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Topological optimization of the layup of a monolithic CFRP wingbox

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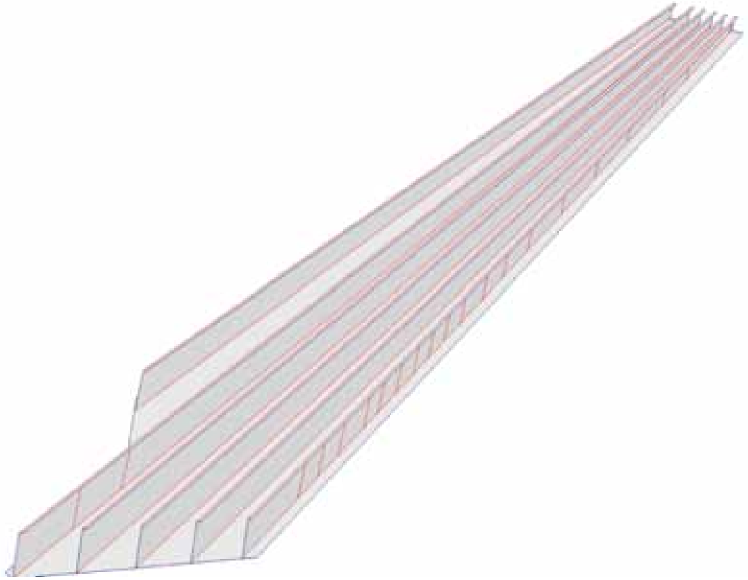
Agenda

- Exemplar srl
  - composite design know-how
- Problem introduction
  - Wing box layup definition
  - Manufacturing requirement
- iDA optimization tool
  - Features description
  - Why iDA
  - Graphical interface
  - iDA method
- Wing box Results
- Questions & Answer



Exemplar and the composite design

- 12 years of experience in composite simulation
  - Aerospace, Automotive and Ship building
  - Aero-elasticity analysis
  - Static, Buckling and Dynamic analysis
- R&D and founded project with innovative composite material
  - Green composite research
  - Nanotube application on composite on “TOP” project with ALENIA-THALES
- Training and technological update
  - Know-how transfer
  - Training on the job
- Software development for composite optimization
  - Dedicated interface for CAE solver

Problem introduction

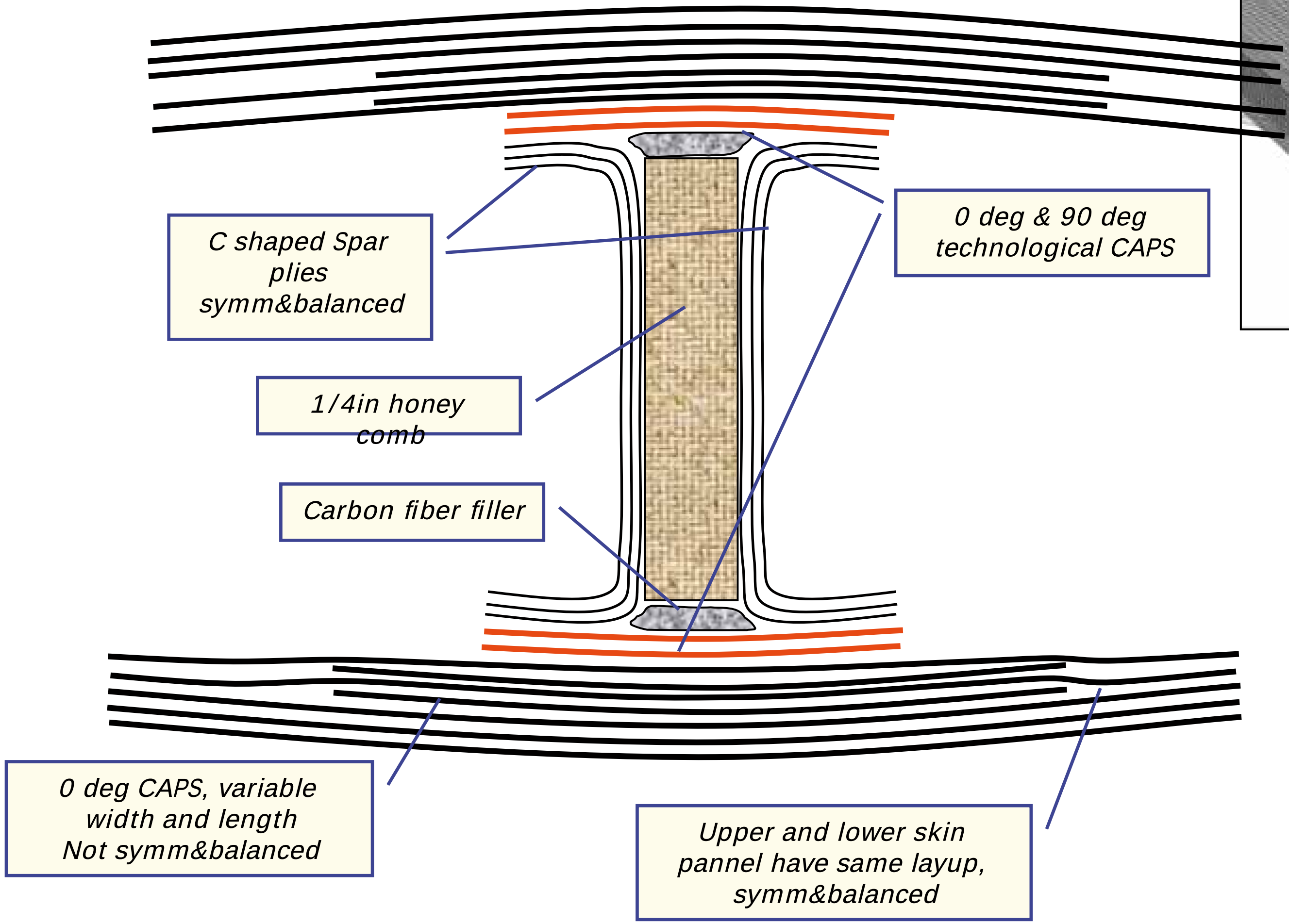
- Problem description

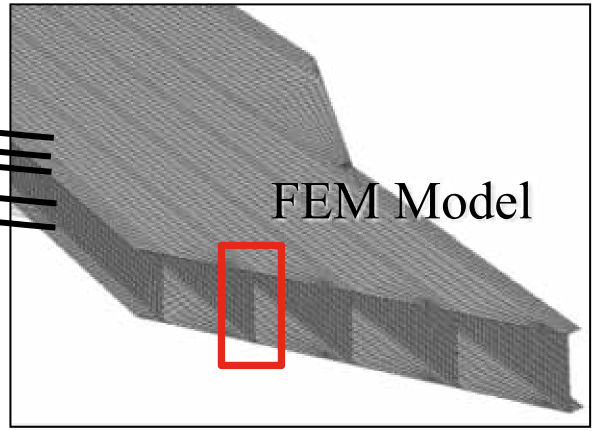
- iDA [*i*ntelligent *D*ecision *A*dvisor] software was been used to design a new layup for a monolithic CFRP Horizontal Tail wing box that achieves the goals to :
  - assure adequate static capability and buckling performance
  - reduce the weight respect to the actual design
  - obtain a feasible design (respect the manufacturing constrains)

Problem introduction

- **Manufacturing requirement**
  - Complex layup definition
- **Discrete variables**
  - geometry ply design
  - angle ply (0°/45° / 90°)
  - layup sequence
- **High number of variables** (~1200)
  - 305 different geometry plies evaluated
  - a layup contains from 250 up to 400 independent plies
  - a layup define up to 350 ply angles
- **CPU time consuming to function evaluation** (~ 20 min)
  - FEM Model outstanding 60.000 element number
- **Target weight reduction less than 1500 lbs**
  - critical (M.S.<0) element numbers reduction
  - positive load buckling factor (K>1.0) on each load condition
  - many different load set

Manufacturing requirement



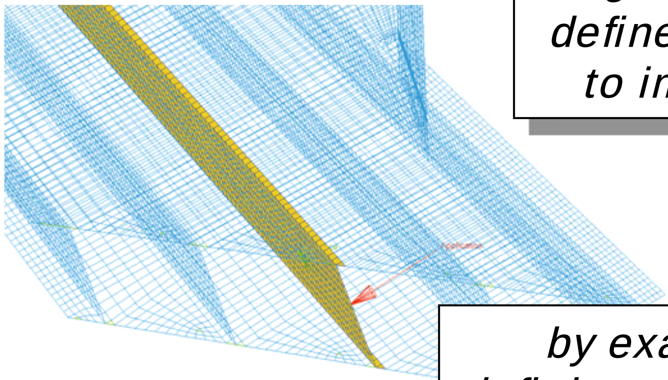


Complex layup definition for manufacturing constrains has to be defined in the model geometry

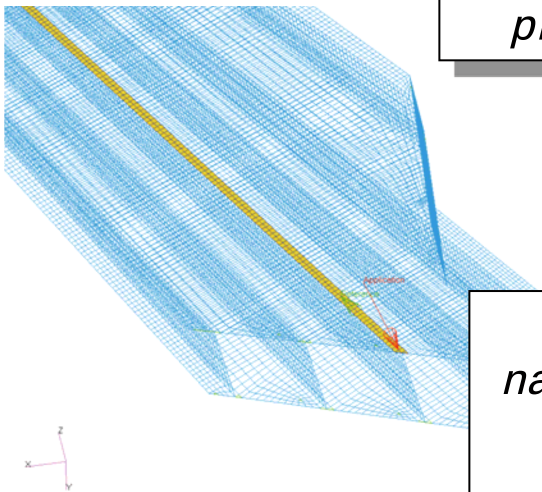
Manufacturing description in the FEM

a complete dataset of the manufacturing plies geometry has been defined and used by iDA to improve the design

