Optimization of Composite layers lay-up of an aeronautical component using an ISight-based intelligent decision advisor, iDA

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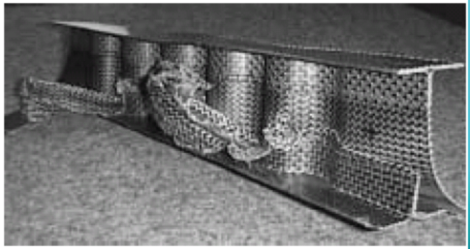
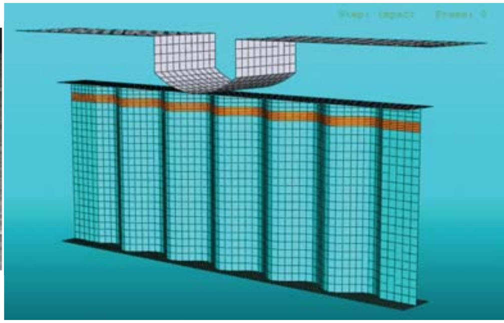
Exemplar in a glance

***Exemplar** supplies solutions in the field of **Computer Aided Engineering** (CAE) and **Process Integration Design Exploration & Optimization** (PIDEO) with a high added value, developing software and methodologies based on customer specific requirements*
*Headquartered in **Torino (Turin), Italy c/o I3P (Turin Politecnico Incubator)***

Products, Services and Technologies:

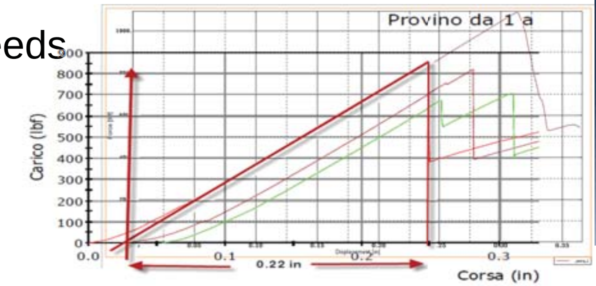
- Exemplar's approach is to provide a complete portfolio of computer-aided engineering (CAE) simulation software **for structural, thermal, electromagnetic, multibody, computational fluid-dynamics, acoustic and durability**

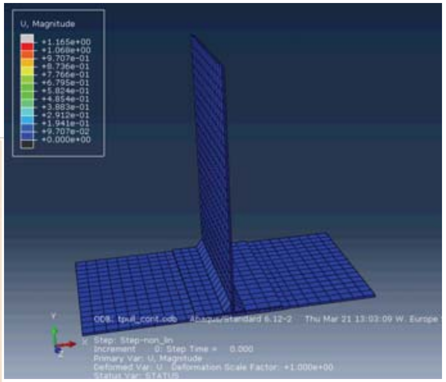




from McCarthy, M.A., Harte, CG, Wiggenraad, J.F.M., Michielsen, A.L.P.J., Kohlgruber, D., and Kamoulakos, A., *Finite Element Modeling of Crash Response of Composite Aerospace Sub-floor Structures*, Computational Mechanics, 26(3), Sept. 2000

- Dedicated knowledge and experience in simulation process automation for design optimization and to reduce design cycle time.
- We offer regularly **CAE public seminars** as well as **training courses at customer sites**
- Supports for your **engineering service** needs with innovative CAE methods
- **Dedicated Software development for Simulation Engineering and Sciences**



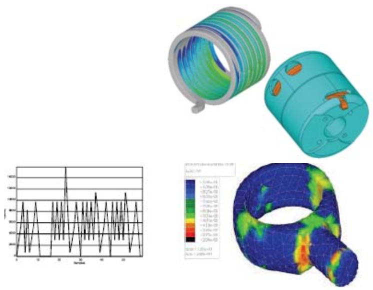


CAE Software Sales

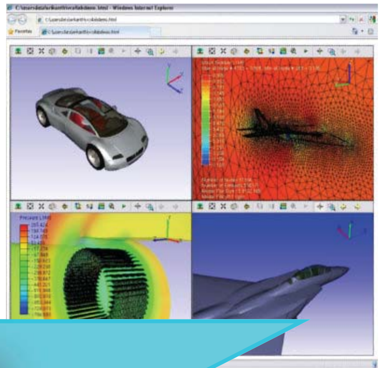
exemplar
Solutions for Complexity

INTERNATIONAL 2014 ramspec
raw materials specialties chemistry

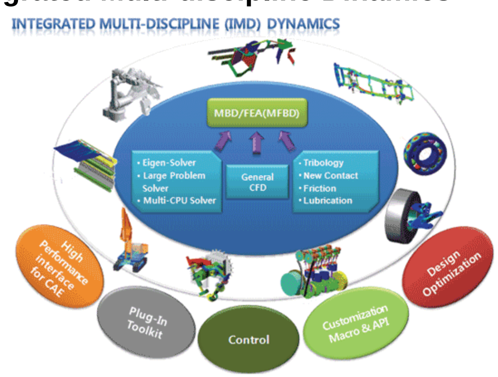
fe-safe Composites
durability analysis software



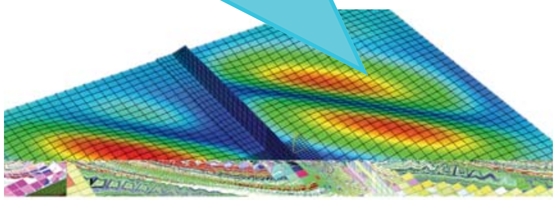
VCollab
Leading CAE viewing technology for SDM



RecurDyn
Integrated Multi-discipline Dinamics



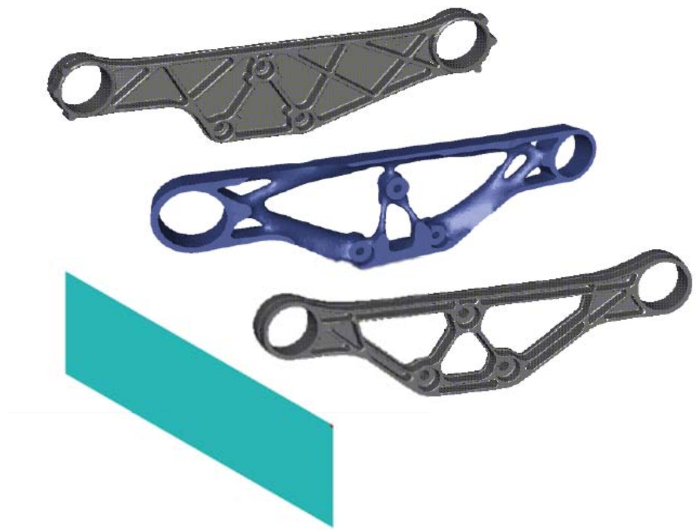
Abaqus | Isight | Tosca
Leading tools for CAE & PIDEO
Process Integration Design Exploration & Optimizartion



Optimization at a glance

Parametric Optimization:

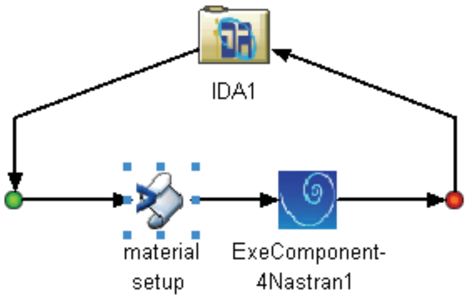
Topologic Optimization:



