

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

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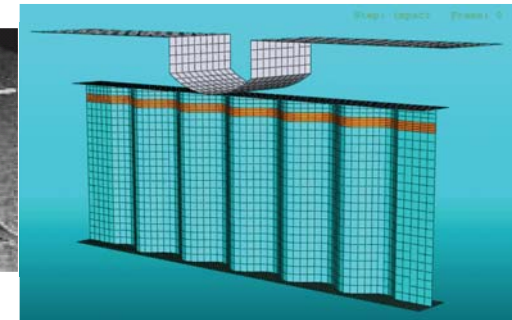
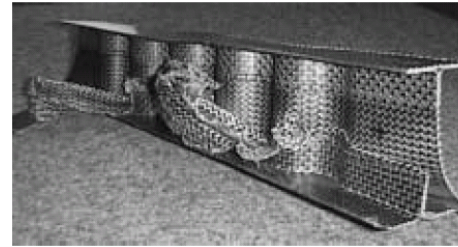
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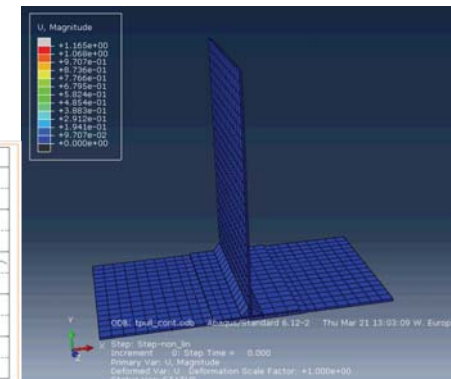
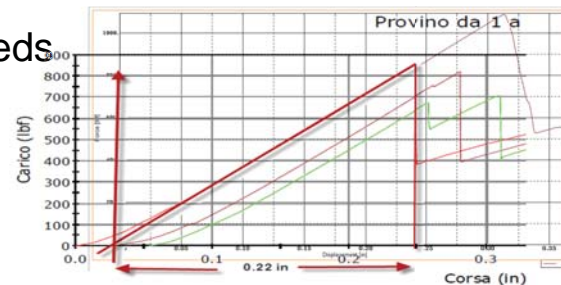
**Exemplar** supplies solutions in the field of **Computer Aided Engineering (CAE)** and **Process Integration Design Exploration & Optimization (PIDEO)** with a high added value, developing software and methodologies based on customer specific requirements  
Headquartered in **Torino (Turin), Italy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

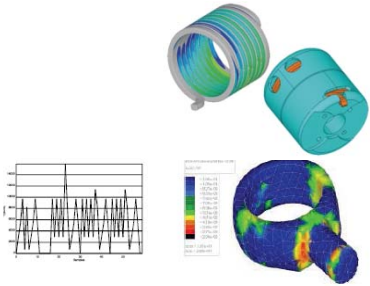


from McCarthy, M.A., Harte, CG, Wigenraad, J.F.M.,  
Michielsen, A.L.P.J., Kohlgruber, D., and Kamoulakos, A.,  
*Finite Element Modeling of Crash Response of Composite  
Aerospace Sub-floor Structures*, Computational Mechanics,  
26(3), Sept. 2000



