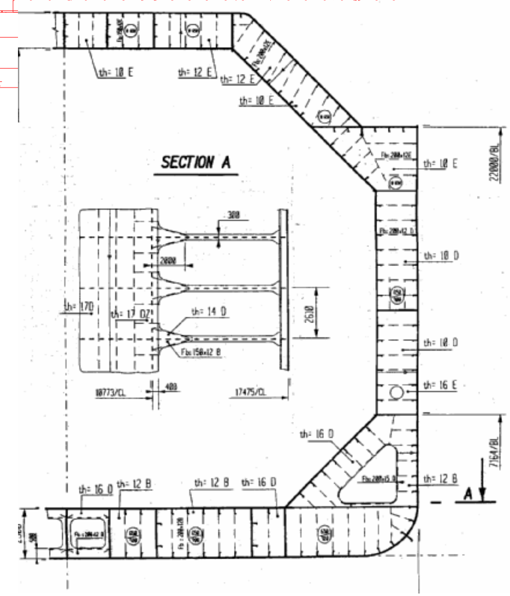
Outline

- problem definition
- LBR-5 optimization tool
- Structural Model
- Loading cases
- Constraints to optimization
- Objective function
- Results, conclusions

Problem definition

- Aim : To provide least construction cost and feasible scantlings of four tanks of a medium capacity gas carrier





Capacity : 72.000 m³

4 tanks

Classification : Bureau Veritas

Problem definition

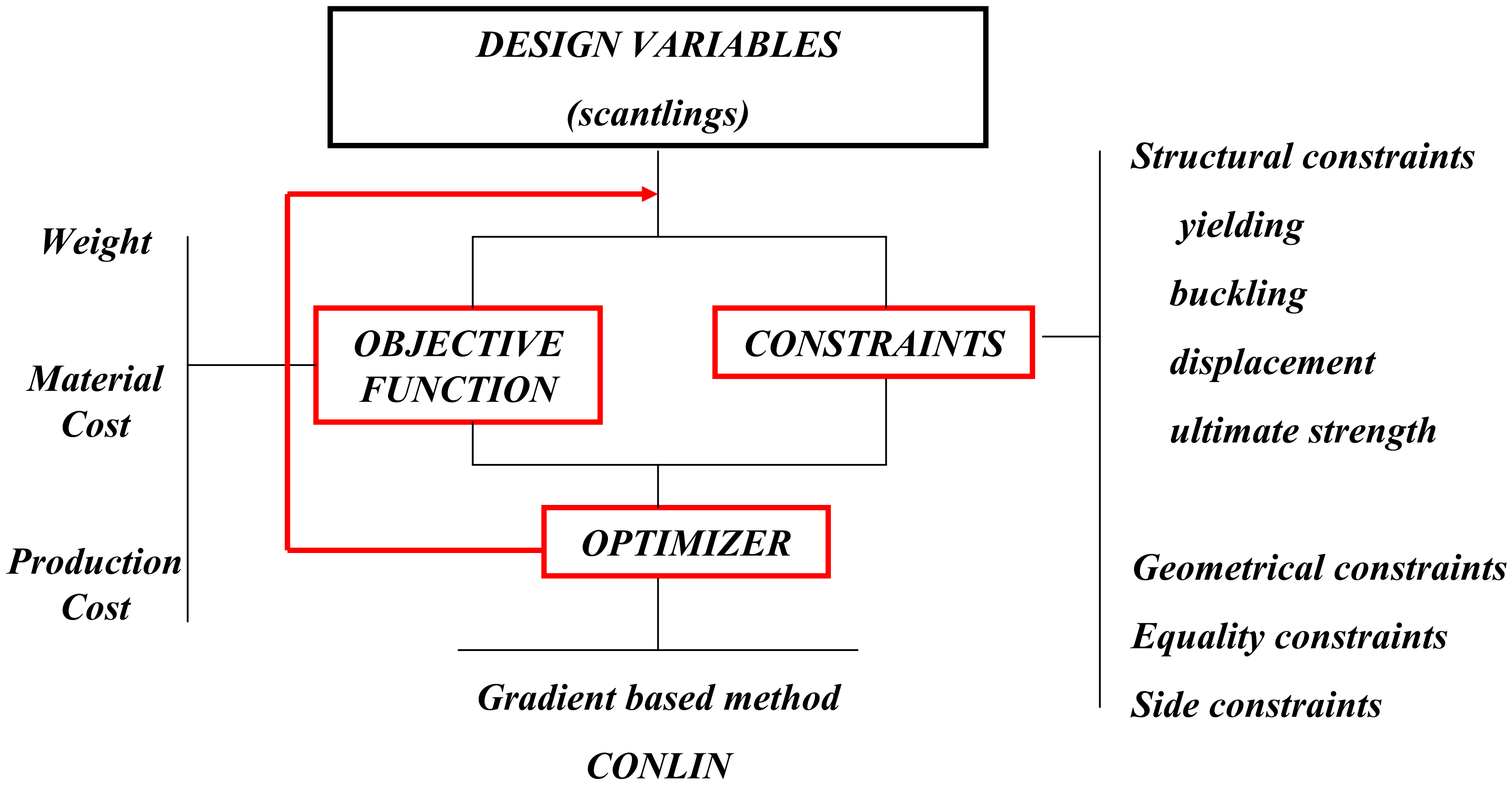
- Scantlings optimization to be performed using LBR-5 software (University of Liege)

- Two different ways to assess the construction cost and scantlings sensitivities to be investigated :

1. Simplified cost model : early stage of design, low level of information

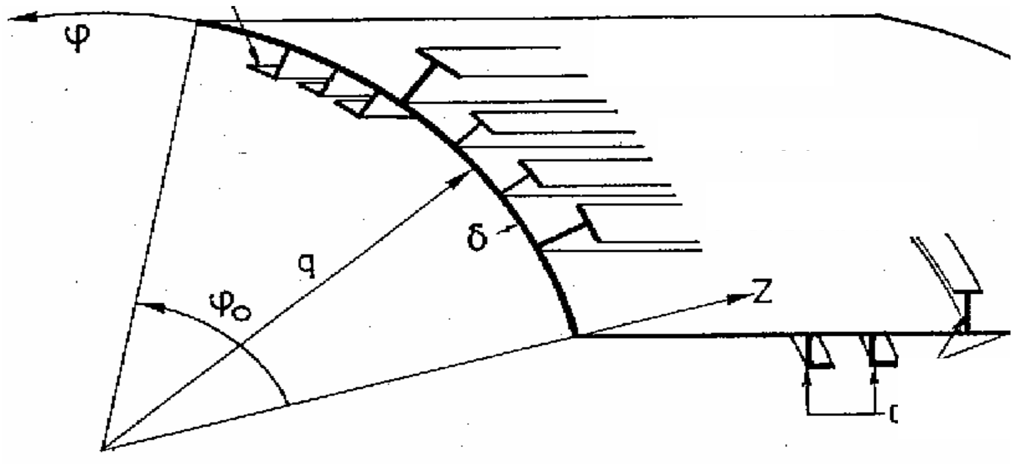
2. Advanced cost model : based on production breakdown, information about structural details are already known