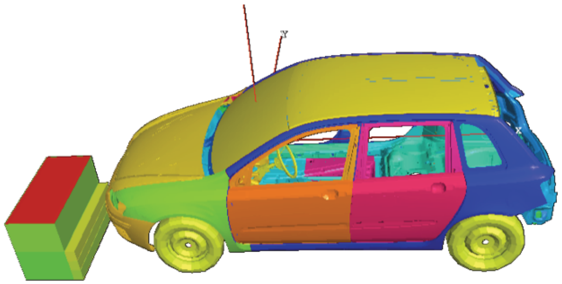
iDA [*i*ntelligent *D*ecision *A*dvisor]

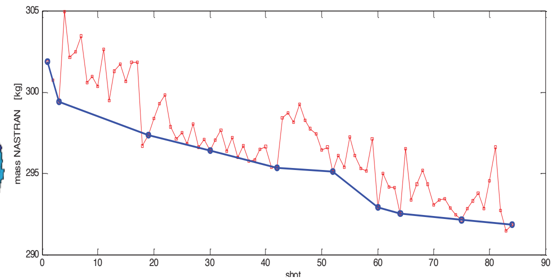
iDA introduction

- iDA [*i*ntelligent *D*ecision *A*dvisor] software is an innovative tool that by means of intelligent explorative methods Drive the Design towards pre-established targets
- iDA is available as plugin in the iSight optimization software
- iDA in this example is used to design a new layup for a wing pylon that achieves the goals to :
  - assure adequate static capability
  - reduce the weight respect to the actual design
  - obtain a feasible design
    (➔ respect the manufacturing constrains of ply shape and continuity)



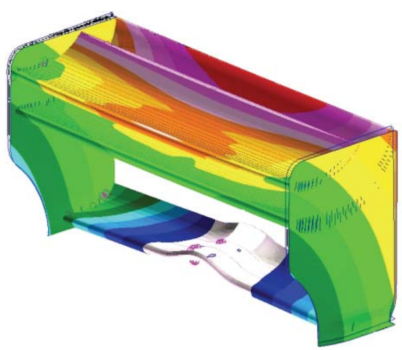
i-DA intelligent Design Advisor

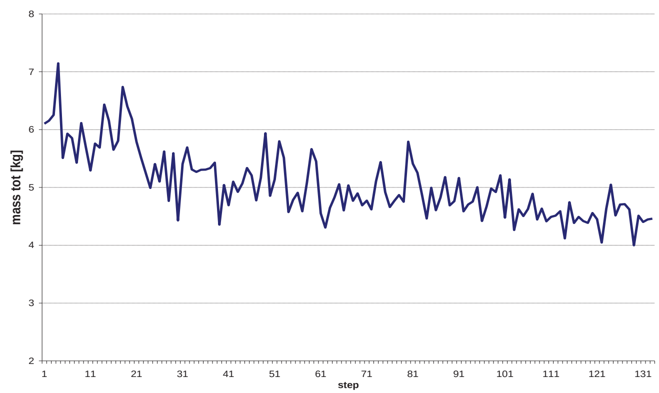




yrs: 2002. CAR Body
NVH+CRASH - Weight Reduction

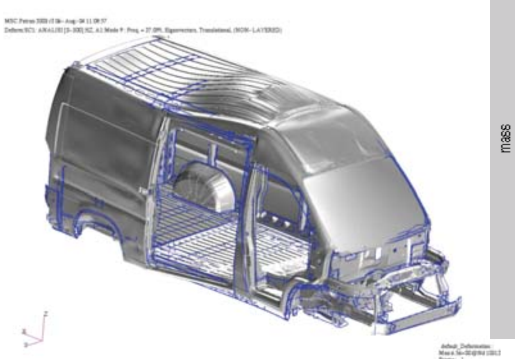
- Results & Bill:
  - *30 discrete parameters*
  - *-10kg , 90 function eval*

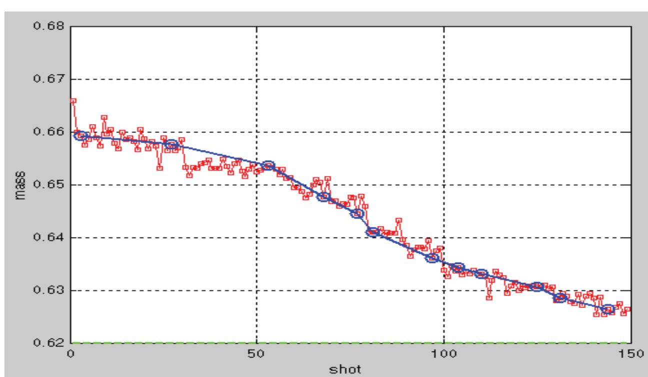




yrs: 2003 F1 Rear Wing
FIA requirement - Weight Reduction

- high number of discrete variables
  - *800 independent variables*
- Results & Bill:
  - *-15% weight reduction , 140 function eval*





yrs: 2004 VAN Body
NVH+ DYN. STIFFNESS- Weight Reduction

- 124 different part thickness
- Results & Bill:
  - *Same weight, get the target, 150 eval*

i-DA intelligent Design Advisor

exemplar Solutions for Complexity

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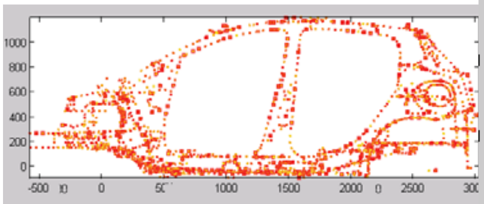
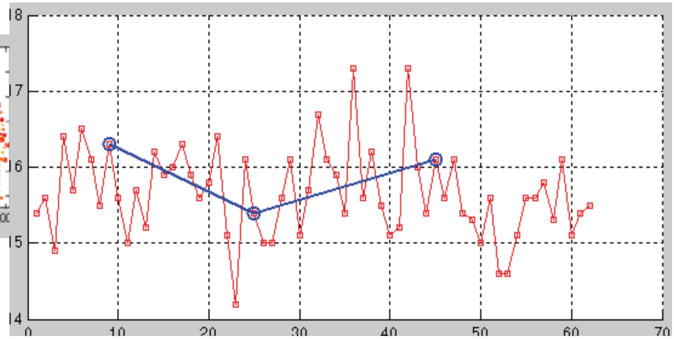


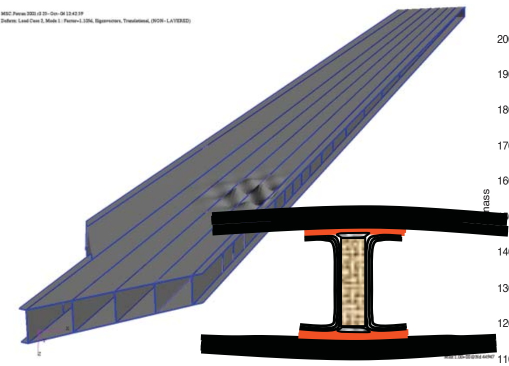


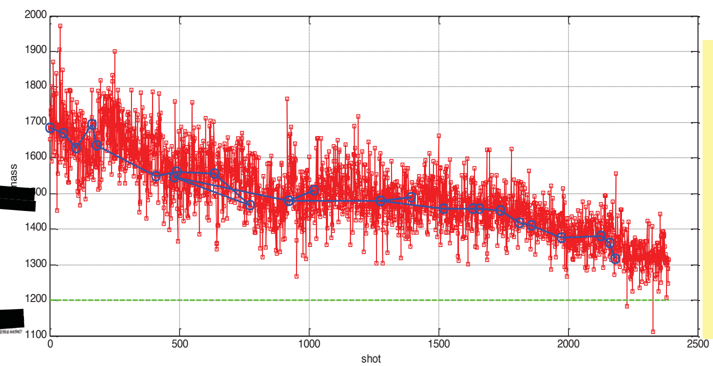
yrs: 2004. CAR BODY
NVH + Welding Robustness evaluation