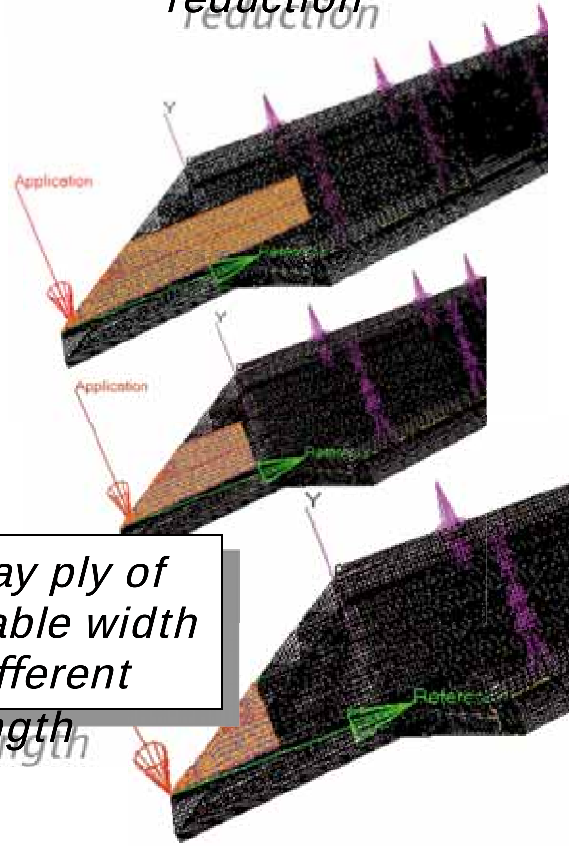
for each shape a cost can be estimated: iDA can handle the final manufacture cost reduction



by example defining a C shape ply in the spar

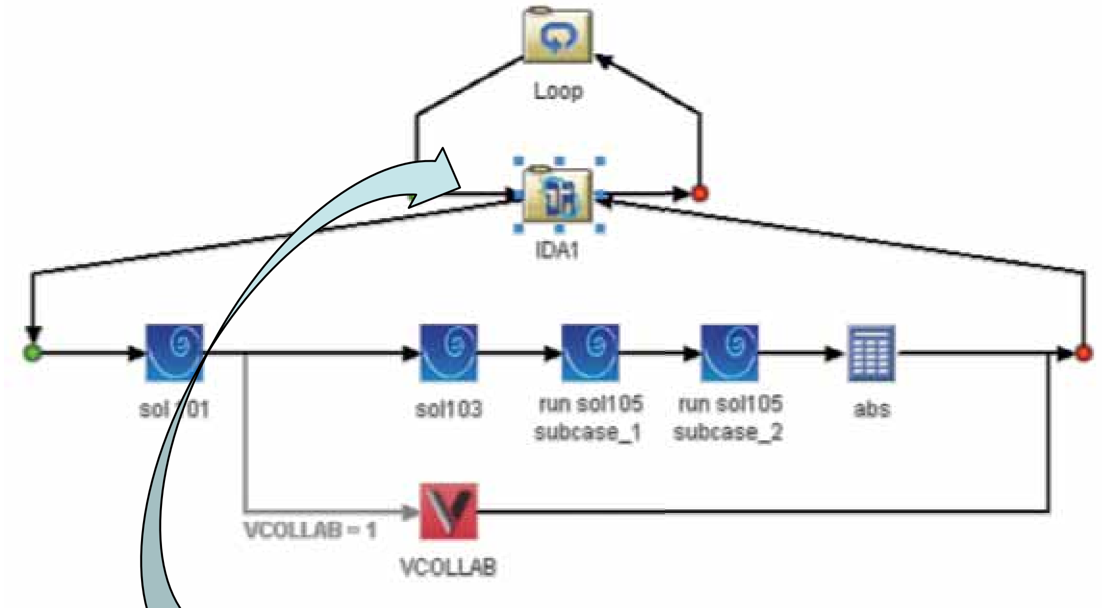


or defining a narrow cap ply to the skin/spar intersection



skin bay ply of the available width but different length

iDA - *intelligent Decision Advisor*



The iSight-FD workflow with iDA used to solve HT structural problem

- iDA is a algorithm able to improve the design in the real world environment (limited time, limited resources, complex problem)
- iDA has been developed by EXEMPLAR team. It collects 10 years of experience on optimization problem for the industry.
- iDA is also available as a plug-in on Isight process integration software.

Why iDA ?

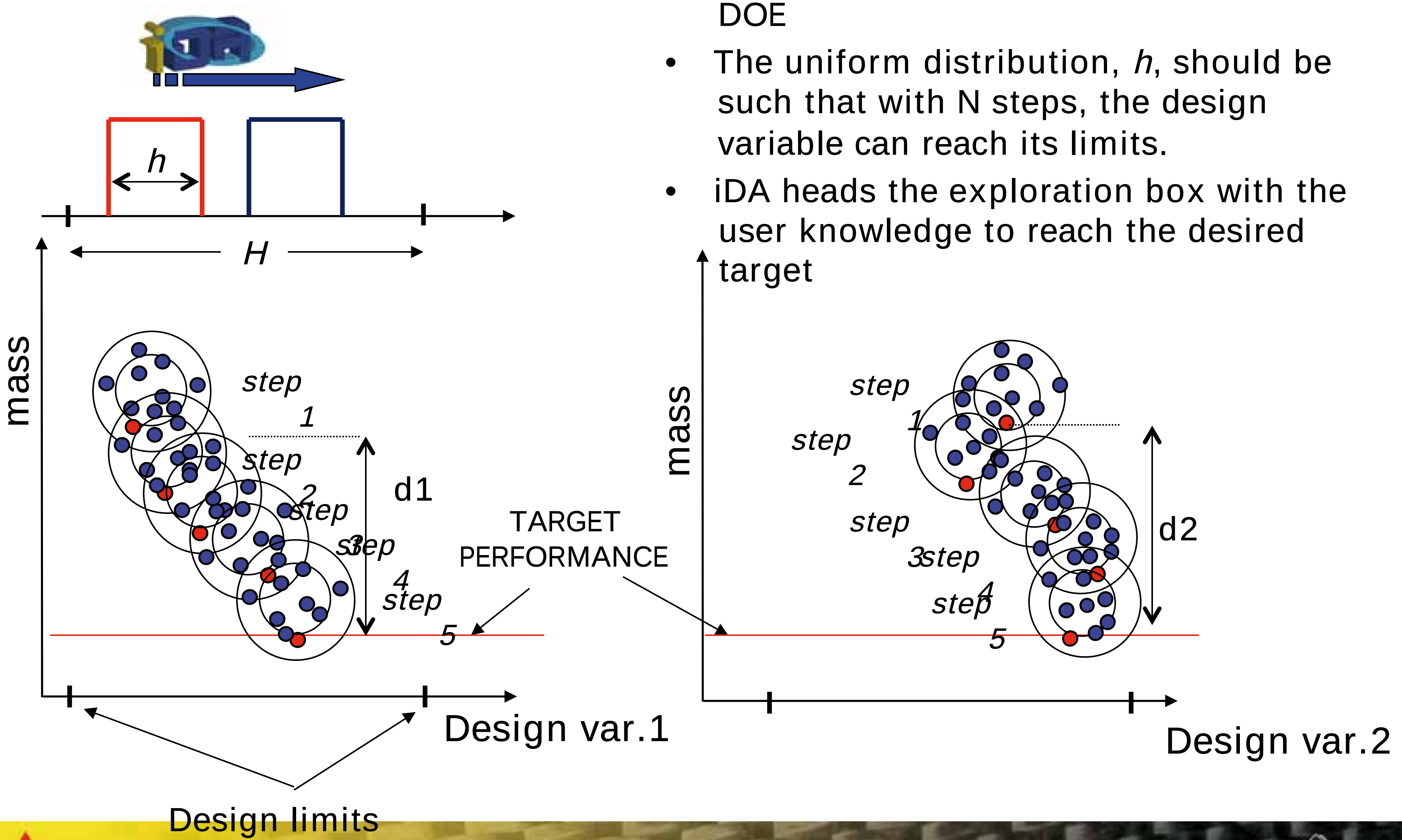
- The multi-disciplinary optimization problem dramatically increase the design parameter: in the real world, the number of design parameter is huge, and only an efficient exploration of their interaction can achieve a innovation design.

- For engineering problems many optimization method are available. EXEMPLAR experienced that all of them have a limited number of design parameter, because they are “generic” method.

- In the classical optimization methods, the user cannot supply his knowledge about the problem.

- The aim of iDA method is allow the expert to supply all available useful information which can help the exploration method to reach its goals.