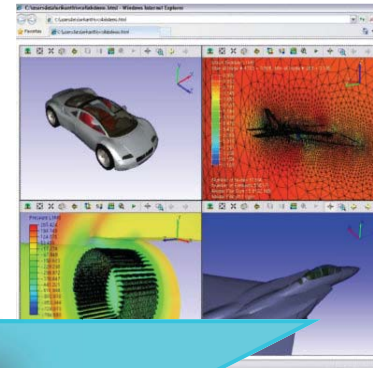
# CAE Software Sales

**fe-safe Composites**  
durability analysis software



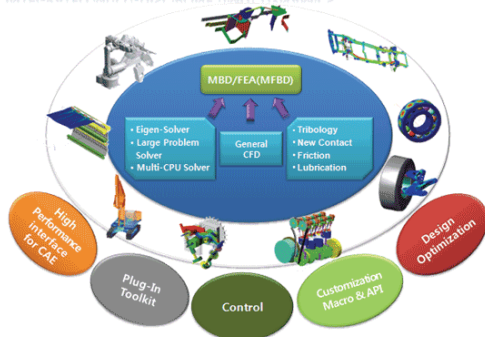
**VCollab**

Leading CAE viewing technology for SDM



**RecurDyn**  
Integrated Multi-discipline Dynamics

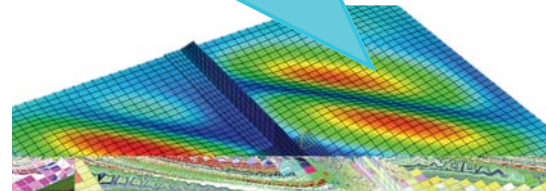
INTEGRATED MULTI-DISCIPLINE (IMD) DYNAMICS



**Abaqus | Isight | Tosca**

Leading tools for CAE & PIDEO

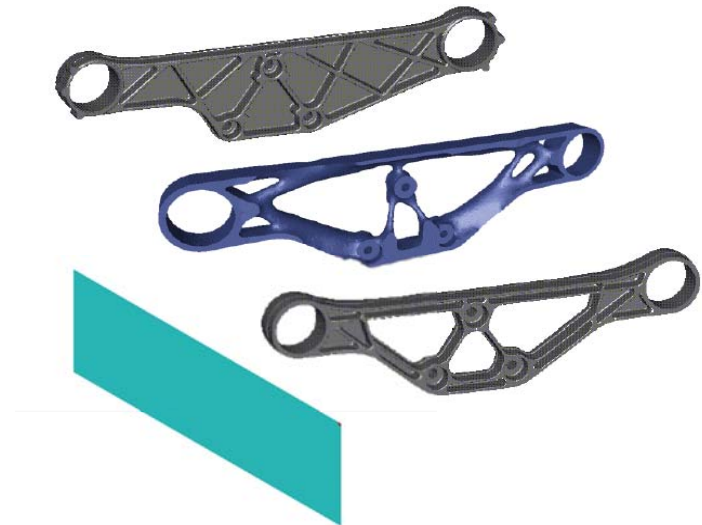
Process Integration Design Exploration & Optimizartion



## Parametric Optimization:



## Topologic Optimization:

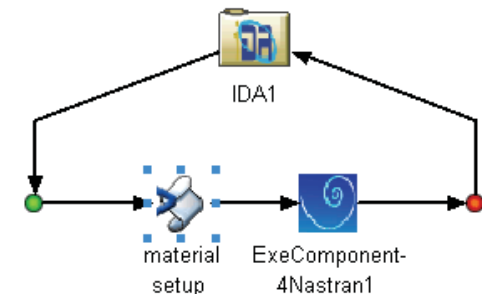


iDA [*i*ntelligent *D*ecision *A*dvisor]

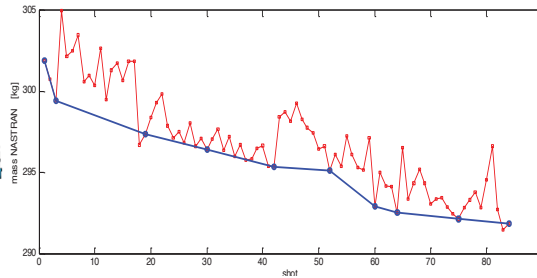
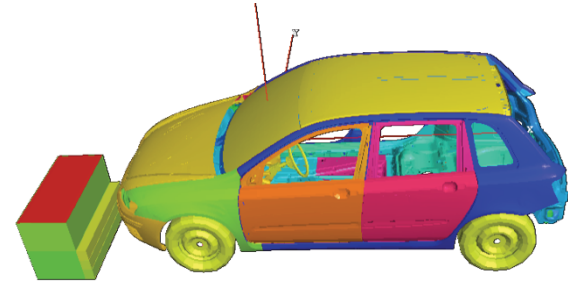




- iDA [*intelligent Decision Advisor*] software is an innovative tool that by means of intelligent explorative methods Drive the Design towards pre-established targets
- iDA is available as plugin in the iSight optimization software
- iDA in this example is used to design a new layup for a wing pylon 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 )