- *22 independent variables: thickness*
- *weld failure simulated: noise*

Results & Bill:

- -3.5% weight, + 5% First Freq, 70 evaluation

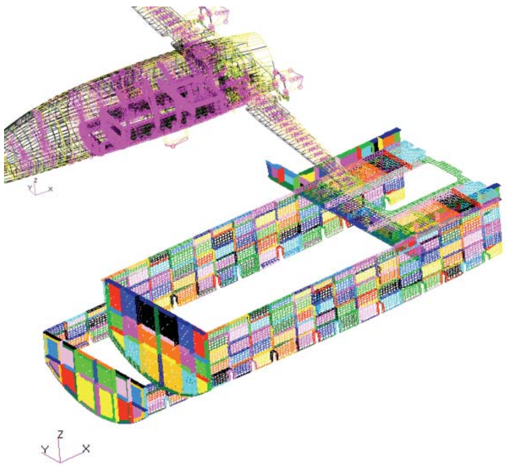


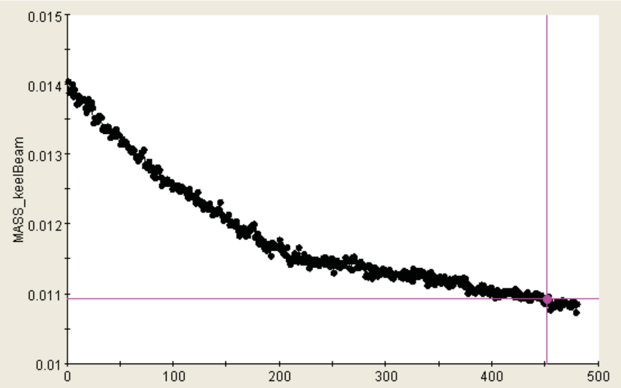


yrs: 2006. CFRP WingBox HorzTail
Structural Stiff- Weight Reduction

•*1200 independent variables*
(plies geometry and layup stack sequence)
•Results & Bill:

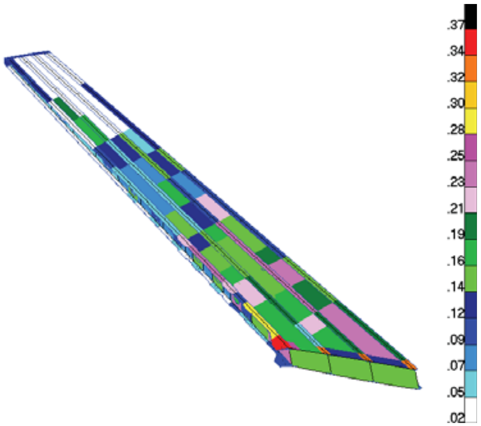
- *-50lbs , 2300 function eval, strength improvoement*

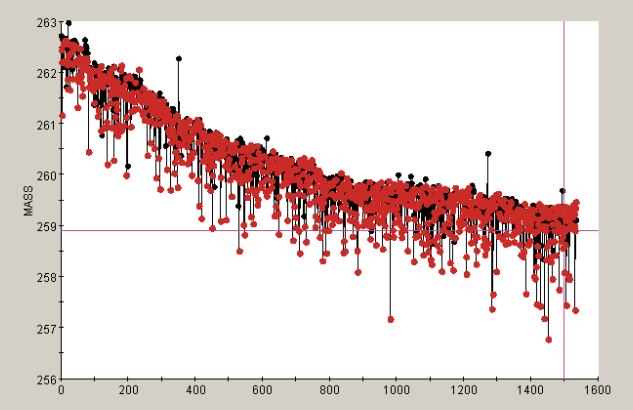




yrs: 2012. Airplane metallic frame sizing
Weight reduction

- *350 discrete independent variables (thicknesses)*
- Results & Bill:
  - *-15kg weight save, + 15% overal buckling strenght*
  1000 function eval



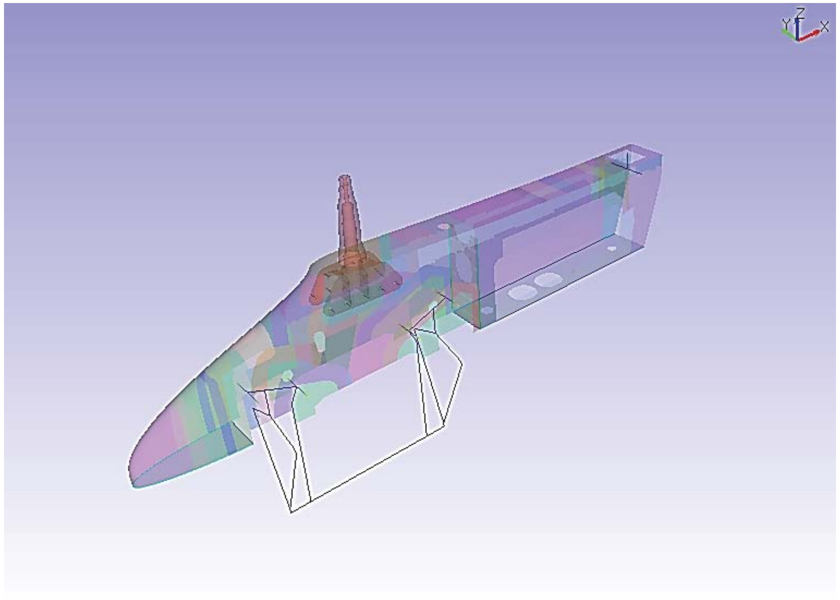


yrs: 2013. CFRP WingBox HorizTail
Strength improvement

- *300 independent variables (plies geometry and layup stack sequence)*
- Results & Bill:
  - *same weight, + 15% buckling strenght*
  3600 function eval

Problem introduction

- **Manufacturing requirement**
  - Complex layup definition
- **Discrete variables**
  - geometry ply design
  - angle ply (0°/45° / 90°) and thickness
  - layup sequence
  - Material (tape or fabric:)
- **High number of variables** (~1000)
  - 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** (~ 10 min)
  - 4 Nastran non-linear loadcases are considered: B113, B114, B115, B116
- **weight reduction**
  - critical (F.I. >1) element numbers reduction



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.