The iDA method



- iDA can be “briefly” defined as a drove DOE
- The uniform distribution, *h*, should be such that with N steps, the design variable can reach its limits.
- iDA heads the exploration box with the user knowledge to reach the desired target

iDA and composite

GLOBAL LAYUP SEQUENCE: the independent plies PLY NAME	ANGLE	MATERIAL
Ply_shape_#1000	angle=0°	Mat=A
Ply_shape_#1010	angle=0°	Mat=A
Ply_shape_#1012	angle=0°	Mat=A
Ply_shape_#1020	angle=0°	Mat=A
Ply_shape_#1000	angle=0°	Mat=A
Ply_shape_#2040	angle=0°	Mat=A
Ply_shape_#2045	angle=0°	Mat=A
Ply_shape_#2044	angle=0°	Mat=A
Ply_shape_#1072	angle=0°	Mat=A
Ply_shape_#1045	angle=0°	Mat=A
Ply_shape_#2040	angle=0°	Mat=A
Ply_shape_#2045	angle=0°	Mat=A
Ply_shape_#2044	angle=0°	Mat=A
Ply_shape_#1072	angle=0°	Mat=A
Ply_shape_#1045	angle=0°	Mat=A

STEP - 0 - : initial configuration

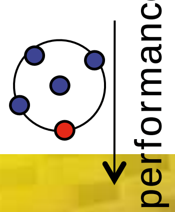
and composite

- In the composite design, iDA doesn't considered the parameter like thickness, angles or materials as cardinal numbers, but it manage them as "*configuration state*"
- A stochastic distance is defined for each design parameter: the ply shape, the angle and the ply material;
  the list table of all these parameters is a "configuration state"
- The Euclid distance between the configuration state and the user desired performance is automatic computed based on the user physics consideration.
- At the step -0-, each parameter has the maximum distance to the desired target performance

GLOBAL LAYUP SEQUENCE: the independent plies	PLY NAME	ANGLE	MATERIAL
	Ply_shape_#1000	angle=45°	Mat=A
	Ply_shape_#1010	angle=0°	Mat=B
	Ply_shape_#1012	angle=90°	Mat=A
	Ply_shape_#1020	angle=0°	Mat=C
	Ply_shape_#1000	angle=45°	Mat=C
	Ply_shape_#2040	angle=45°	Mat=A
	Ply_shape_#2045	angle=0°	Mat=B
	Ply_shape_#2044	angle=0°	Mat=A
	Ply_shape_#1072	angle=90°	Mat=B
	Ply_shape_#1045	angle=45°	Mat=A
	Ply_shape_#2040	angle=90°	Mat=A
	Ply_shape_#2045	angle=45°	Mat=B
	Ply_shape_#2044	angle=0°	Mat=C
	Ply_shape_#1072	angle=0°	Mat=B
	Ply_shape_#1045	angle=45°	Mat=A

iDA and composite

GLOBAL LAYUP SEQUENCE: the independent plies	PLY NAME	ANGLE	MATERIAL
	Ply_shape_#1000	angle=0°	Mat=A
	Ply_shape_#1010	angle=0°	Mat=A
	Ply_shape_#1012	angle=0°	Mat=A
	Ply_shape_#1020	angle=0°	Mat=A
	Ply_shape_#1000	angle=0°	Mat=A
	Ply_shape_#2040	angle=0°	Mat=A
	Ply_shape_#2045	angle=0°	Mat=A
	Ply_shape_#2044	**angle=45°**	Mat=A
	Ply_shape_#1072	angle=0°	Mat=A
	Ply_shape_#1045	angle=0°	Mat=A
	Ply_shape_#2040	angle=0°	Mat=A
	Ply_shape_#2045	angle=0°	**Mat=C**
	Ply_shape_#2044	angle=0°	Mat=A
	Ply_shape_#1072	angle=0°	Mat=A
	Ply_shape_#1045	angle=0°	Mat=A

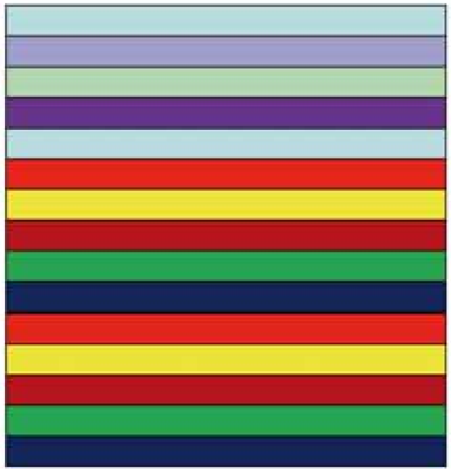


STEP -1- : first design exploration

iDA and composite

- The history of the evolution of each design parameters (shape, thick, mat, etc..) and the history of the evolution of the performance's "configuration state" are related such as a cardinal ordering in the stochastic metric is created
- The stochastic distance of the parameters is used to chose which parameter will be in the next iDA step perturbed

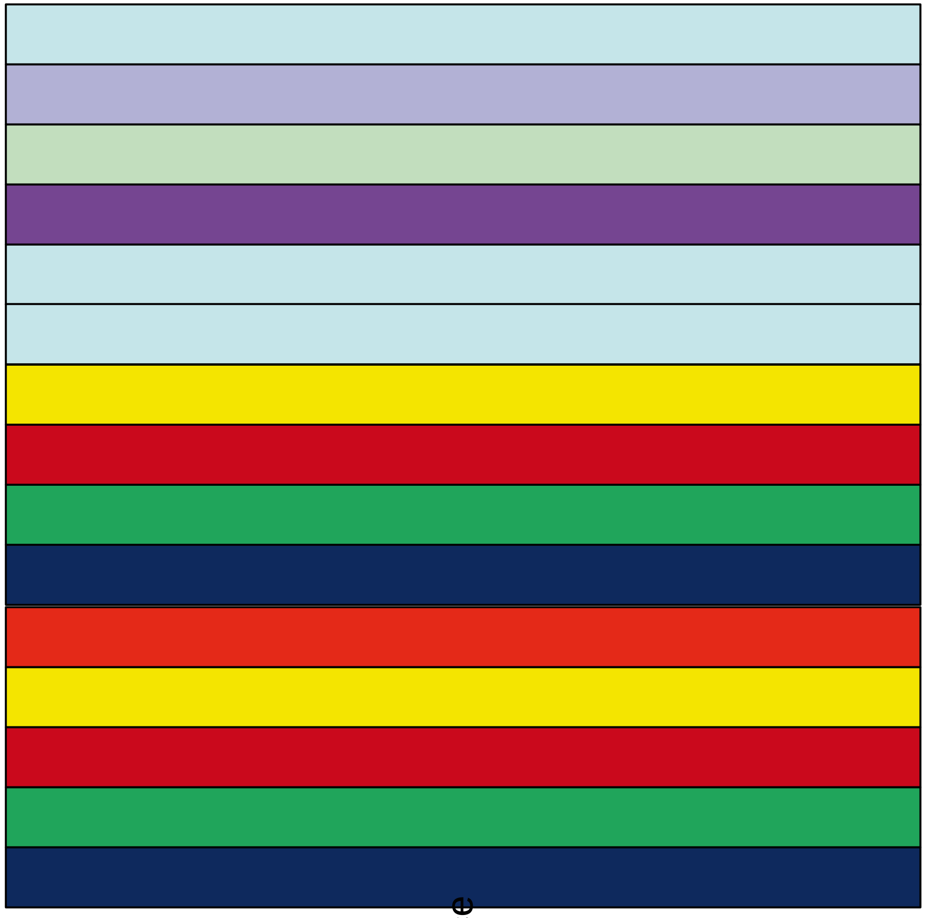
GLOBAL LAYUP SEQUENCE: the independent plies



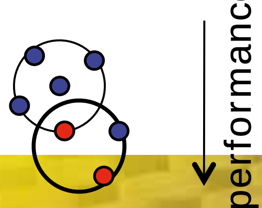
PLY NAME	ANGLE	MATERIAL
Ply_shape_#1000	angle=45°	Mat=A
Ply_shape_#1010	angle=0°	Mat=B
Ply_shape_#1012	angle=90°	Mat=A
Ply_shape_#1020	angle=0°	Mat=C
Ply_shape_#1000	angle=45°	Mat=C
Ply_shape_#2040	angle=45°	Mat=A
Ply_shape_#2045	angle=0°	Mat=B
Ply_shape_#2044	angle=0°	Mat=A
Ply_shape_#1072	angle=90°	Mat=B
Ply_shape_#1045	angle=45°	Mat=A
Ply_shape_#2040	angle=90°	Mat=A
Ply_shape_#2045	angle=45°	Mat=B
Ply_shape_#2044	angle=0°	Mat=C
Ply_shape_#1072	angle=0°	Mat=B
Ply_shape_#1045	angle=45°	Mat=A