LBR-5 Optimization Tool



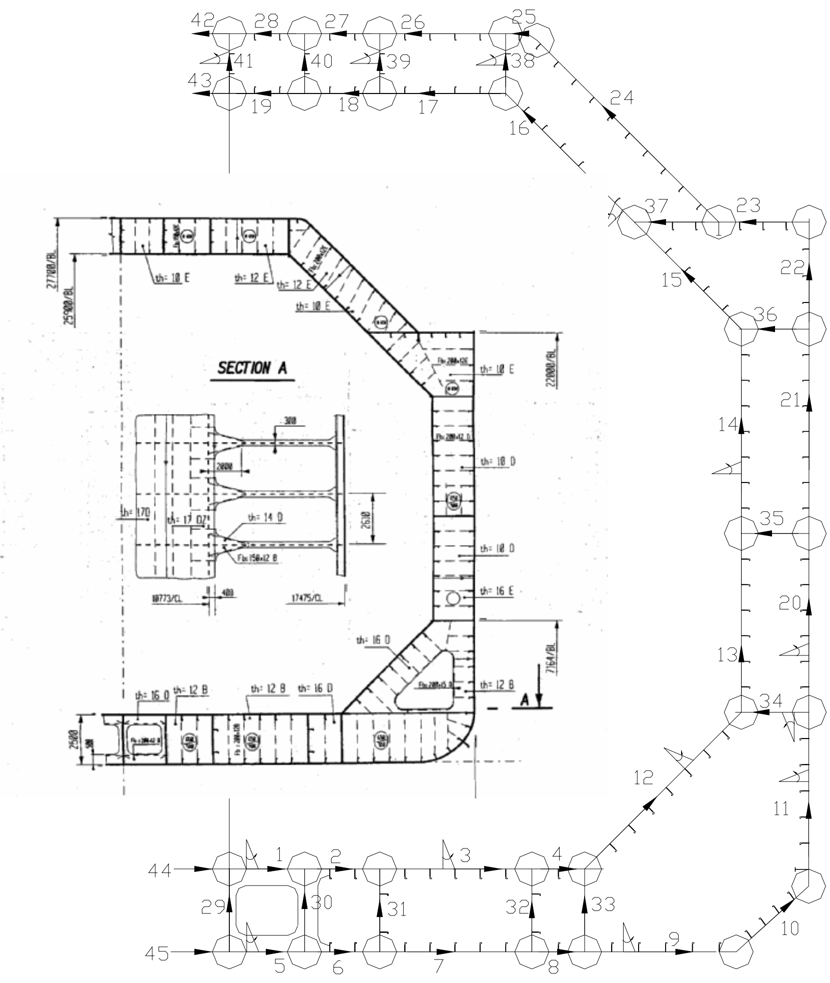
LBR-5 Optimization Tool

- scantlings optimization of cylindrical structures
- basic structural element : stiffened panel (longitudinally and transversally)



- analytical solver
- fast convergence of optimizer (10 – 15 iterations)

Structural Model

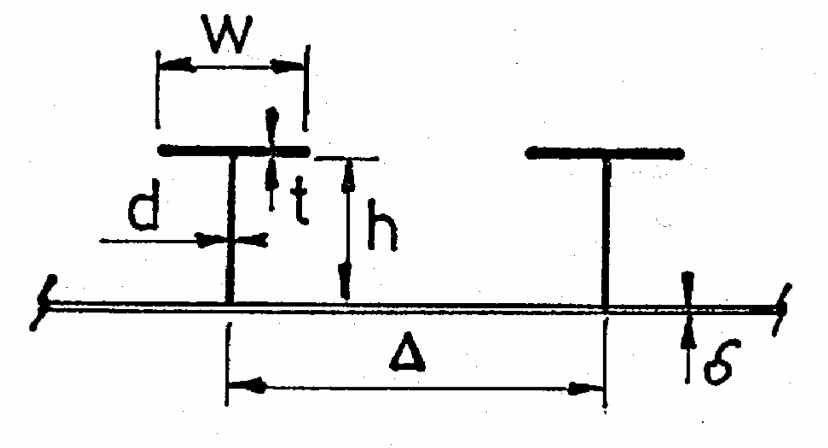


- 41 stiffened panels
- 4 additional panels to simulate sym. axis
- total 278 design variables (5 to 9 per panel)
- initial design defined by CAT (AKER Yards) using MARS software (BV)

Structural Model

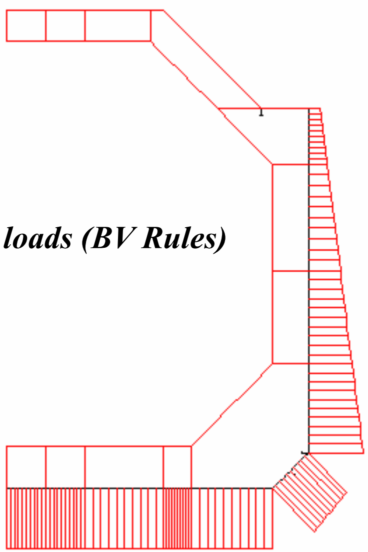
9 design variables (scantlings) are defined for each panel :

- plate thickness
- longitudinal stiffeners : 3 sizes + 1 spacing
- Frames : 3 sizes + 1 spacing