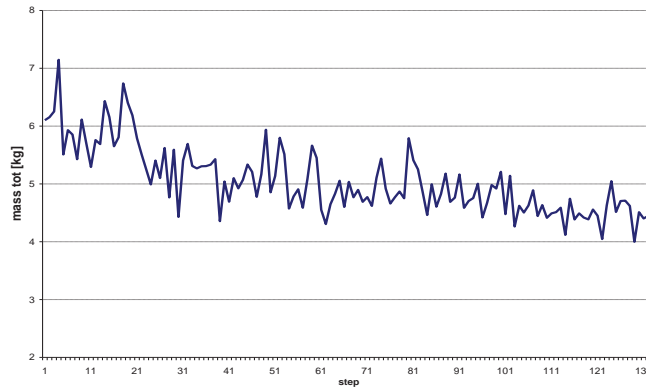
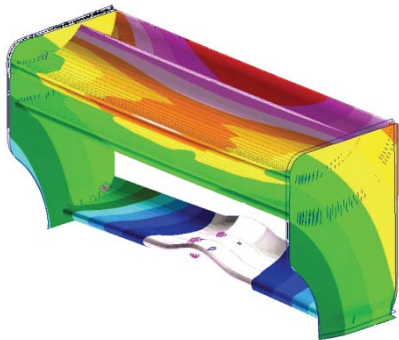






## yrs: 2002. CAR Body NVH+CRASH - Weight Reduction

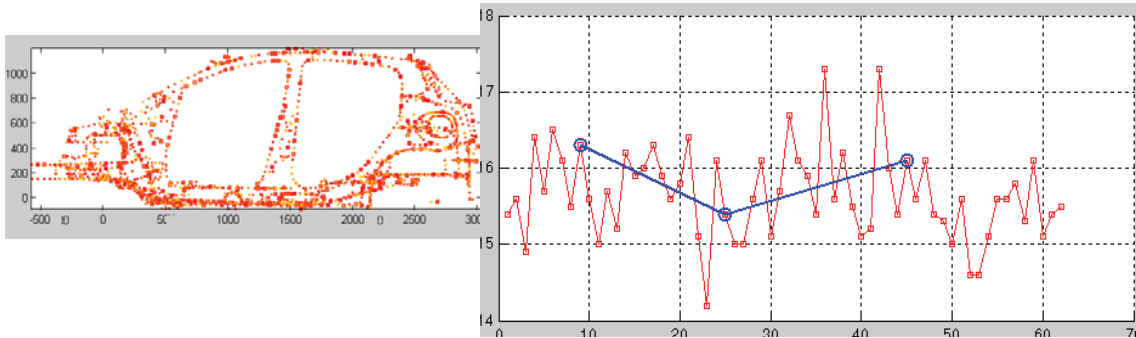
- Results & Bill:
  - 30 discrete parameters
  - 10kg , 90 function eval