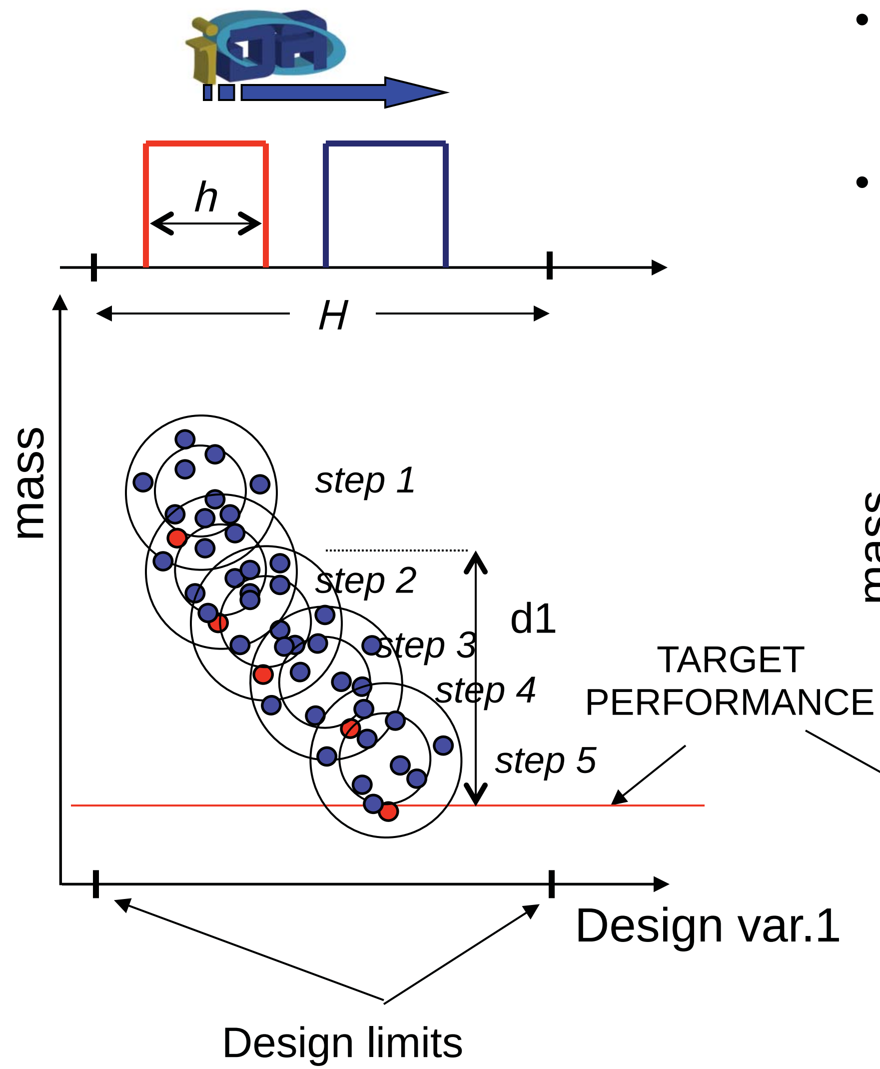
- For engineering problems many optimization method are available. EXEMPLAR experienced that all of them have a limited number of design parameter, because they are “generic” method. The multi-objective method require many computational effort, and can become prohibitive with high input parameter number

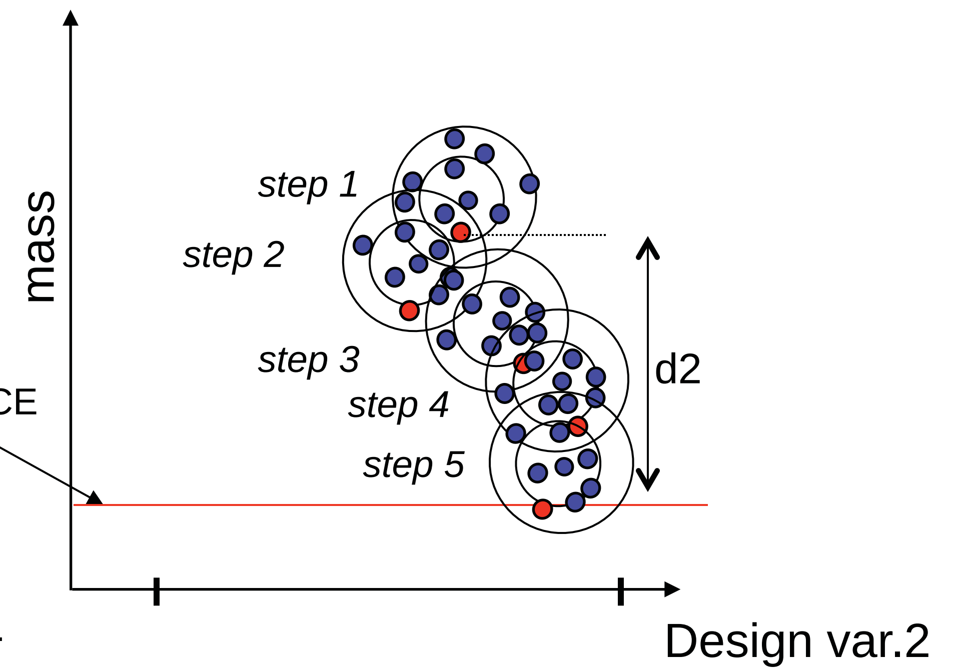
- In the classical optimization methods, the user cannot supply some of his knowledge about the problem.

- The aim of iDA algorithm is allow the expert to supply all useful information to drive the exploration method to reach its goals.

The iDA method

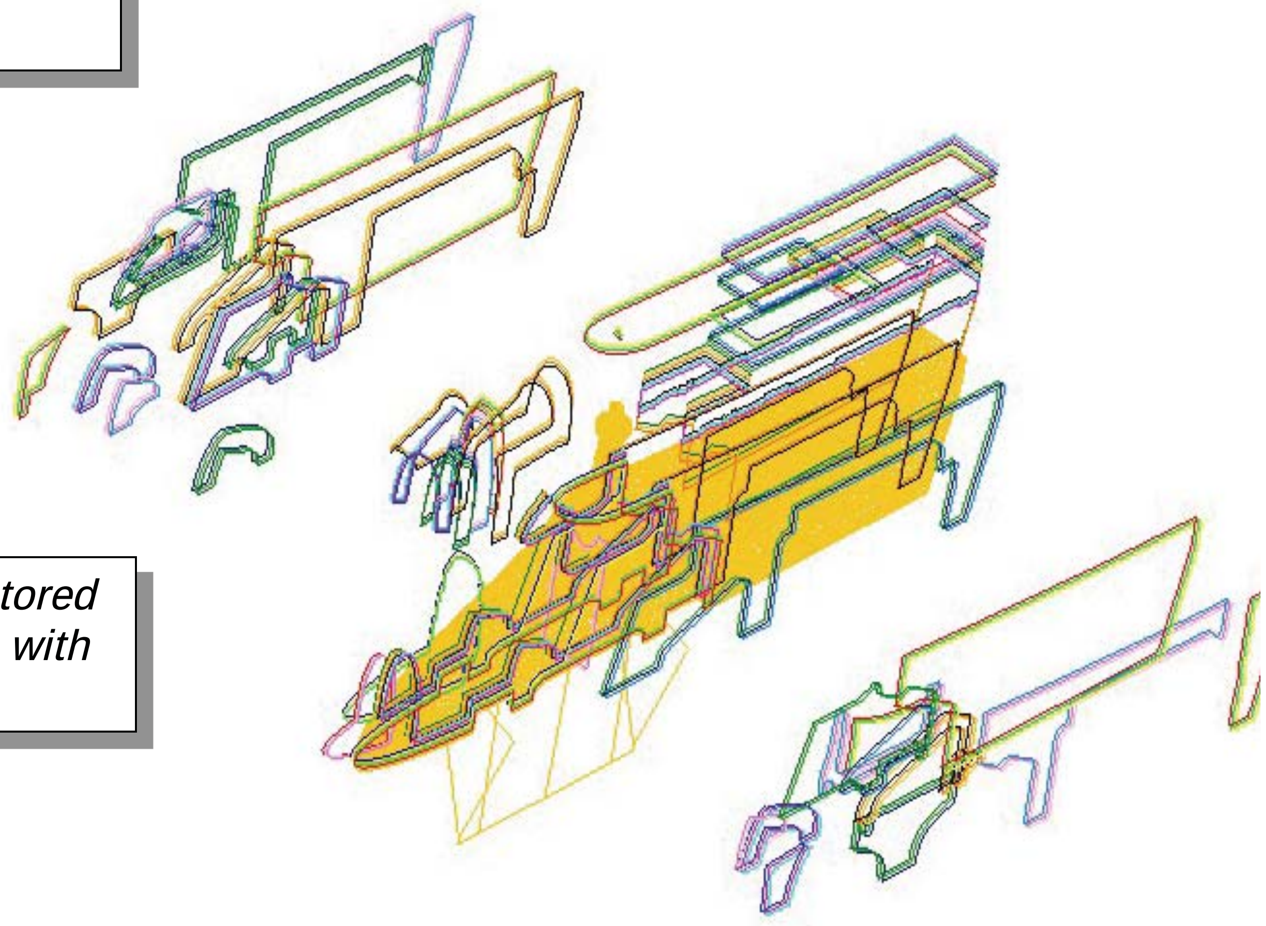
- iDA can be “briefly” defined as a driven DOE
- The uniform distribution, *h*, should be such that with N steps, the design variables can bounce between their limits.
- iDA heads the exploration box with the user knowledge to reach the desired target