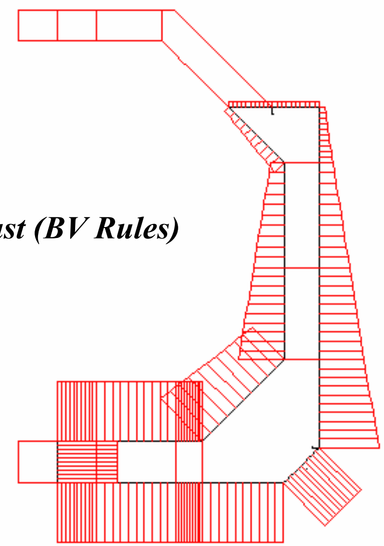


Loading cases

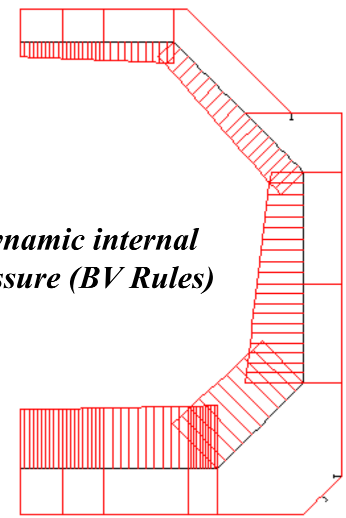
- 18 basic loading cases were defined by ALSTOM using BV rules (MARS)
- 5 loading cases (combinations of basic loading cases) were selected for LBR-5



Sea loads (BV Rules)

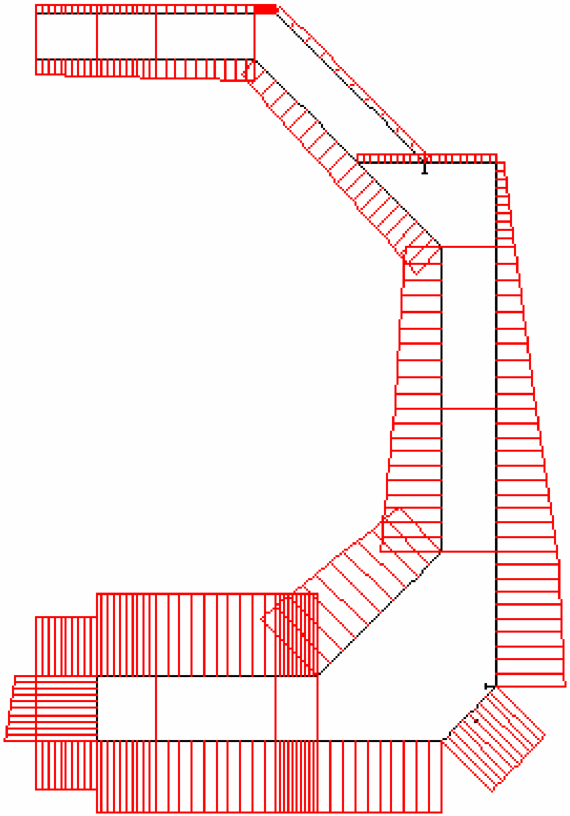


Ballast (BV Rules)

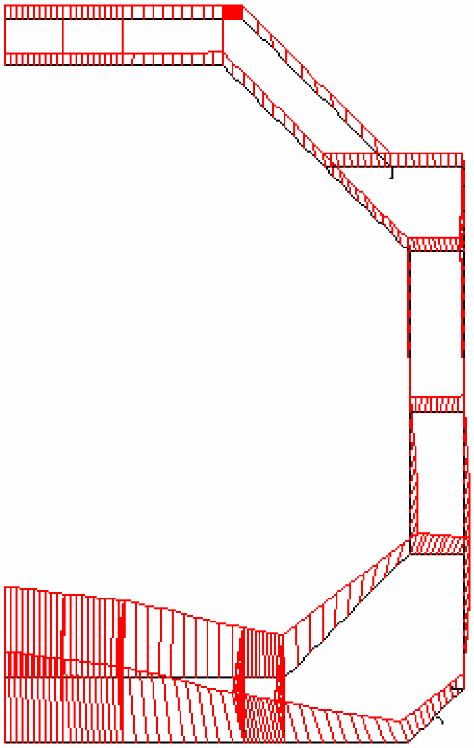


Dynamic internal pressure (BV Rules)