## 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

MSC Patran 2009-01-09-10-11-12-13-14-15-16-17  
Patran 2009-01-09-10-11-12-13-14-15-16-17-18-19-20-21-22-23-24-25-26-27-28-29-30-31-32-33-34-35-36-37-38-39-40-41-42-43-44-45-46-47-48-49-50-51-52-53-54-55-56-57-58-59-60-61-62-63-64-65-66-67-68-69-70-71-72-73-74-75-76-77-78-79-80-81-82-83-84-85-86-87-88-89-90-91-92-93-94-95-96-97-98-99-100-101-102-103-104-105-106-107-108-109-110-111-112-113-114-115-116-117-118-119-120-121-122-123-124-125-126-127-128-129-130-131-132-133-134-135-136-137-138-139-140-141-142-143-144-145-146-147-148-149-150-151-152-153-154-155-156-157-158-159-160-161-162-163-164-165-166-167-168-169-170-171-172-173-174-175-176-177-178-179-180-181-182-183-184-185-186-187-188-189-190-191-192-193-194-195-196-197-198-199-200-201-202-203-204-205-206-207-208-209-210-211-212-213-214-215-216-217-218-219-220-221-222-223-224-225-226-227-228-229-230-231-232-233-234-235-236-237-238-239-240-241-242-243-244-245-246-247-248-249-250-251-252-253-254-255-256-257-258-259-260-261-262-263-264-265-266-267-268-269-270-271-272-273-274-275-276-277-278-279-280-281-282-283-284-285-286-287-288-289-290-291-292-293-294-295-296-297-298-299-300-301-302-303-304-305-306-307-308-309-310-311-312-313-314-315-316-317-318-319-320-321-322-323-324-325-326-327-328-329-330-331-332-333-334-335-336-337-338-339-340-341-342-343-344-345-346-347-348-349-350-351-352-353-354-355-356-357-358-359-360-361-362-363-364-365-366-367-368-369-370-371-372-373-374-375-376-377-378-379-380-381-382-383-384-385-386-387-388-389-390-391-392-393-394-395-396-397-398-399-400-401-402-403-404-405-406-407-408-409-410-411-412-413-414-415-416-417-418-419-420-421-422-423-424-425-426-427-428-429-430-431-432-433-434-435-436-437-438-439-440-441-442-443-444-445-446-447-448-449-450-451-452-453-454-455-456-457-458-459-460-461-462-463-464-465-466-467-468-469-470-471-472-473-474-475-476-477-478-479-480-481-482-483-484-485-486-487-488-489-490-491-492-493-494-495-496-497-498-499-500-501-502-503-504-505-506-507-508-509-510-511-512-513-514-515-516-517-518-519-520-521-522-523-524-525-526-527-528-529-530-531-532-533-534-535-536-537-538-539-540-541-542-543-544-545-546-547-548-549-550-551-552-553-554-555-556-557-558-559-560-561-562-563-564-565-566-567-568-569-570-571-572-573-574-575-576-577-578-579-580-581-582-583-584-585-586-587-588-589-590-591-592-593-594-595-596-597-598-599-600-601-602-603-604-605-606-607-608-609-610-611-612-613-614-615-616-617-618-619-620-621-622-623-624-625-626-627-628-629-630-631-632-633-634-635-636-637-638-639-640-641-642-643-644-645-646-647-648-649-650-651-652-653-654-655-656-657-658-659-660-661-662-663-664-665-666-667-668-669-670-671-672-673-674-675-676-677-678-679-680-681-682-683-684-685-686-687-688-689-690-691-692-693-694-695-696-697-698-699-700-701-702-703-704-705-706-707-708-709-710-711-712-713-714-715-716-717-718-719-720-721-722-723-724-725-726-727-728-729-730-731-732-733-734-735-736-737-738-739-740-741-742-743-744-745-746-747-748-749-750-751-752-753-754-755-756-757-758-759-760-761-762-763-764-765-766-767-768-769-770-771-772-773-774-775-776-777-778-779-780-781-782-783-784-785-786-787-788-789-790-791-792-793-794-795-796-797-798-799-800-801-802-803-804-805-806-807-808-809-810-811-812-813-814-815-816-817-818-819-820-821-822-823-824-825-826-827-828-829-830-831-832-833-834-835-836-837-838-839-840-841-842-843-844-845-846-847-848-849-850-851-852-853-854-855-856-857-858-859-860-861-862-863-864-865-866-867-868-869-870-871-872-873-874-875-876-877-878-879-880-881-882-883-884-885-886-887-888-889-890-891-892-893-894-895-896-897-898-899-900-901-902-903-904-905-906-907-908-909-910-911-912-913-914-915-916-917-918-919-920-921-922-923-924-925-926-927-928-929-930-931-932-933-934-935-936-937-938-939-940-941-942-943-944-945-946-947-948-949-950-951-952-953-954-955-956-957-958-959-960-961-962-963-964-965-966-967-968-969-970-971-972-973-974-975-976-977-978-979-980-981-982-983-984-985-986-987-988-989-990-991-992-993-994-995-996-997-998-999-1000-1001-1002-1003-1004-1005-1006-1007-1008-1009-1010-1011-1012-1013-1014-1015-1016-1017-1018-1019-1020-1021-1022-1023-1024-1025-1026-1027-1028-1029-1030-1031-1032-1033-1034-1035-1036-1037-1038-1039-1040-1041-1042-1043-1044-1045-1046-1047-1048-1049-1050-1051-1052-1053-1054-1055-1056-1057-1058-1059-1060-1061-1062-1063-1064-1065-1066-1067-1068-1069-1070-1071-1072-1073-1074-1075-1076-1077-1078-1079-1080-1081-1082-1083-1084-1085-1086-1087-1088-1089-1090-1091-1092-1093-1094-1095-1096-1097-1098-1099-1100-1101-1102-1103-1104-1105-1106-1107-1108-1109-1110-1111-1112-1113-1114-1115-1116-1117-1118-1119-1120-1121-1122-1123-1124-1125-1126-1127-1128-1129-1130-1131-1132-1133-1134-1135-1136-1137-1138-1139-1140-1141-1142-1143-1144-1145-1146-1147-1148-1149-1150-1151-1152-1153-1154-1155-1156-1157-1158-1159-1160-1161-1162-1163-1164-1165-1166-1167-1168-1169-1170-1171-1172-1173-1174-1175-1176-1177-1178-1179-1180-1181-1182-1183-1184-1185-1186-1187-1188-1189-1190-1191-1192-1193-1194-1195-1196-1197-1198-1199-1200-1201-1202-1203-1204-1205-1206-1207-1208-1209-1210-1211-1212-1213-1214-1215-1216-1217-1218-1219-1220-1221-1222-1223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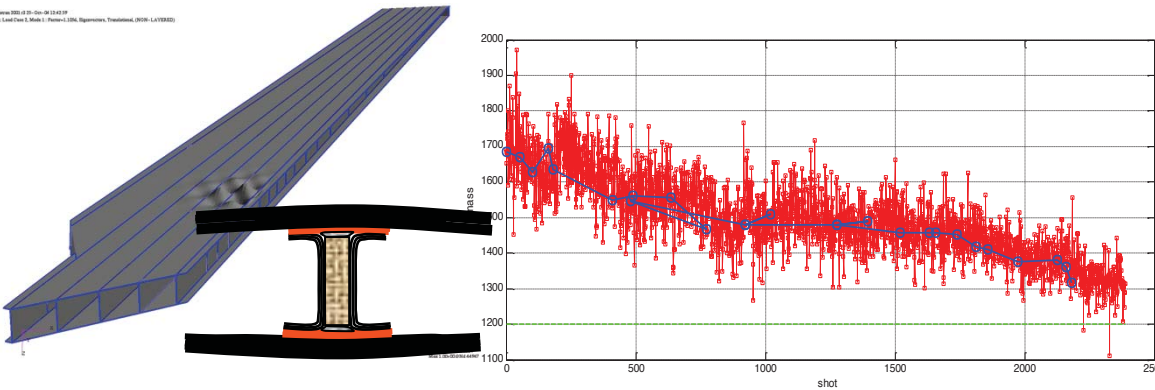
**yrs: 2004. CAR BODY**  
**NVH + Welding Robustness evaluation**