Manufacturing description in the FEM

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



the plies shape are stored in the solver input file with unique ID

(*) Courtesy of **AleniaAermacchi**

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

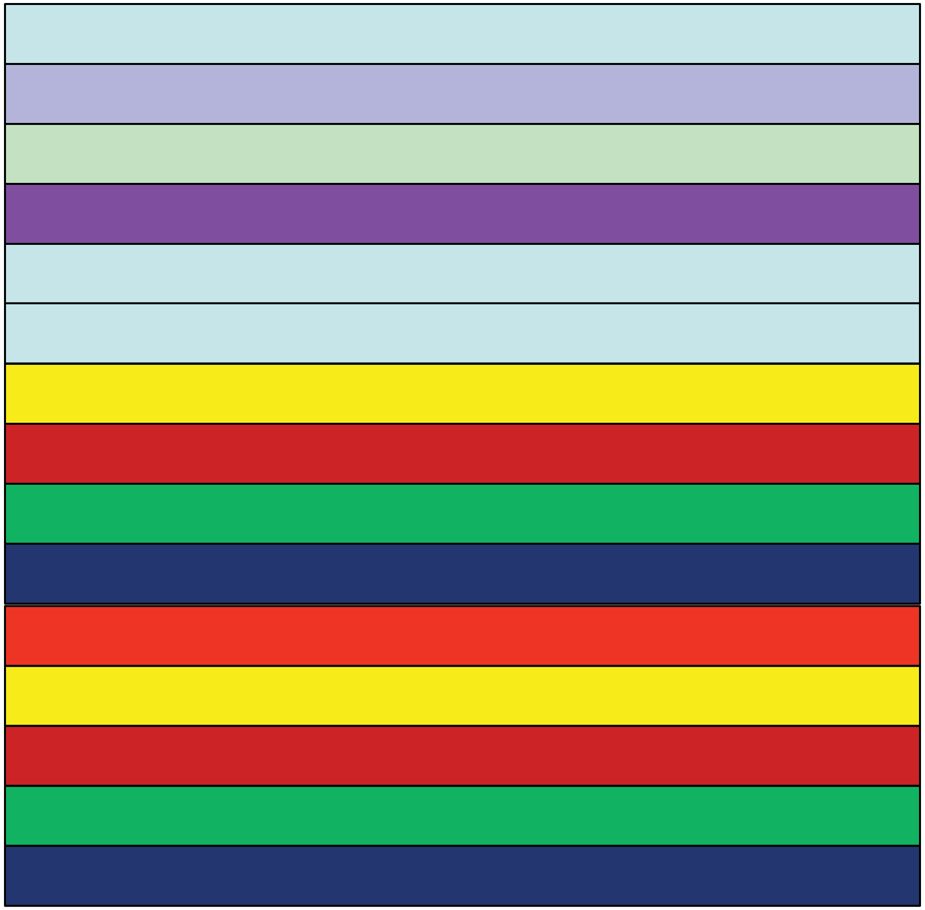
- In the composite design, iDA doesn’t considered the parameter like thickness, angles or materials as cardinal numbers, but it manage them as “*configuration state*”
- A stochastic distance is defined for each design parameter: the ply shape, the angle and the ply material;
  the list table of all these 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

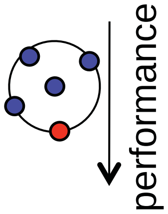
PLY NAME	***ANGLE***	***MATERIAL***
Ply_shape_#1000	angle=45°	Mat=A
Ply_shape_#1010	angle=0°	Mat=B
Ply_shape_#1012	angle=90°	Mat=A
Ply_shape_#1020	angle=0°	Mat=C
Ply_shape_#1000	angle=45°	Mat=C
Ply_shape_#2040	angle=45°	Mat=A
Ply_shape_#2045	angle=0°	Mat=B
Ply_shape_#2044	angle=0°	Mat=A
Ply_shape_#1072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