Loading cases

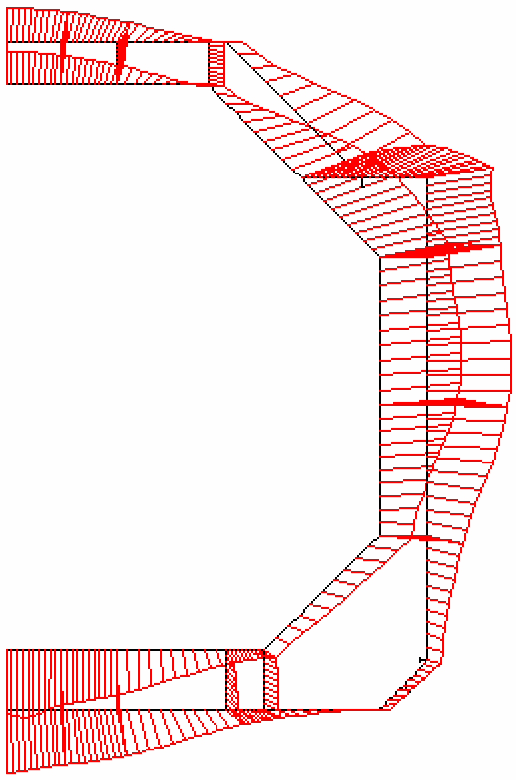


LBR5 Loading case 1 : maximum lateral pressure

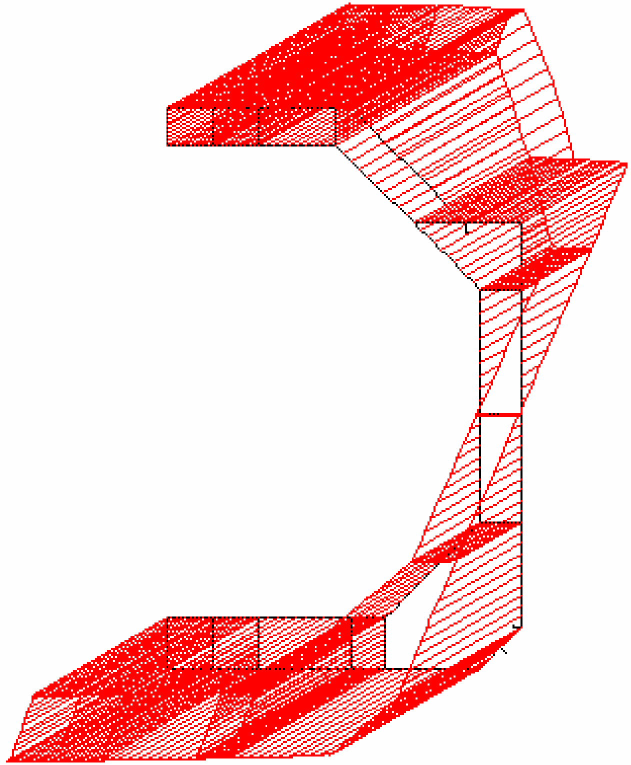


LBR5 Loading case 2 : maximum deflexion of the double bottom

Loading cases

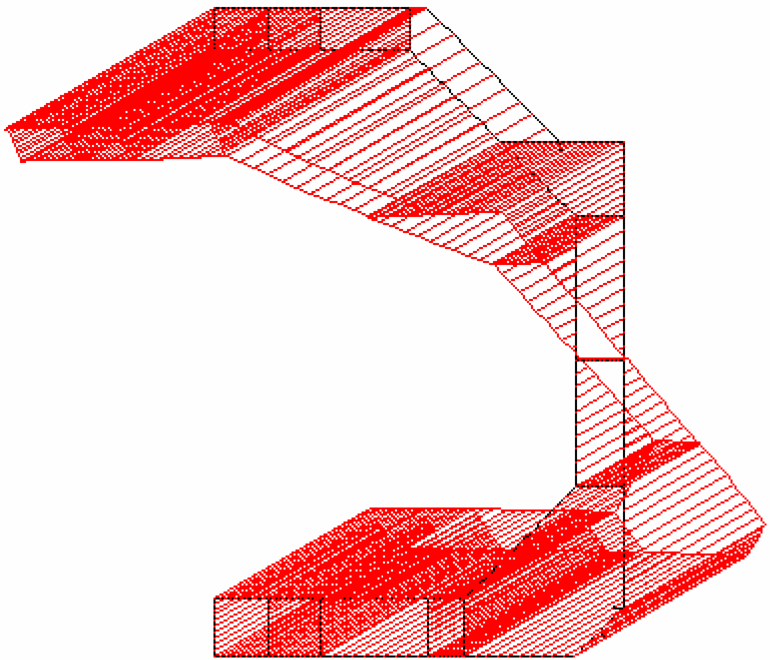


LBR5 Loading case 3 : maximum deflection of side tank



LBR5 Loading case 4 : longitudinal stresses under Hogging

Loading cases



LBR5 Loading case 5 : longitudinal stresses under Sagging

- the maximal still water bending moments were valued by CAT through direct calculation (loading manual)
- the wave bending moments were obtained from classification rulebook (BV)

Constraints to optimization

- 106 equality constraints between design variables are used, e.g., to impose uniform frame spacing for the deck, bottom and the side ballast tanks.

- 203 geometrical constraints (about 5 to 6 x 41 panels).

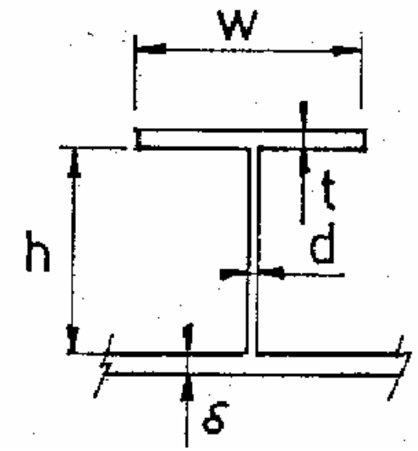
  - Ratio web / flange :

    $1{,}0 \leq h/w \leq 2{,}0$
  - Web Slenderness :

    $h - 40\, d \leq 0$
  - Web/Plate Compatibility

    $\delta - 2\, d \leq 0$

    (welding ability)



Constraints to optimization

1900 structural constraints (380 per load case):

- σ_c frame & σ_c stiffener (web/plate connexion – web/flange connexion),
- σ_c plate , to check if $\sigma_c \leq s_1.\sigma_o$ (with s_1 a partial safety factor and σ_o the yield stress);
- Local plate buckling: $\delta_{MIN} \leq \delta$ (with δ_{MIN} the minimum plate thickness to avoid buckling and local yielding);
- Ultimate strength of stiffened panel: $\sigma / \sigma_{ULT} \leq s_2$ with s_2 a partial safety factor.

Constraints to optimization

Side constraints for all design variables were recommended by CAT :

- the upper limit for plate thickness is fixed to 25 mm.
- $2.00\ m \leq \Delta_{Frames} \leq 4.00\ m$
- $0.50\ m \leq \Delta_{Stiffeners} \leq 1.00\ m$
- $0.10\ m \leq h_{web\ stiffeners} \leq 0.50\ m$
- $8.0\ mm \leq$ Web-frames thickness $\leq 25.0\ mm$

Objective function

LBR-5 <u>Simplified</u> Cost Module : MATERIAL COST

$$F_{MAT} = \gamma \; L \; B \left[\begin{array}{l} C_1 \, . \, \delta \\ + \, C_2 \, . \, \dfrac{(h.d + w.t)_X}{\Delta_X} \\ + \, C_3 \, . \, \dfrac{(h.d + w.t)_Y}{\Delta_Y} \end{array} \right]$$

Objective function

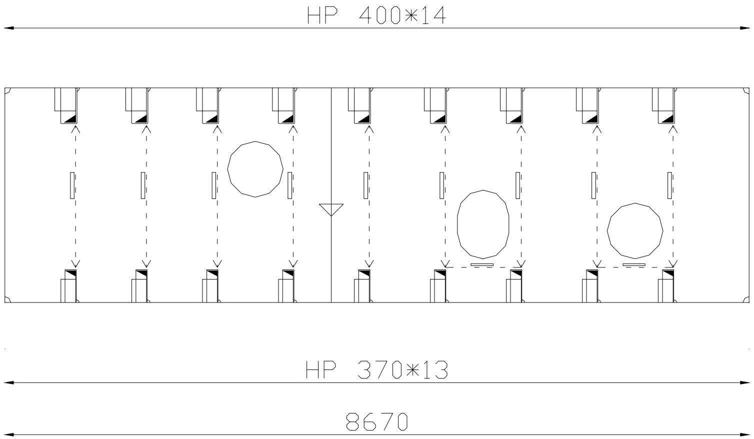
LBR-5 Simplified Cost Module : LABOR COST