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

Results & Bill:

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

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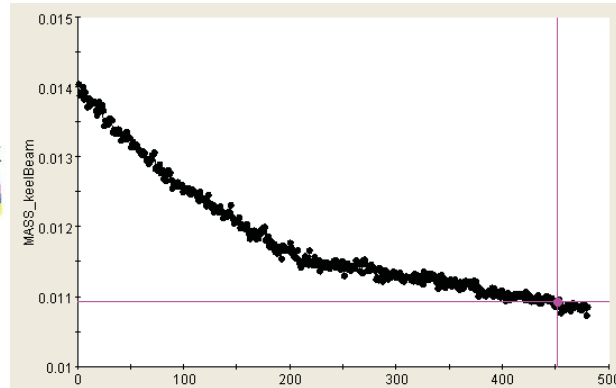
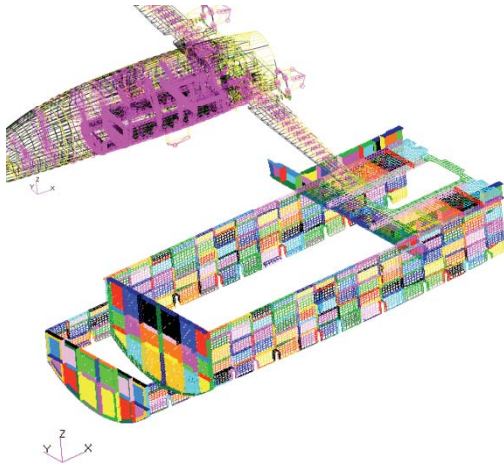


**yrs: 2006. CFRP WingBox HorzTail**  
**Structural Stiff- Weight Reduction**

- 1200 independent variables  
(plies geometry and layup stack sequence)