iDA and composite

GLOBAL LAYUP SEQUENCE: the independent plies



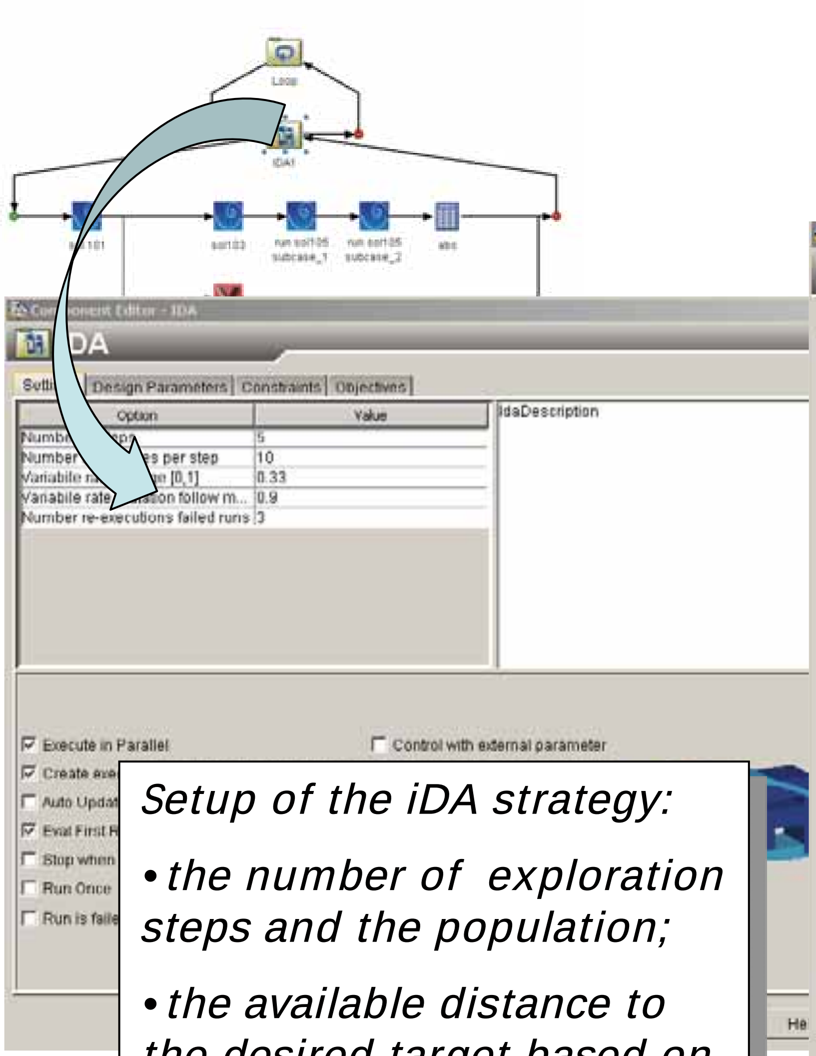
PLY NAME	ANGLE	MATERIAL
Ply_shape_#1000	angle=0°	Mat=A
Ply_shape_#1010	angle=0°	Mat=A
Ply_shape_#1012	angle=0°	Mat=A
Ply_shape_#1020	angle=0°	Mat=A
Ply_shape_#1000	angle=0°	Mat=A
Ply_shape_#1000	angle=0°	Mat=A
Ply_shape_#2045	angle=0°	Mat=A
Ply_shape_#2044	**angle=45°**	Mat=A
Ply_shape_#1072	angle=0°	Mat=A
Ply_shape_#1045	**angle=90°**	Mat=A
Ply_shape_#2040	angle=0°	Mat=A
Ply_shape_#2045	angle=0°	**Mat=C**
Ply_shape_#2044	angle=0°	Mat=A
Ply_shape_#1072	angle=0°	Mat=A
Ply_shape_#1045	angle=0°	Mat=A



STEP -2- : next step design exploration

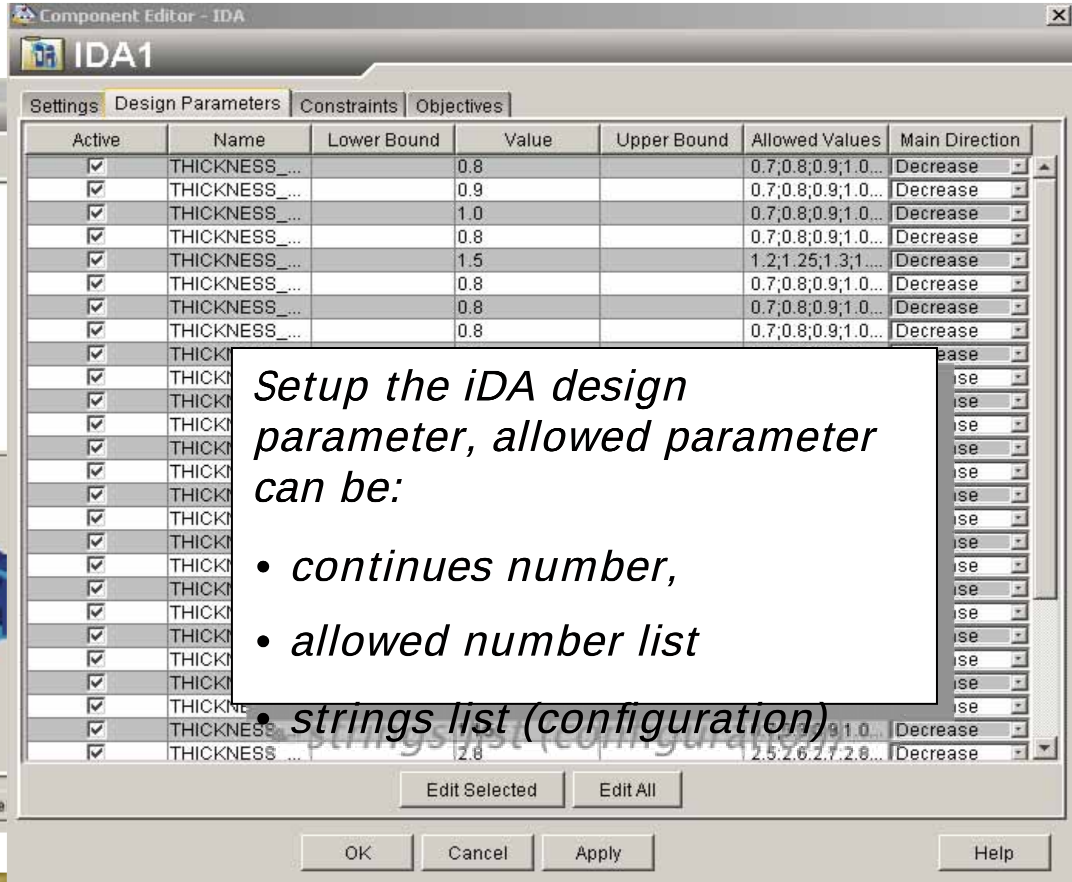
The iDA graphical interface

- iDA has a GUI to quickly setup the engineering problem.



Setup of the iDA strategy:

- *the number of exploration steps and the population;*
- *the available distance to the desired target based on physic consideration*

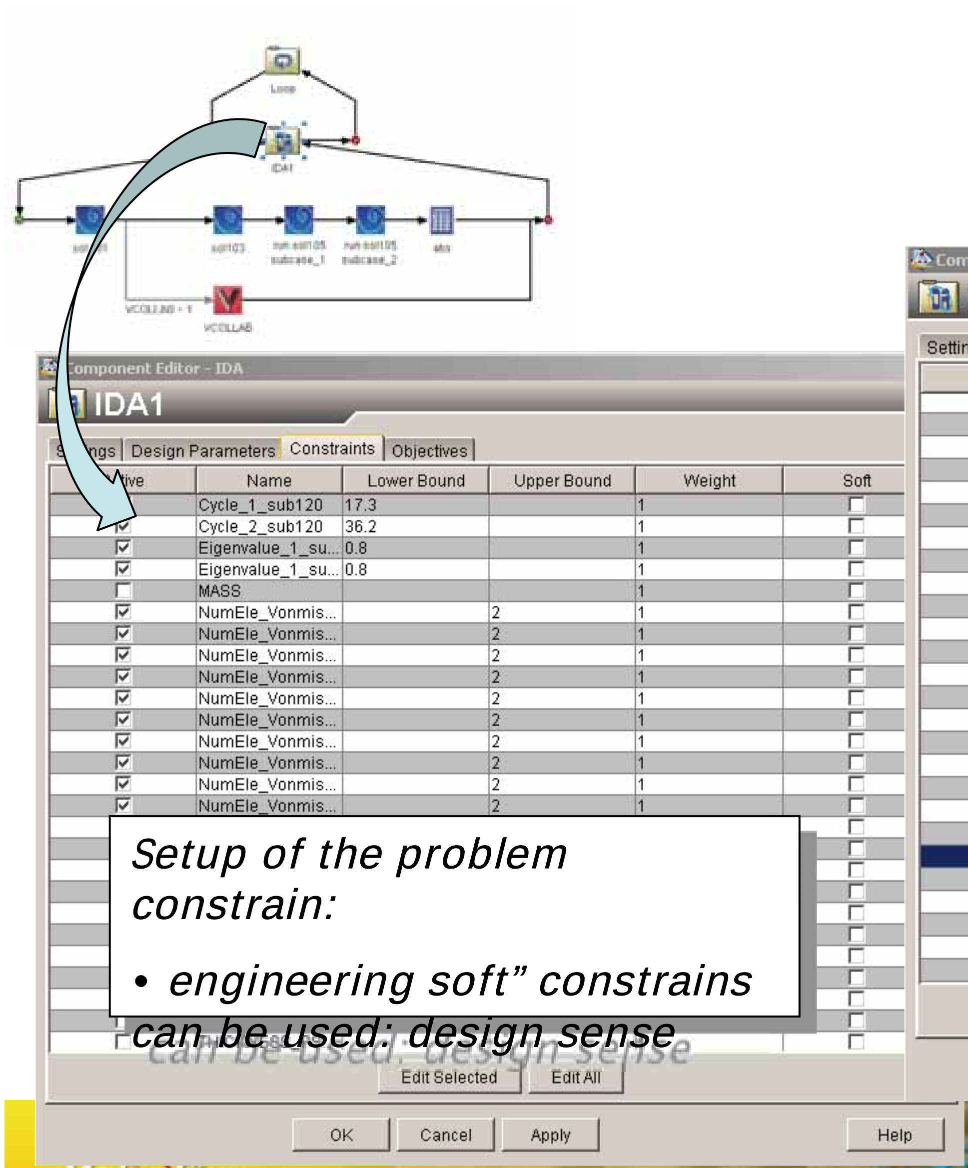


Setup the iDA design parameter, allowed parameter can be:

- *continues number,*
- *allowed number list*
- *strings list (configuration)*

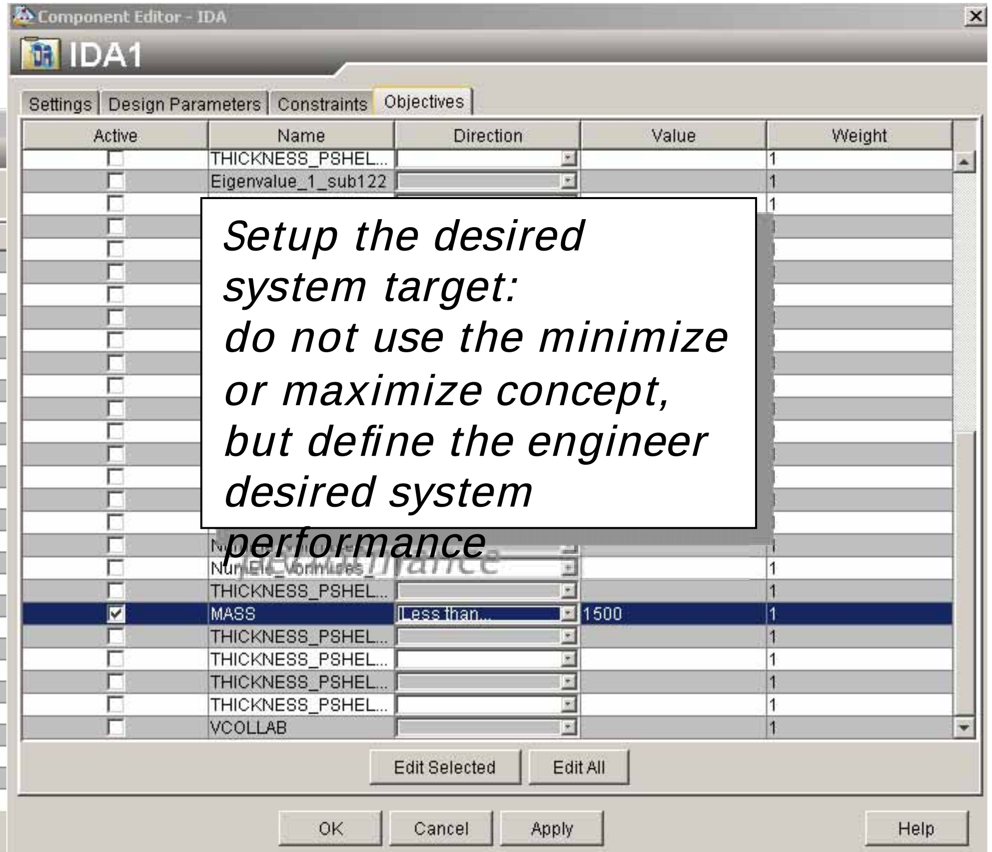
The iDA GUI

- Constrains and target can be defined using engineering sense.



Setup of the problem constrain:

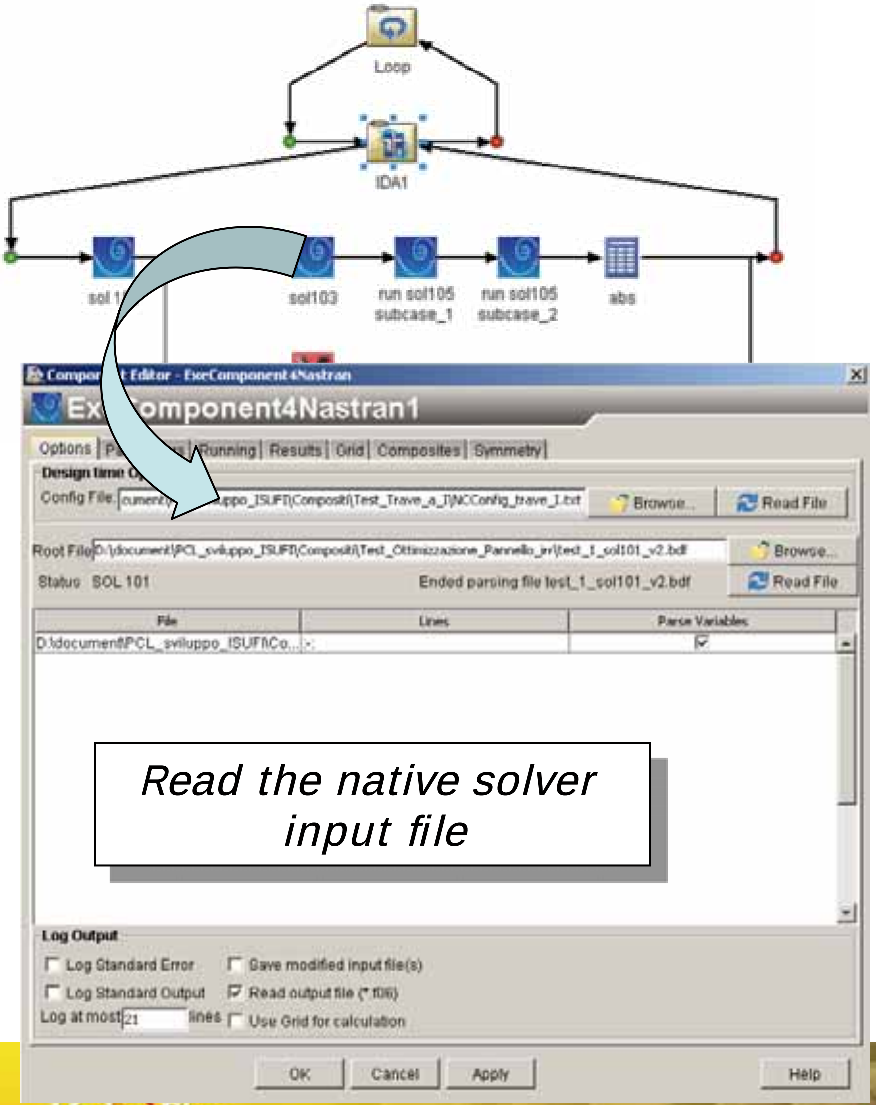
- *engineering soft" constrains can be used: design sense*



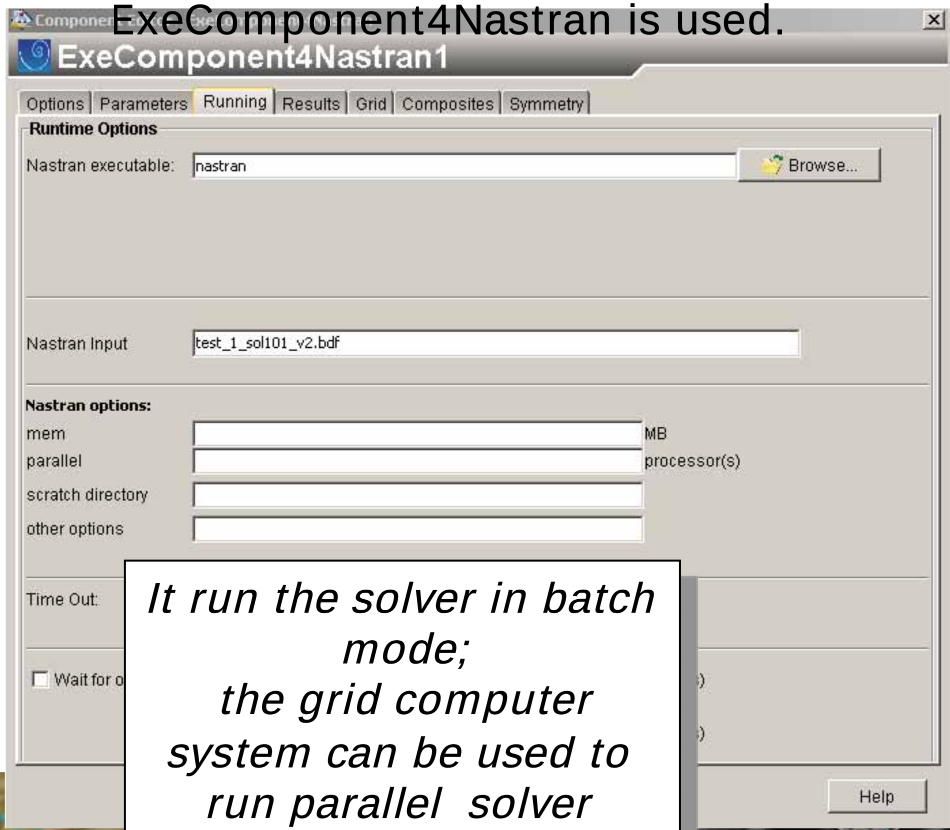
Setup the desired system target: do not use the minimize or maximize concept, but define the engineer desired system performance

The final recipe: &

- The iDA generic interface can handle all kind of optimization problem
- But a dedicated interface has been developed for a quick composite complex problem setup, based on rules design.
- In the current example the ExeComponent4Nastran is used.