$$F_{Labour} = \eta \,.\, k \,.\, C_1^o \,.\, LAB$$

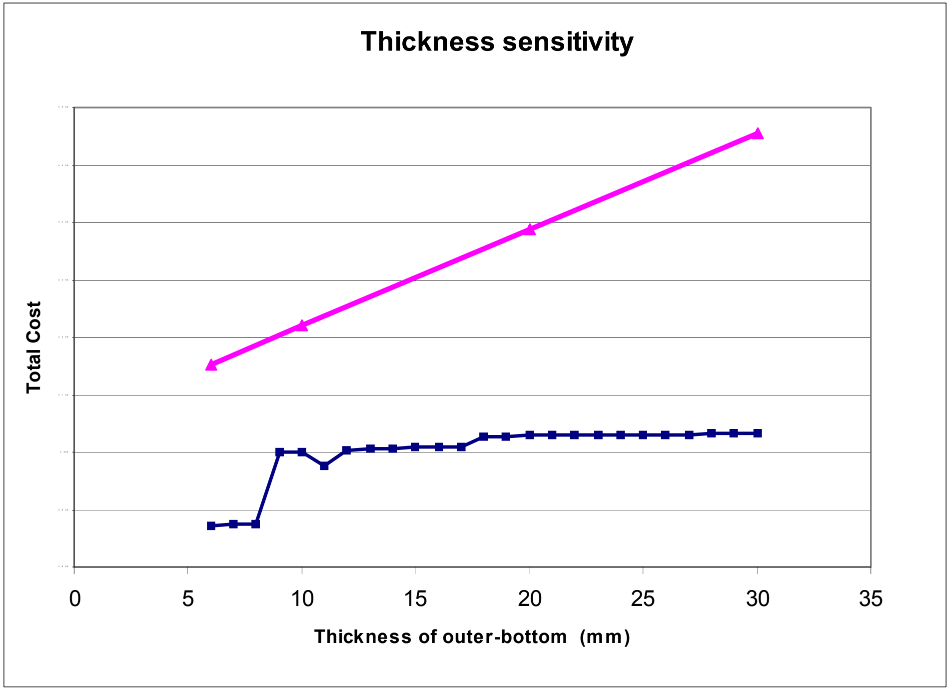
$$LAB = L \,.\, B \left[\begin{array}{l} \dfrac{1}{\Delta_X} \,.\, P_4 + \dfrac{1}{\Delta_Y} \,.\, P_5 \\ + \dfrac{1}{\Delta_X \,.\, \Delta_Y} \left(P_6 + \beta_X \,.\, \beta_Y \,.\, P_7 \right) \\ + \dfrac{1-\alpha_X}{\Delta_X} \,.\, P_9(X) + \dfrac{1-\alpha_Y}{\Delta_Y} \,.\, P_9(Y) \\ + P_{10} \end{array} \right]$$

Objective function

LBR-5 Simplified Cost Module : test on sensitivities



Double-bottom panel of LNG ship



Objective function

LBR-5 Advanced Cost Module

- only labor cost is detailed
- take into account a specific cost database from CAT
- about 60 different fabrication operations were selected
- take into account about 30 types of welding and theirs unitary costs
- requires additional data about the structural model

Objective function

LBR-5 Advanced Cost Module : Labor Cost

$$CO_{i\,k} = Q_{ik} \times CU_{ik} \times K_{ik} \times CA_{ik} \times CAT_{ik}$$