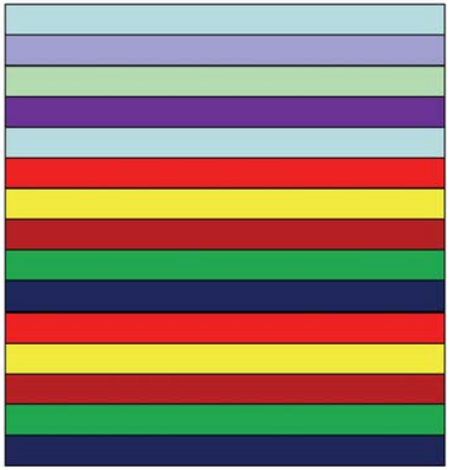


STEP -1- : first design exploration

and composite

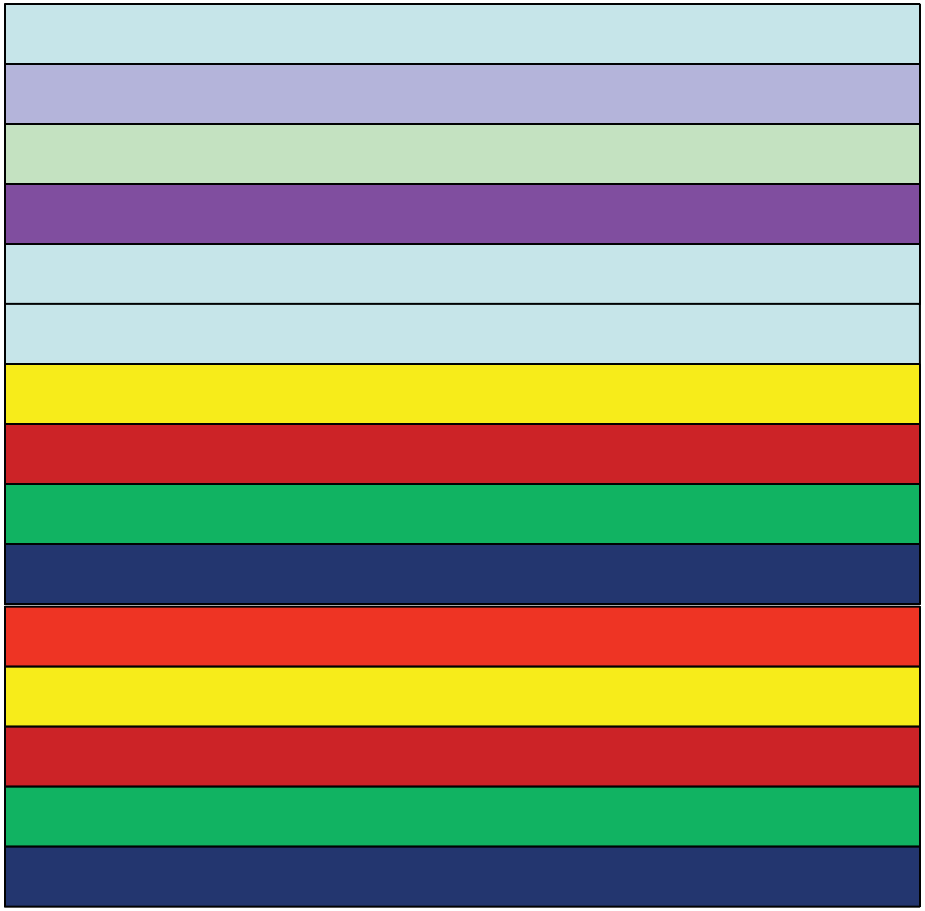
- The history of the evolution of each design parameters (shape, thick, mat, etc..) and the history of the evolution of the performance's "configuration state" are related such as a cardinal ordering in the stochastic metric is created
- The stochastic distance of the parameters is used to chose which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

GLOBAL LAYUP SEQUENCE: the independent plies

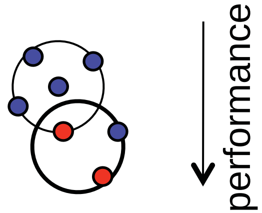


PLY NAME	ANGLE	MATERIAL
Ply_shape_#1000	angle=45°	Mat=A
Ply_shape_#1010	angle=0°	Mat=B
Ply_shape_#1012	angle=90°	Mat=A
Ply_shape_#1020	angle=0°	Mat=C
Ply_shape_#1000	angle=45°	Mat=C
Ply_shape_#2040	angle=45°	Mat=A
Ply_shape_#2045	angle=0°	Mat=B
Ply_shape_#2044	angle=0°	Mat=A
Ply_shape_#1072	angle=90°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



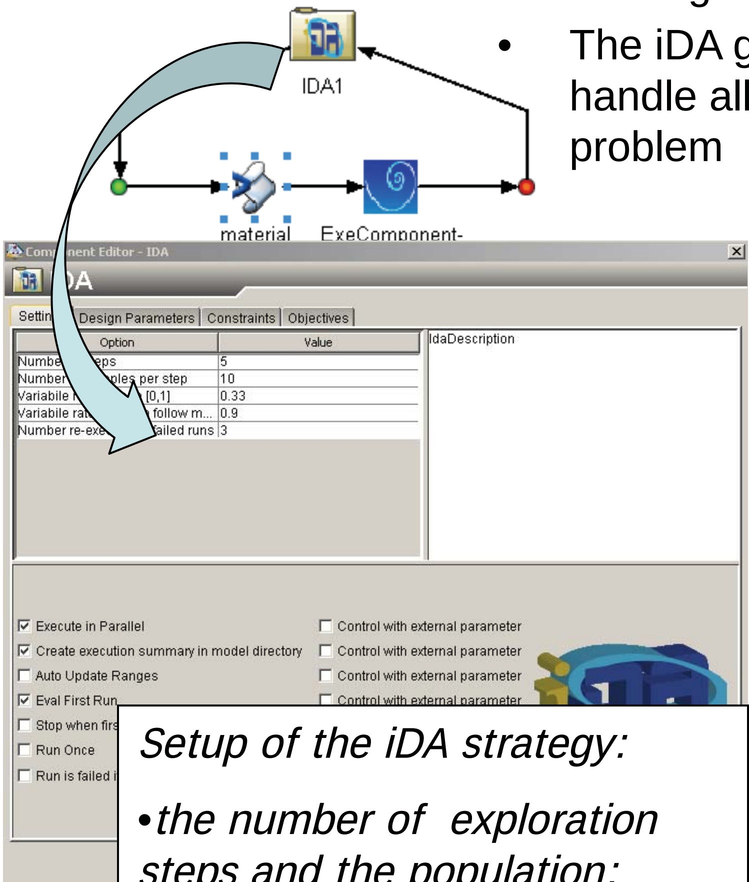
GLOBAL LAYUP SEQUENCE: the independent plies — PLY NAME	ANGLE	MATERIAL
Ply_shape_#1000	angle=0°	Mat=A
Ply_shape_#1010	angle=0°	Mat=A
Ply_shape_#1012	angle=0°	Mat=A
Ply_shape_#1020	angle=0°	Mat=A
Ply_shape_#1000	angle=0°	Mat=A
Ply_shape_#1000	angle=0°	Mat=A
Ply_shape_#2045	angle=0°	Mat=A
Ply_shape_#2044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

- iDA has a GUI to quickly setup the engineering problem.
- The iDA generic interface can handle all kind of optimization problem

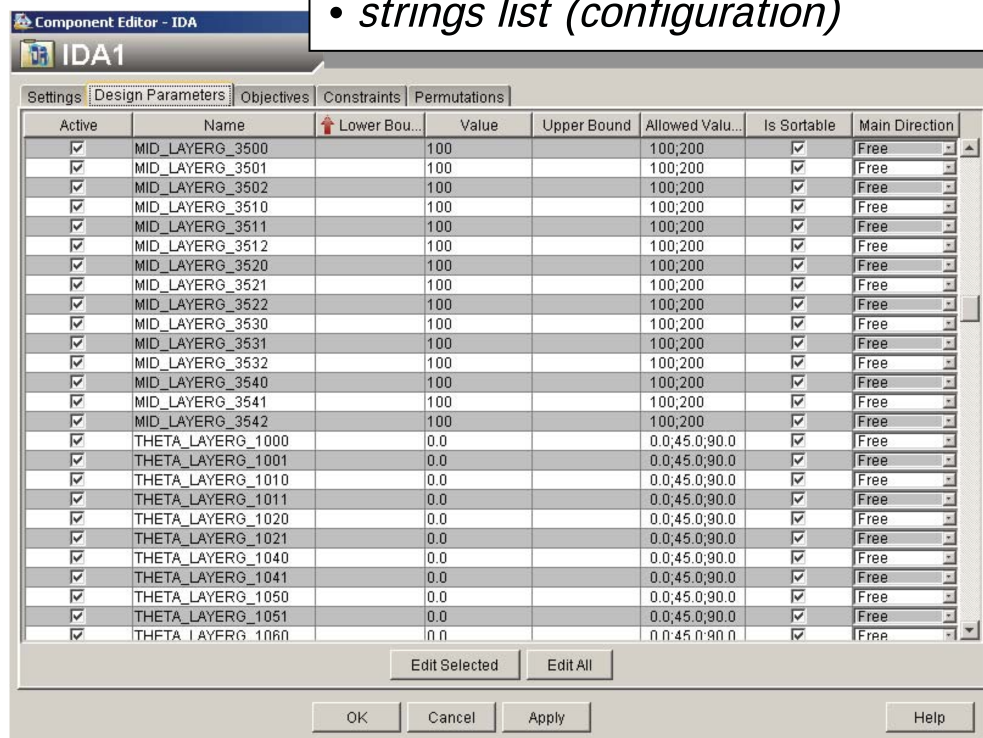


Setup of the iDA strategy:

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

Setup the iDA design parameter, allowed parameter can be:

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



The wing pylon

- **The composite weight is the 70% of the total wing pylon weight**

- **The total amount of parameters involved are <u>990</u> :**
  - **i. Number of plies in a given orientation**
  - **ii. Ply orientation angle**
  - **iii. Ply stacking sequence**
  - **iv. Ply material (e.g. Tape or Fabric)**
  - **v. Ply shape and position**

- **Objective and Constrains of the iDA:**

  Reduce the wing pylon mass of the model:

  mass < actual weight

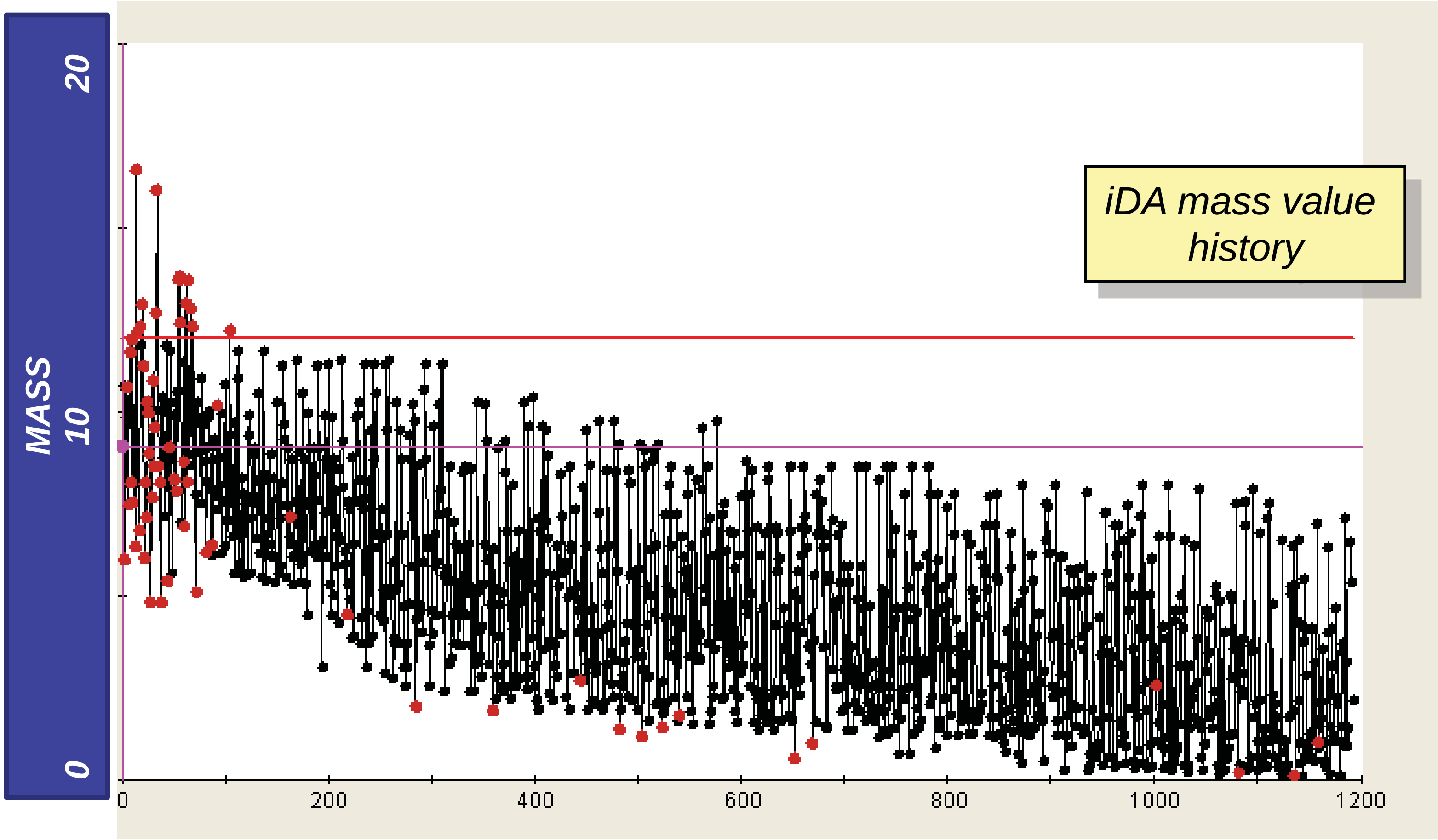
  Nastran max Failure index on the laminate [**max F.I. < 1]** :

  it has been introduced a counter of the element failing the criteria:
  the constrains are to **<u>reduce</u>** the element with F.I.>1
  - (critical element are allowed only at the pins location)