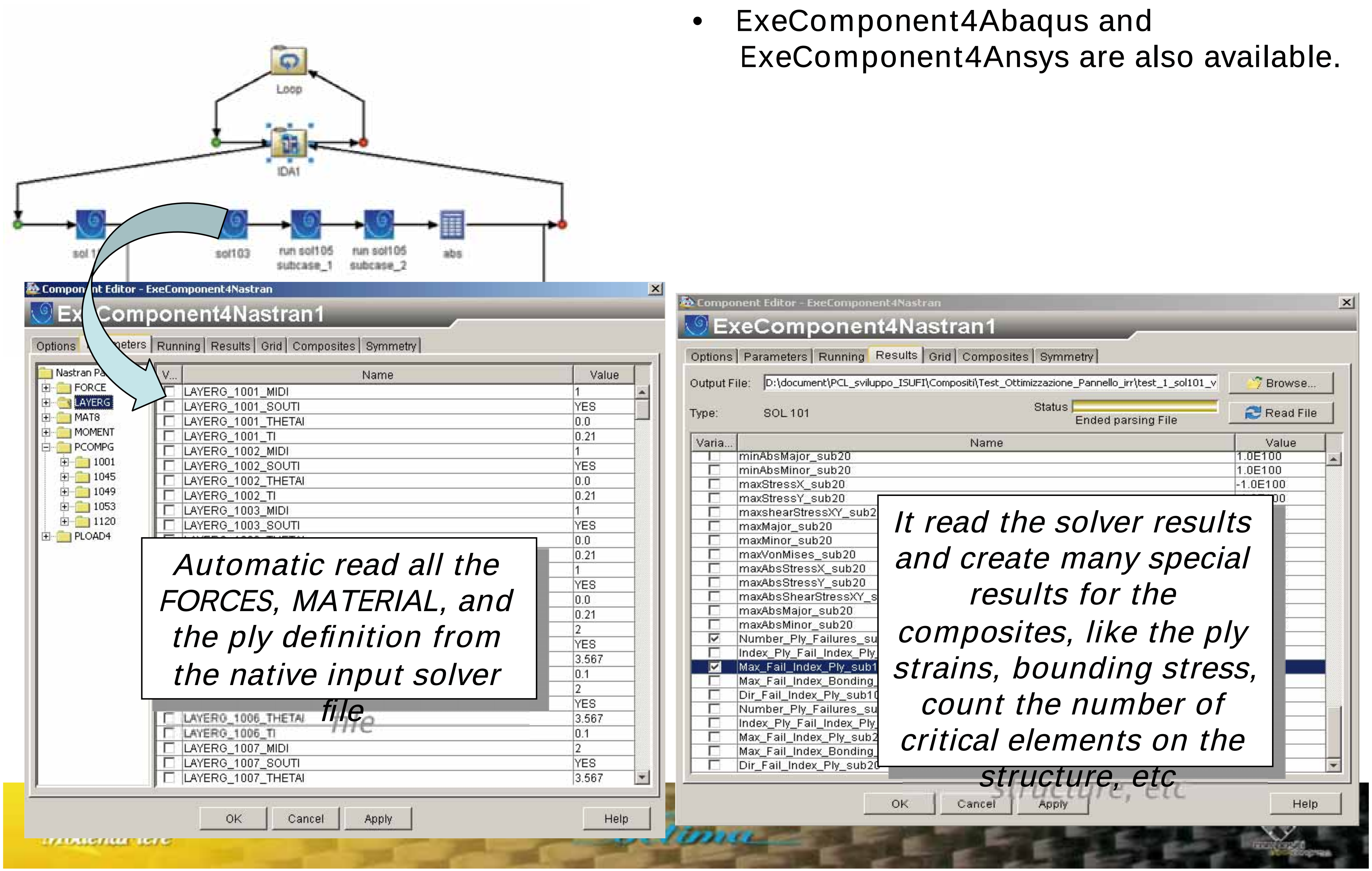
Read the native solver input file



It run the solver in batch mode;
the grid computer system can be used to run parallel solver session

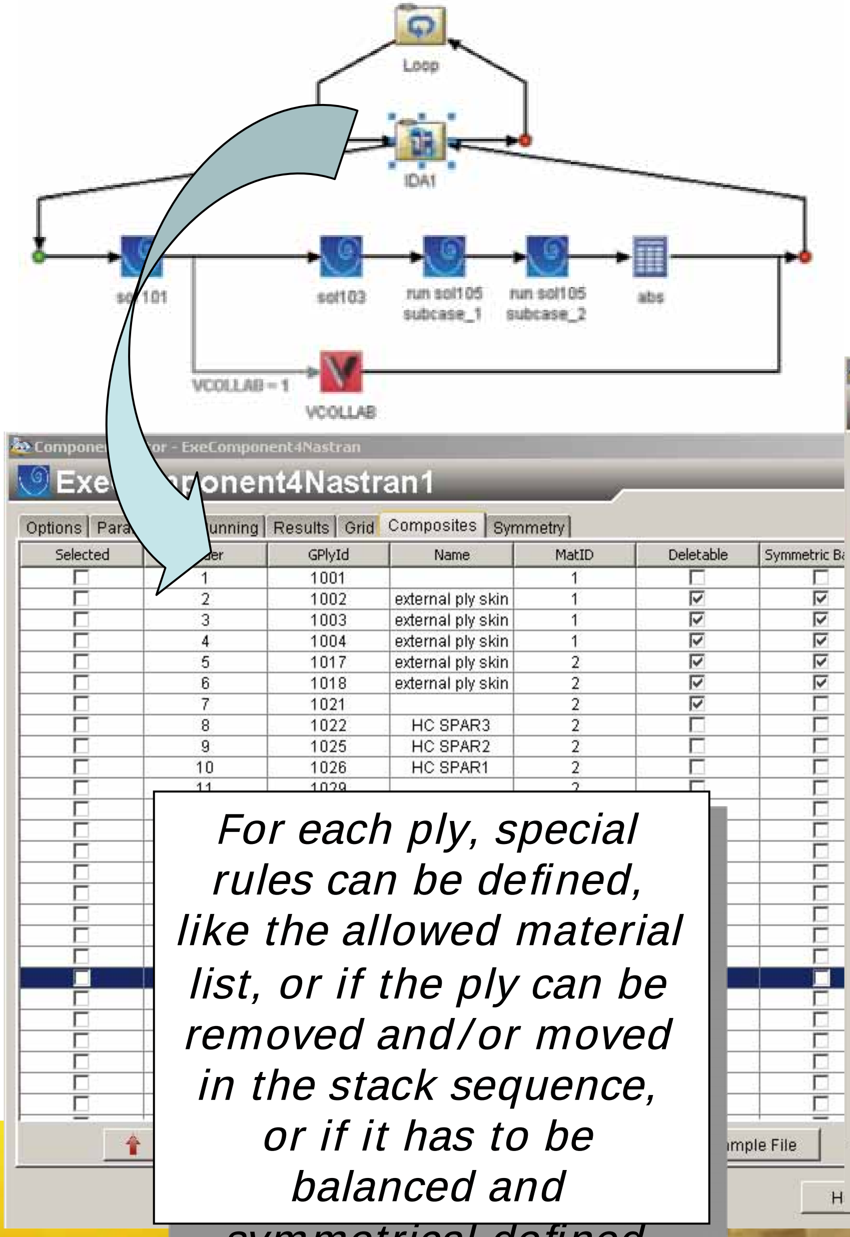
The final recipe: &

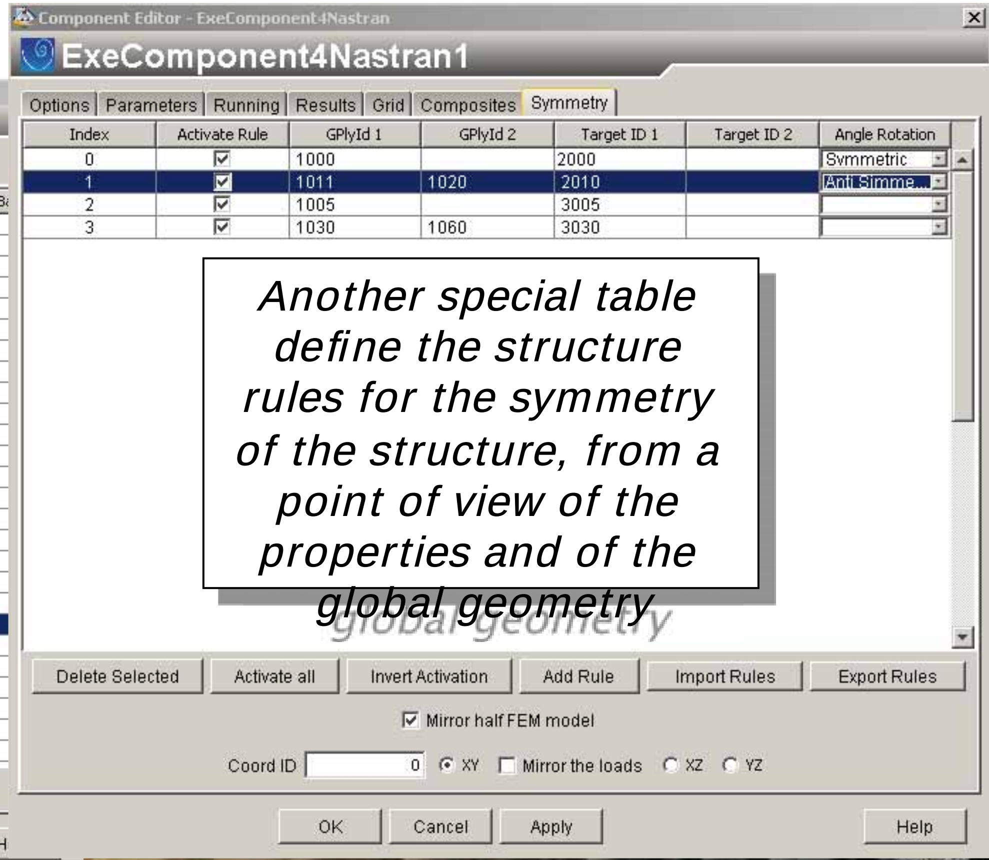
- ExeComponent4Abaqus and ExeComponent4Ansys are also available.