Q_{ik} = quantity

CU_{ik} = unitary cost

K_{ik} = control coefficient

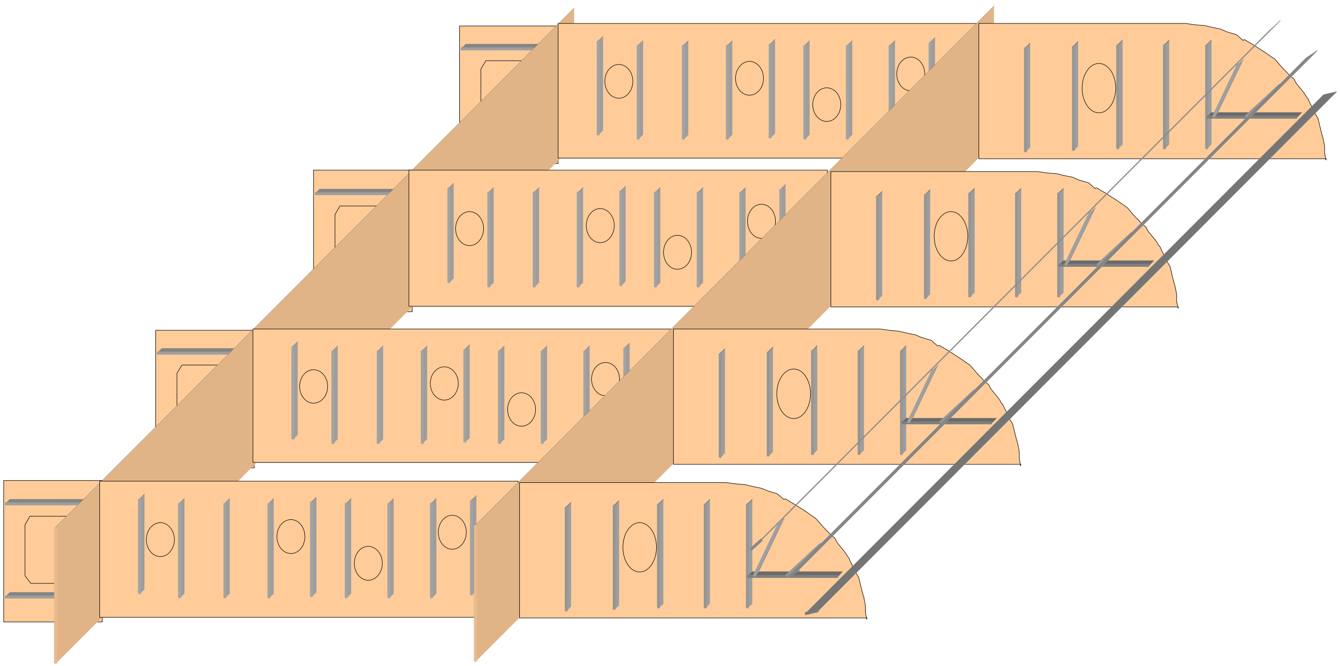
CA_{ik} = access coefficient

CAT_{ik} = workshop coefficient

TOTAL : $CT = \Sigma_i \Sigma_k (CO_{ik})$

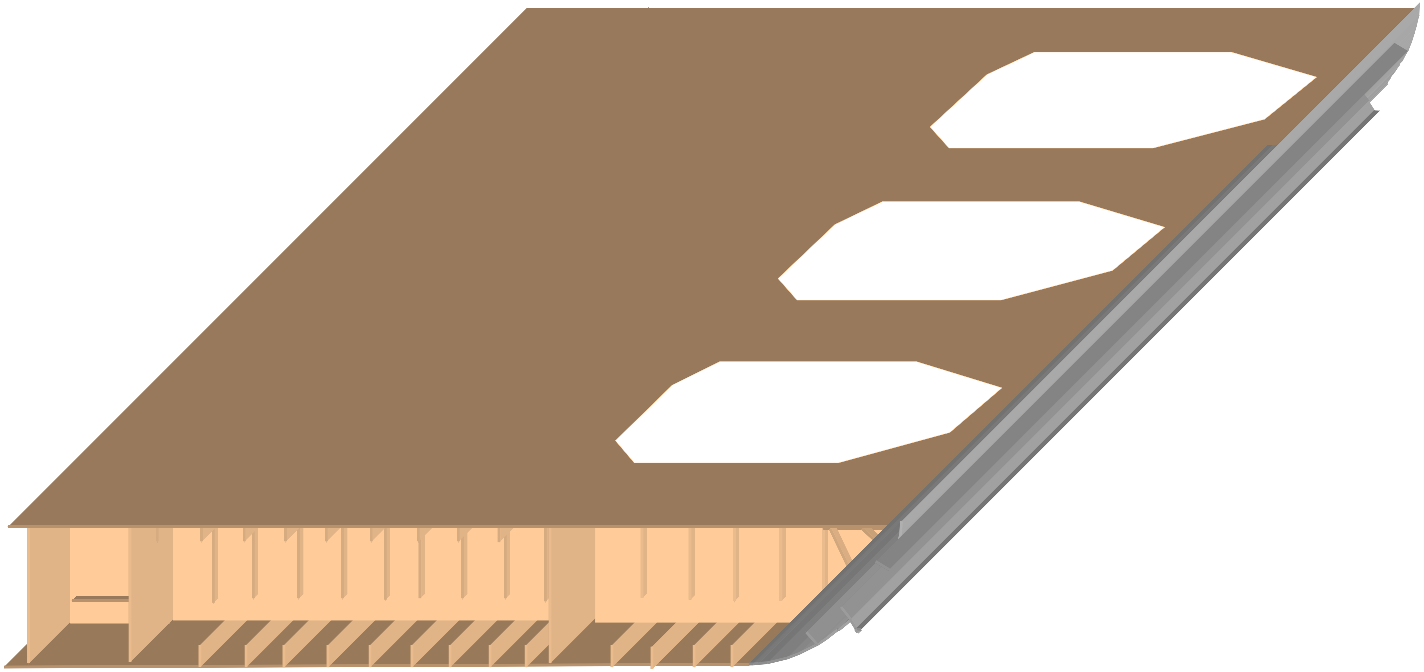
Objective function

CAT : panel assembling



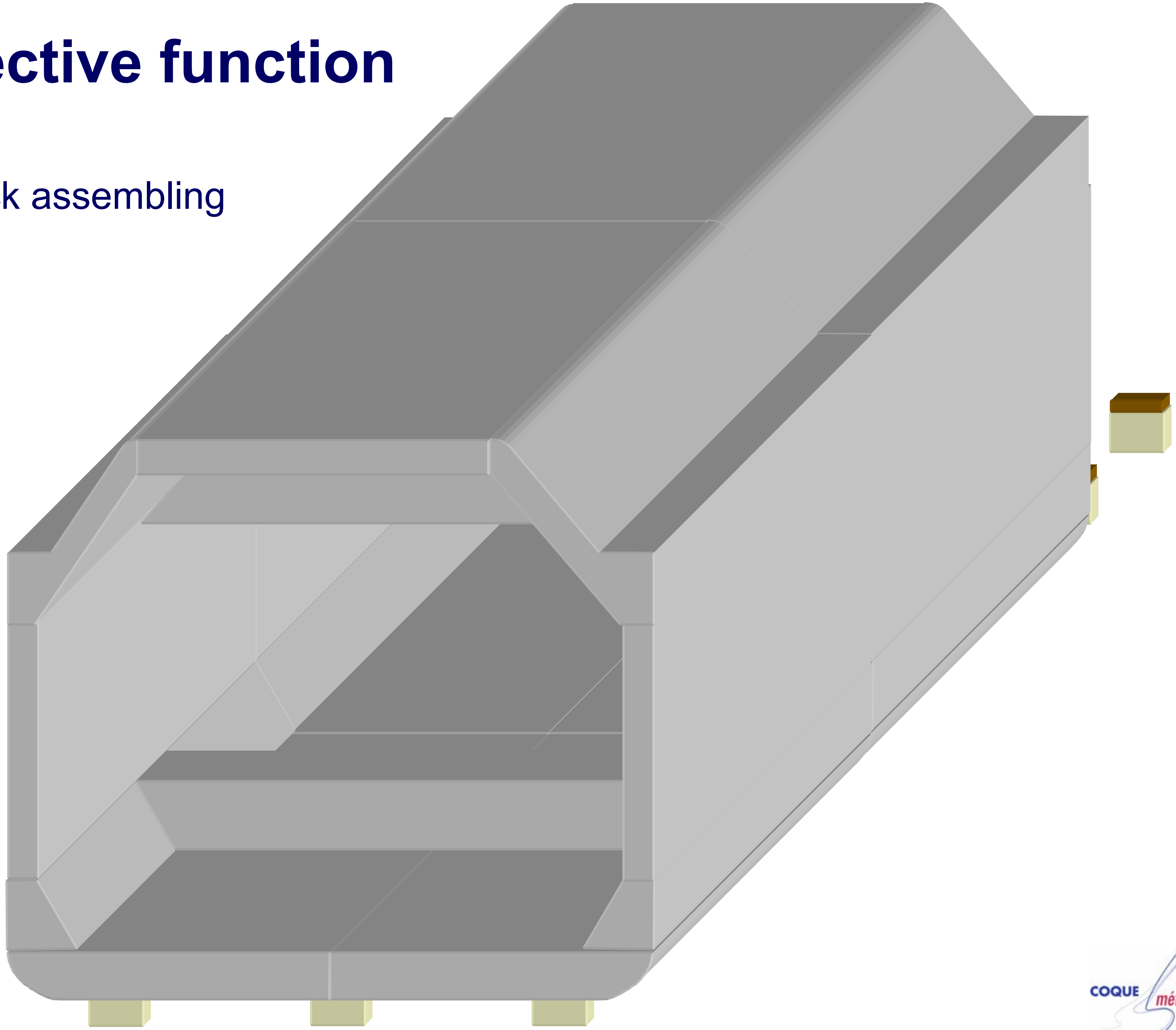
Objective function

CAT : panel assembling



Objective function

CAT : block assembling

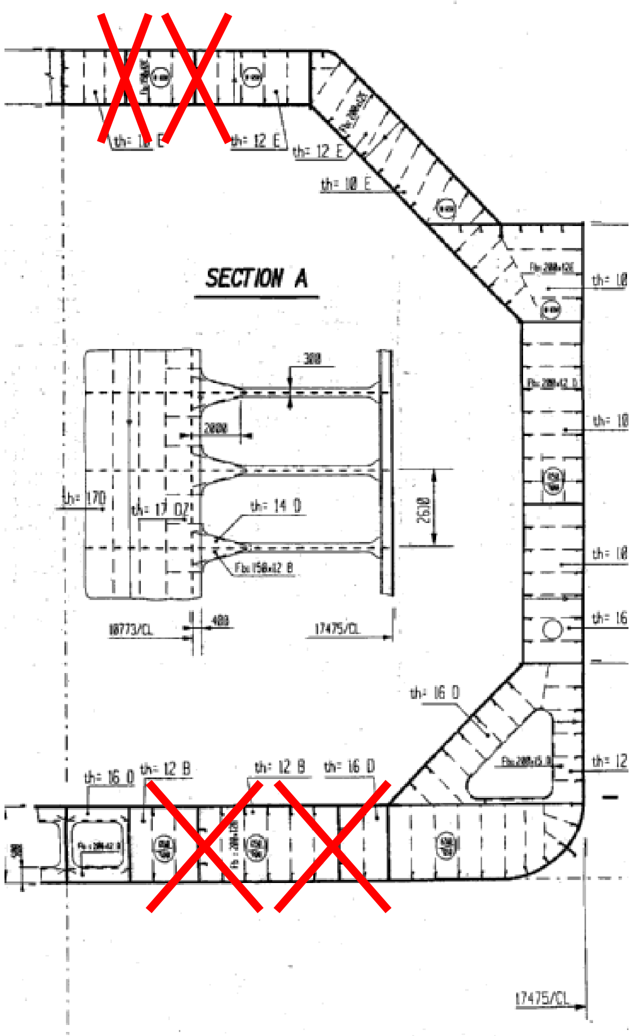


Results – simplified cost module

SEARCH FOR THE LEAST COST DESIGN (with continuous design variables)									
		SPACINGS			Duct keel bulkhead. Plate Thickness	LEAST COST		WEIGHT	
CONFIGU-RATIONS	Optimum Type	Number of Web-frames	Second. Frame (Δ_C)	Stiffeners (Δ_L)		COST SAVING (%) (see 1)		(%)	
	Shown change(s) between 2 successive steps					Between 2 successive steps	Cumulated saving		