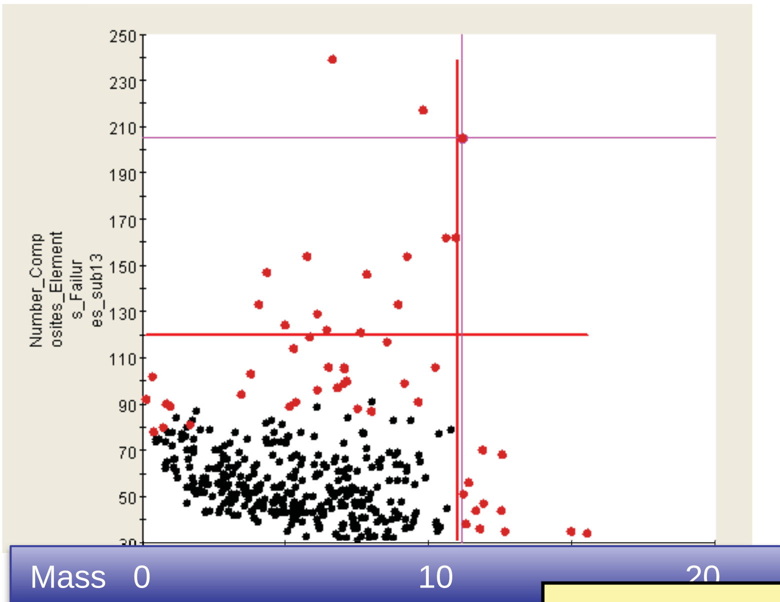
Results

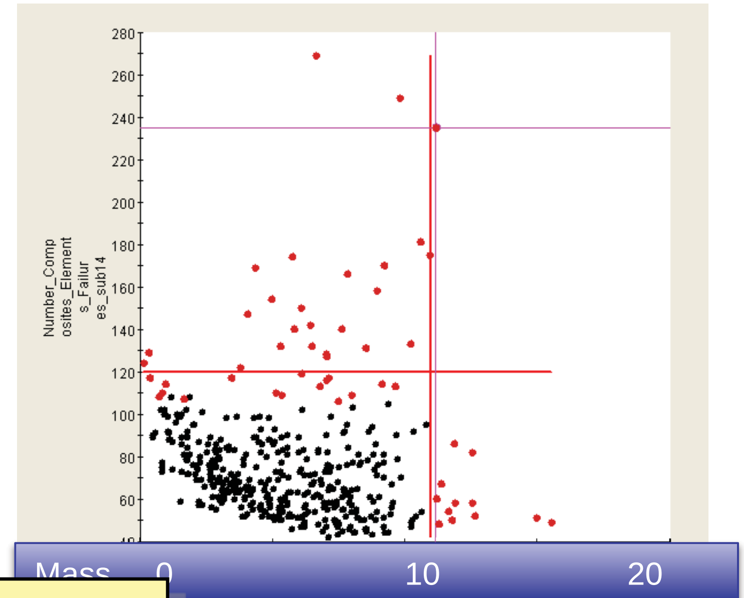
- 1200 function evaluations have been needed to reduce weight and achieve the desired target of mass and strength, starting from a heavy structure

- The final mass reduction has been of 4% of the wing pylon composite structure respect the actual design

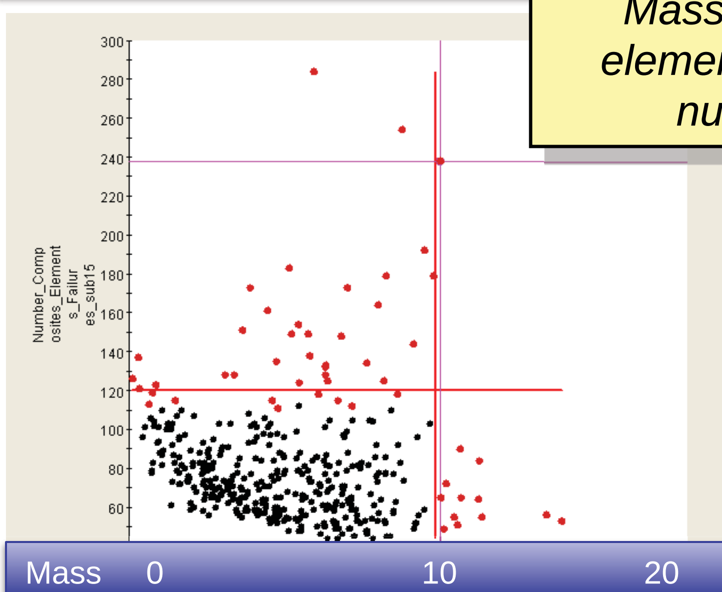


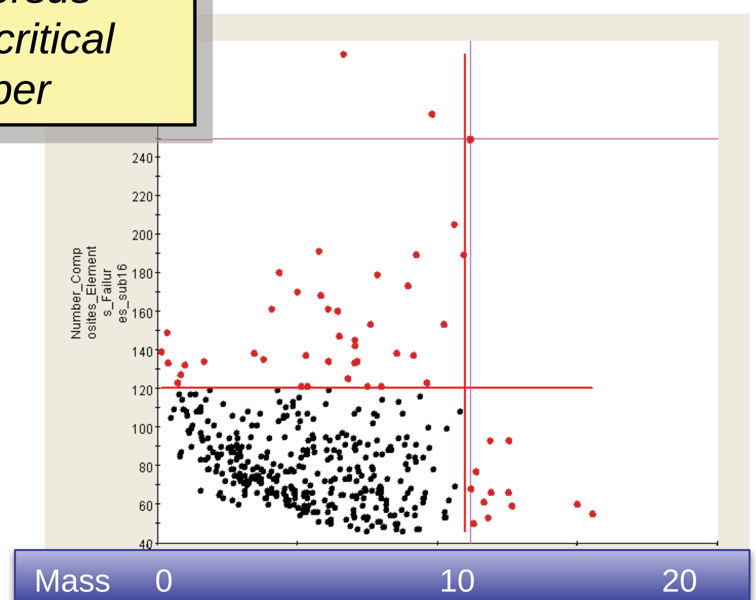
Results



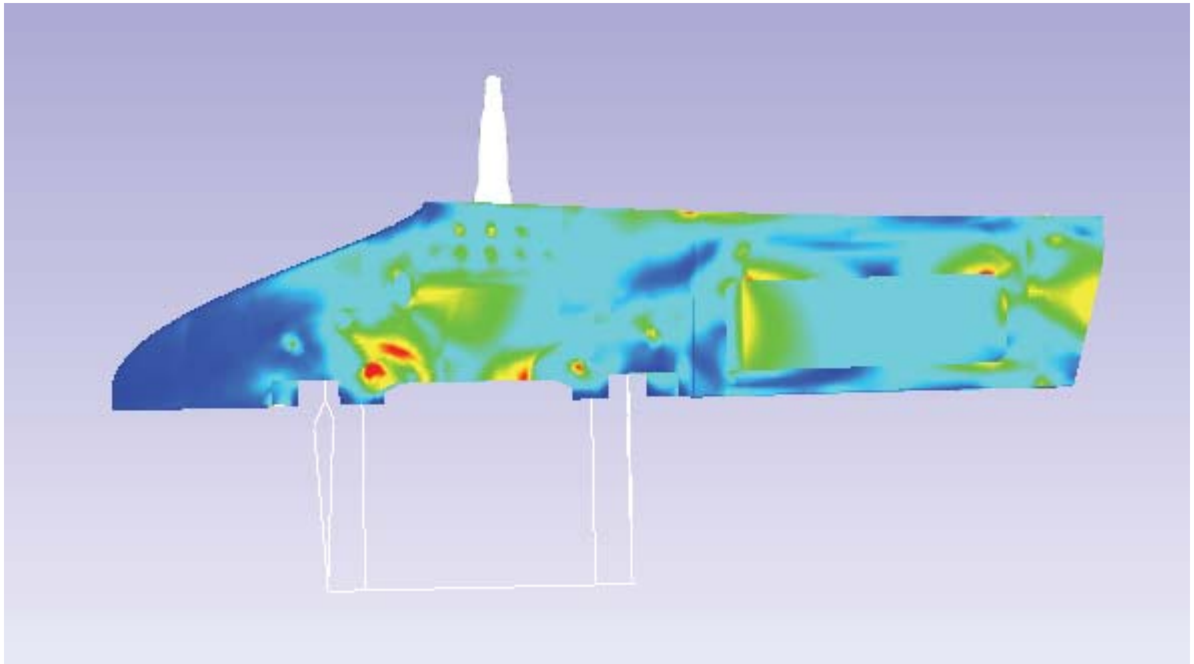


Mass versus element critical number





Results



Critical element location within the most "heavy" load condition

[(*)] Courtesy of
<u>AleniaAermacchi</u>

Conclusion

- The wing pylon has been optimized manually through many iteration, spending 2 man months of an expert engineering

- The mass reduction obtained from iDA has been of the 4% less than to the manual design, but:
  - it has been obtained automatically starting from a new structure that is 100% heavy
  - The result structure show a major strength (less critical “red zones”) due an accurate angle position

- Q&A