The final recipe: &

- Local layup rules
  - § symmetric and balanced
  - § external wrapper
  - § sandwich behaviour, etc
- Global layup rules
  - § Defined by the shape of the manufacture





The desired HT wing box performance

- **Post-Processing NASTRAN output:**

  Mass of the model:

  mass < 1500 lb (target)

  Max absolute Strain in the middle plain of the laminate:

  $||xx_{\text{-strain}}||$ < 4000 µeps (Soft Constrain)

- The number of elements with strain greater than 4000 *µeps* have to be constrain at the root of the wing box

- **Number of Element < 150 (Soft Constrain)**

  the element strain is read in the of the element, the value is not averaged between the near elements

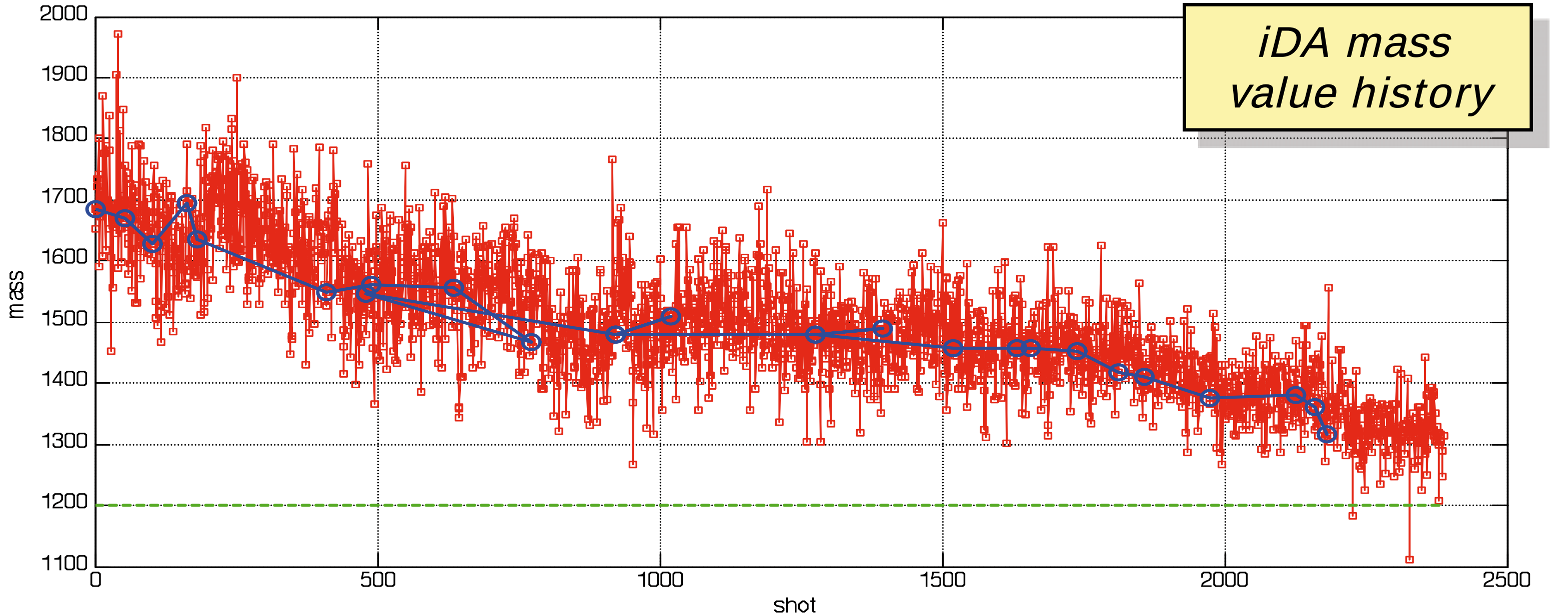
- **First Nastran Buckling Eigenvalue:**

  $\lambda > 1.$ (Hard Constrain)

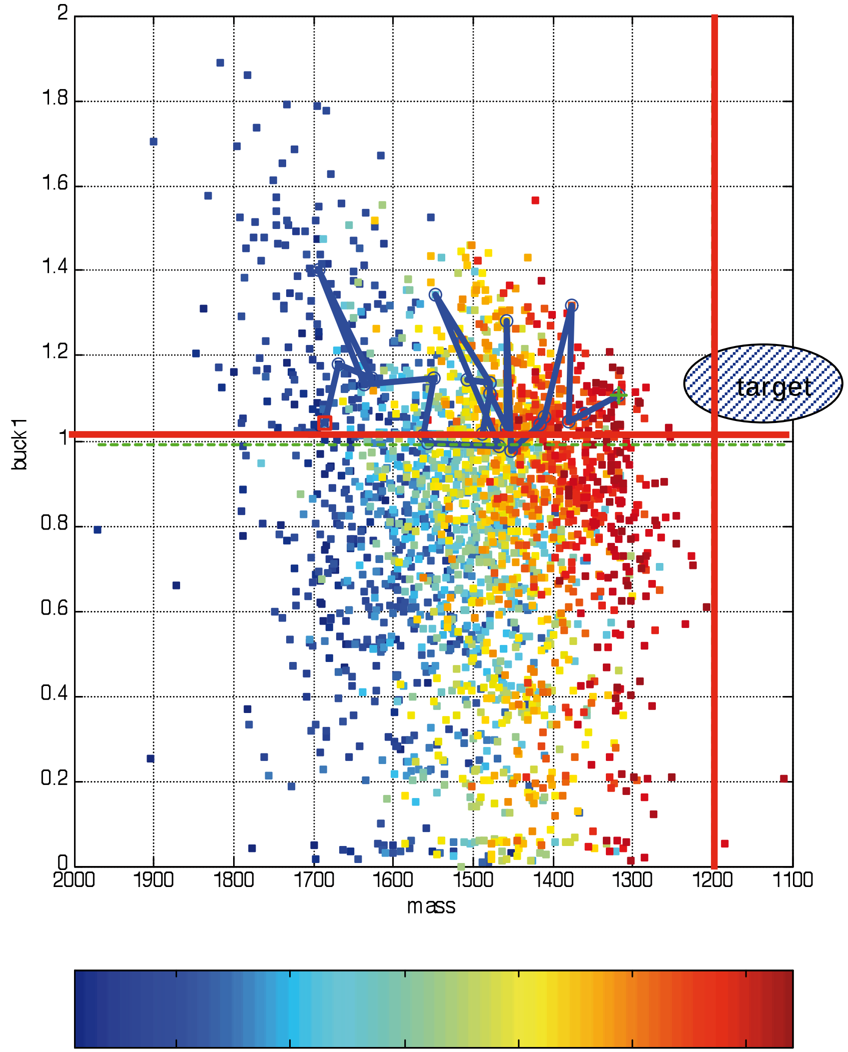
Results

- 2500 function evaluations have been needed to reduce weight and achieve the desired performance (~70 hrs on 32 CPU Linux Cluster)
- 12.5% weight reduction on the expected weight of 1500 lb

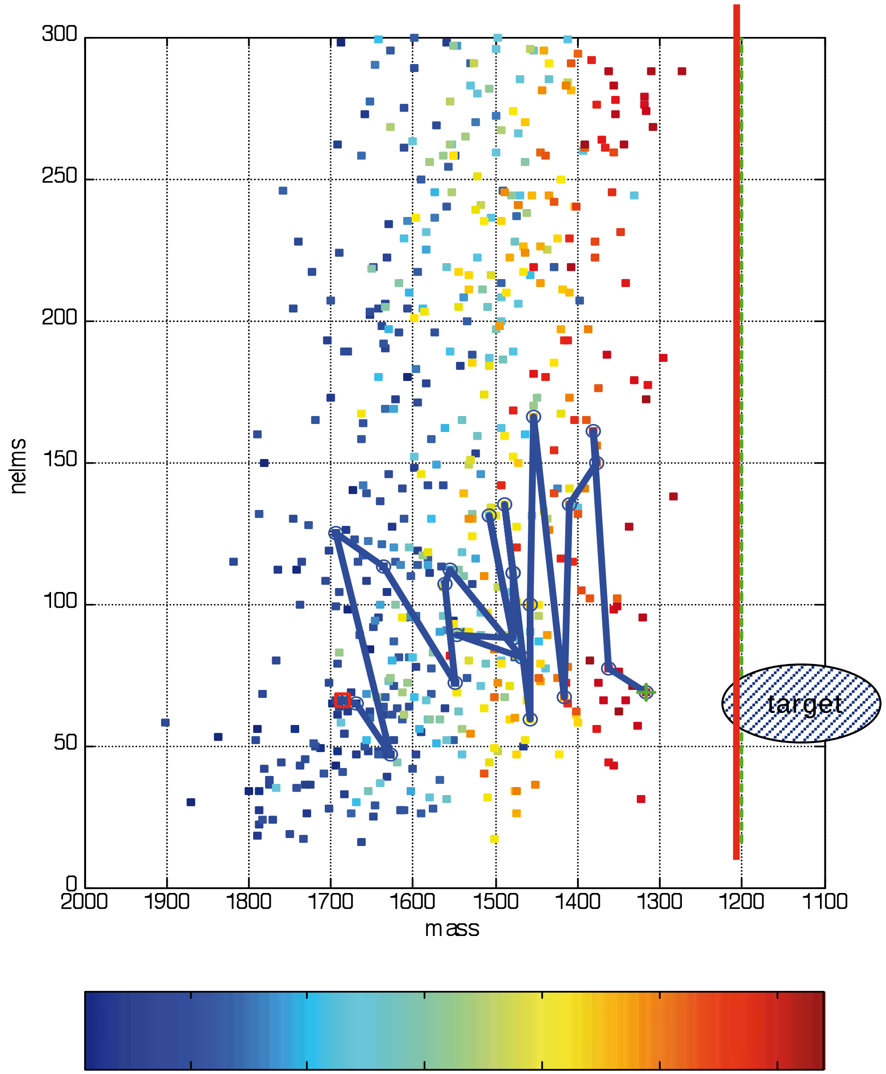
	Desired	iDA Result
Mass of the component	1500 lb	1312 lb
Critical elements	150	69
Buckling Value	1.	1.1