1- ALSTOM	MARS BV	Nw	$\Delta w/3$	Δ_L (Alstom)	100%	0.00%	0.00%	100% (ref)	Initial Design (used as reference)
2- MET8 E00	Least Cost	Nw	$\Delta w/3$	Δ_L (Alstom)	105%	-1.39%	-1.39%	98.34%	
3- MET8 E90	Least Cost	Nw	$\Delta w/3$	1.15 Δ_L	105%	-2.46%	-3.85%	101.61%	
4- MET8 B90	Least Cost	Nw -3	$\Delta w/3$	1.15 Δ_L	130%	-6.40%	-10.25%	104.73%	plate thickness too large
5- MET8 F90	Least Cost	NW -3	$\Delta w/4$	1.15 Δ_L	100%	1.67%	-8.58%	103.42%	OPTIMUM SOLUTION
6- MET8 F	Least Cost	Nw -3	$\Delta w/4$	1.28 Δ_L	100%	-0.53%	-9.11%	105.29%	(*) Poor efficiency
	(*) Stiffener spacing too large ==> cost savings of 0.5% but increased straightening work ==> not efficient !!								
(1 Variation induced by the changes occured between two configurations.									

Results – simplified cost module

- in order to avoid the increase of weight, a new structural layout was proposed by CAT



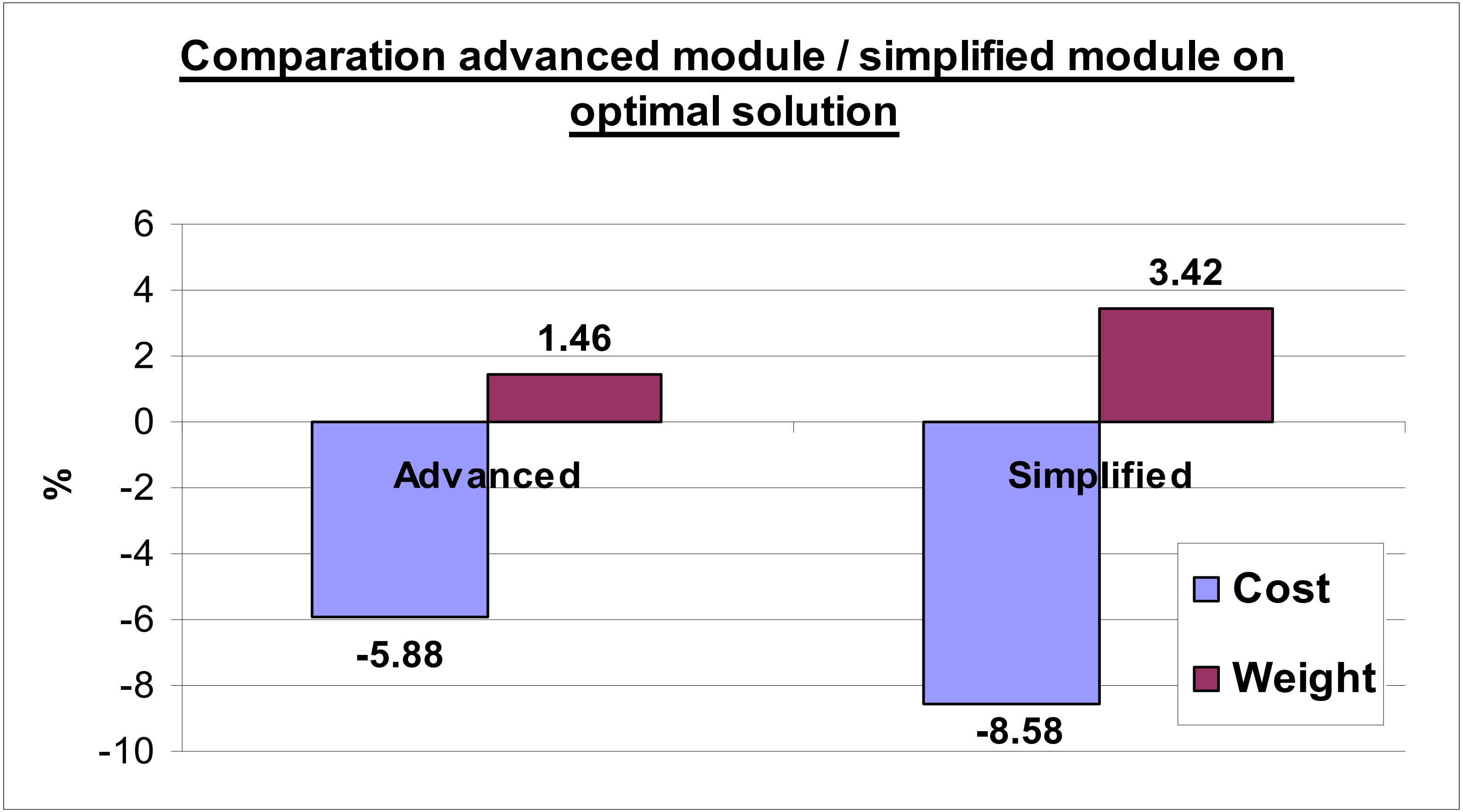
Results – simplified cost module, layout modified