Results

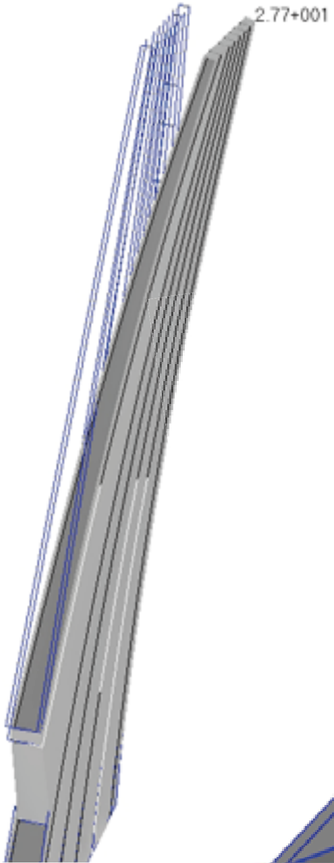


Mass vs.
Buckling factor

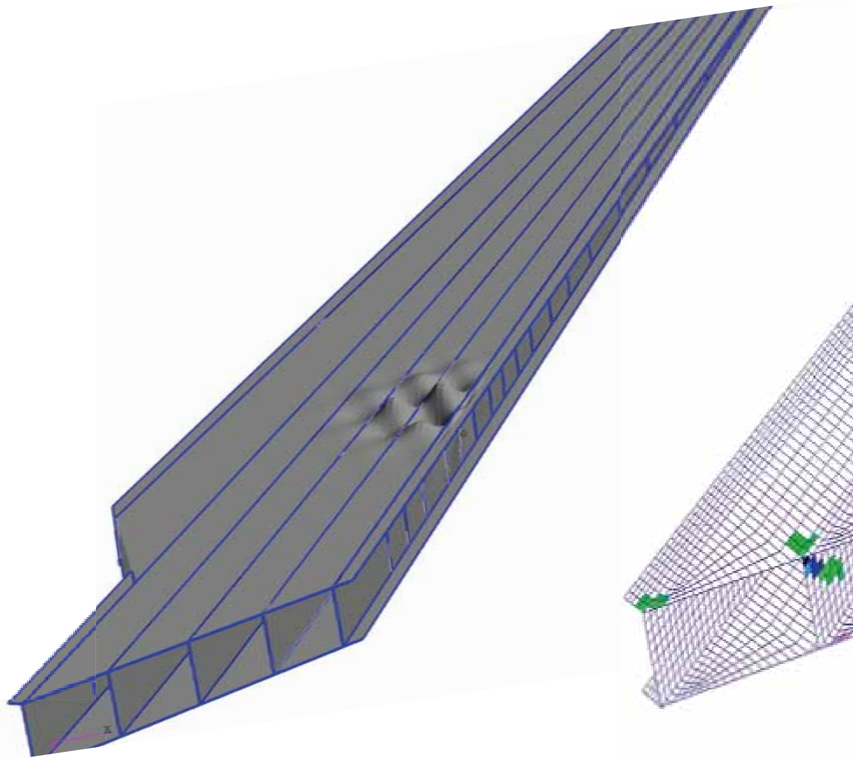


Mass vs.
Critical elements number

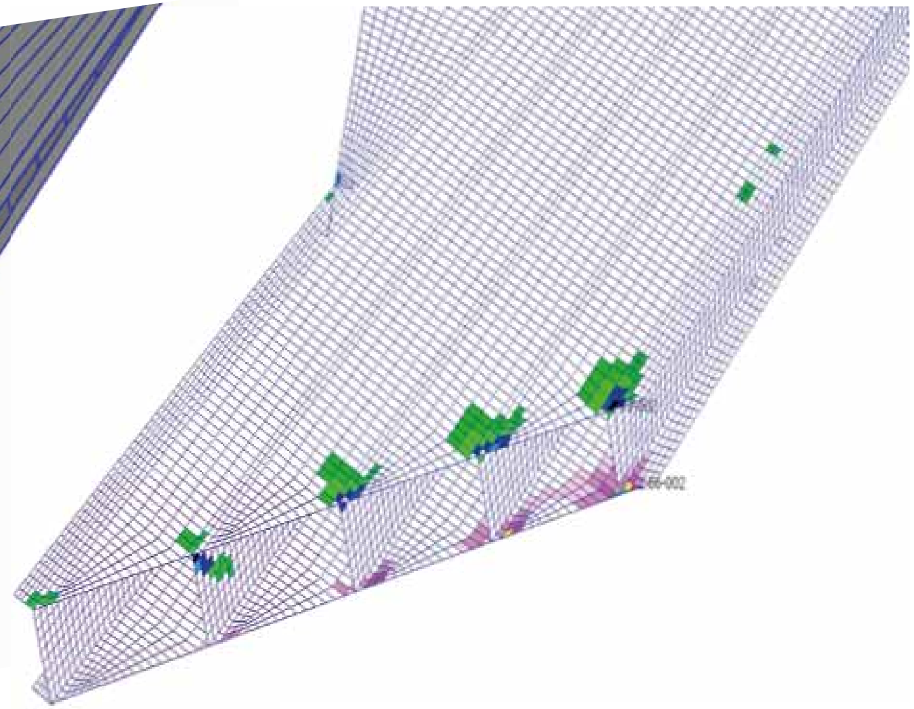
Results



Static Max
def = 27.7 in

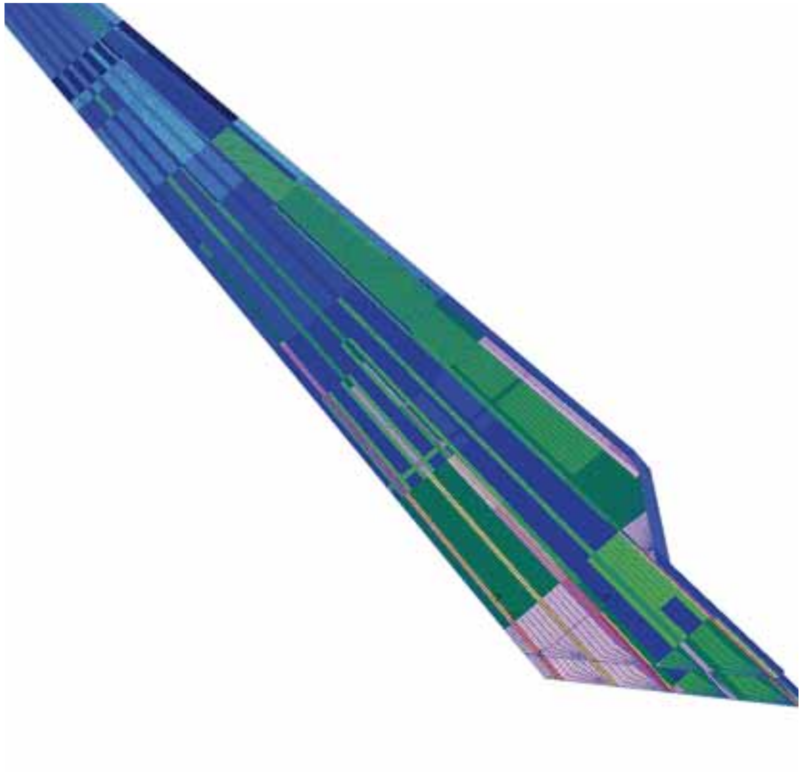


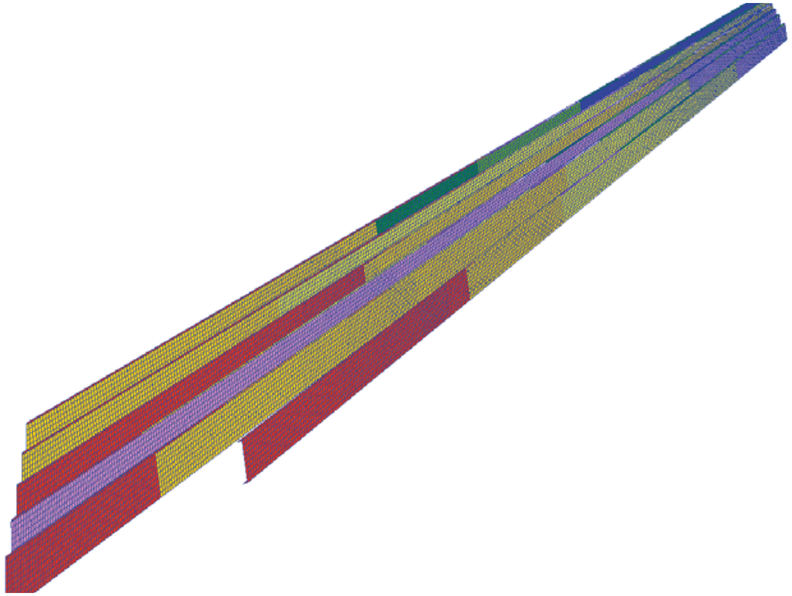
Buckling Value
1.1



Number of critical Elements = 69
mainly at the wing root region

Results





skin & spars thickness distribution

- Questions & answers