SEARCH FOR THE LEAST COST DESIGN (with constraint on the weight)									
		SPACINGS			Duct keel bulkhead. Plate Thickness (mm)	LEAST COST		WEIGHT	
CONFIGU-RATIONS	Optimum Type	Number of Web-frames	Second. Frame (Δ_C)	Stiffeners (Δ_L)		COST SAVING (%) (see 1)		(%)	
	Shown change(s) between 2 successive steps					Between 2 successive steps	Cumulated saving		
ALSTOM	MARS BV	N_W	Δw/3	Δ_L (Alstom)	100%	0.00%	0.00%	100.00%	Initial Design (used as reference)
MET8 E-78	Least Cost	N_W	Δw/3	Δ_L (Alstom)	105%	-1.39%	-1.39%	98.34%	
MET8 C-78	Least Cost	N_W -2	Δw/3	Δ_L (Alstom)	122%	-4.85%	-6.24%	100.21%	Duct-keel plate thickness too large
MET 12 (*) Continuous	Least Cost	N_W -2	Δw/3 (*)	Δ_L (Alstom)	88% (*)	-0.68%	-6.92%	99.68%	OPTIMUM SOLUTION (with discrete design variables)
MET 12.b (*) Discrete	Least Cost	N_W -2	Δw/3 (*)	Δ_L (Alstom)	88% (*)	0.45%	-6.47%	100.88%	OPTIMUM SOLUTION (with continuous design variables)

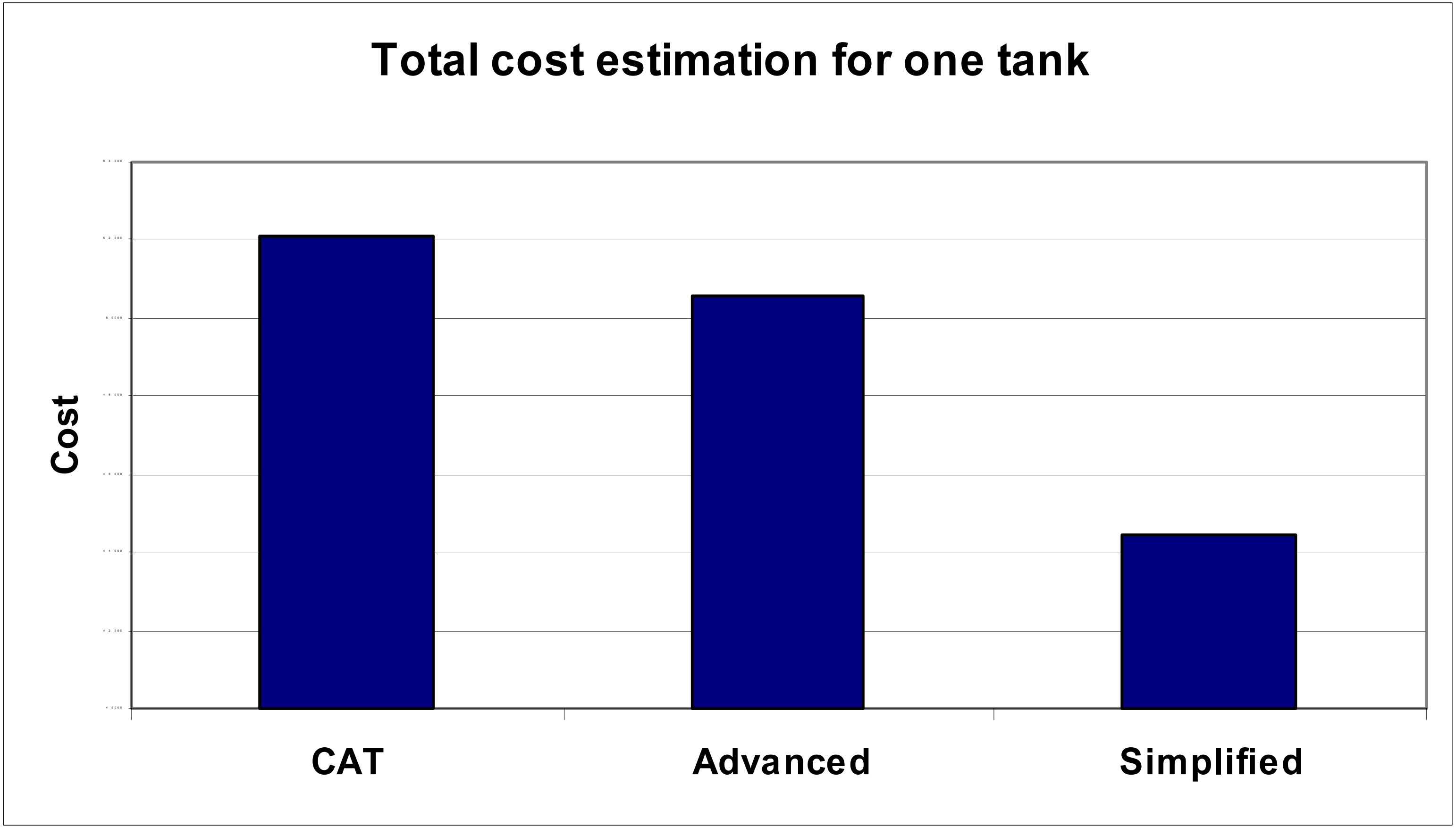
(*) Layout is modified

(1) Variation induced by the changes occured between two configurations.

Results – advanced cost module



Results – advanced cost module



Thank you for your attention !