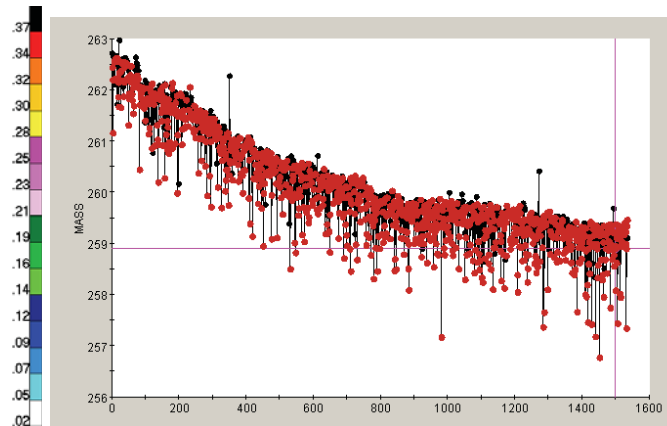
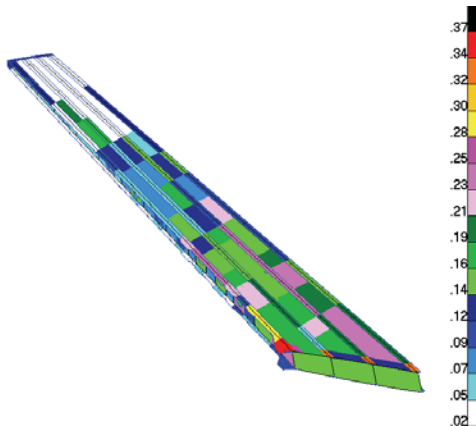
Results & Bill:

• -50lbs , 2300 function eval,  
strength improvement



yrs: 2012. Airplane metallic frame sizing  
Weight reduction

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

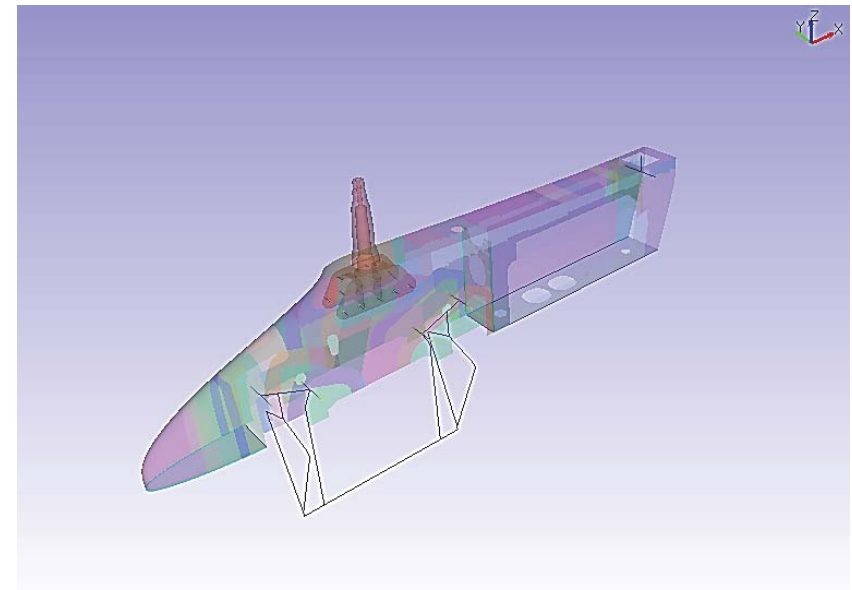


yrs: 2013. CFRP WingBox HorizTail  
Strength improvement

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



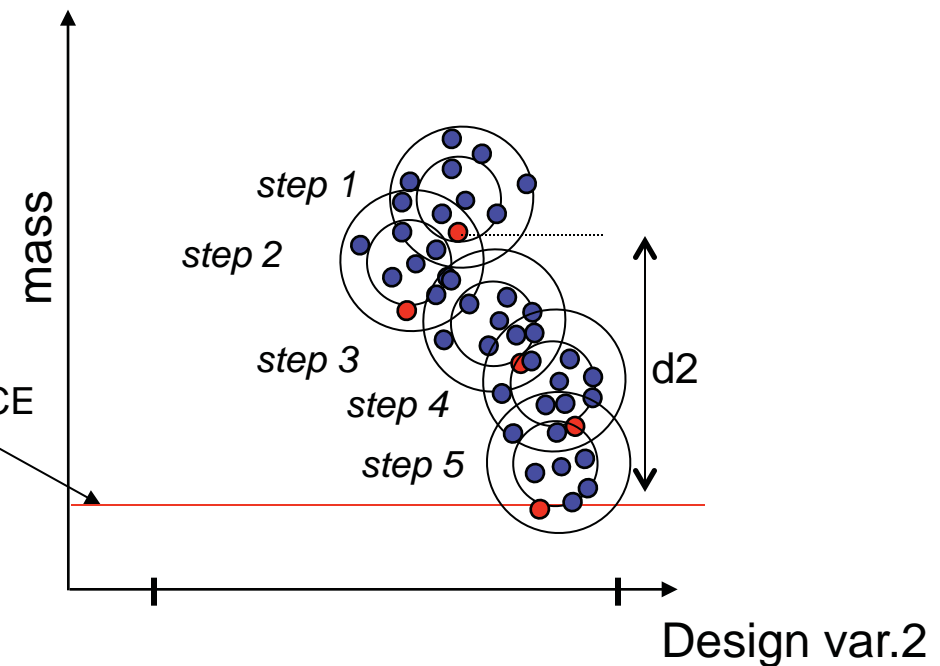
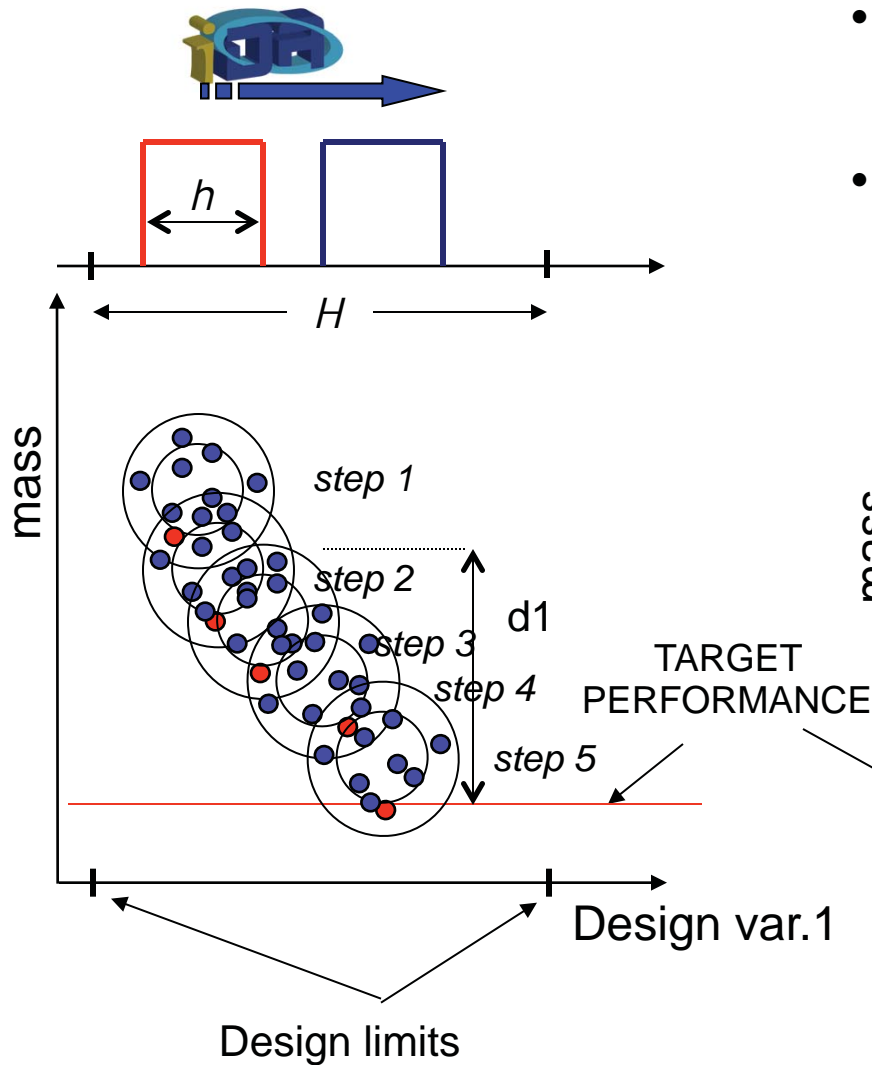
- **Manufacturing requirement**
  - Complex layup definition
- **Discrete variables**
  - geometry ply design
  - angle ply ( $0^\circ/45^\circ / 90^\circ$ ) and thickness
  - layup sequence
  - Material (tape or fabric: )
- **High number of variables (~1000)**
  - 305 different geometry plies evaluated
  - 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



- 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.

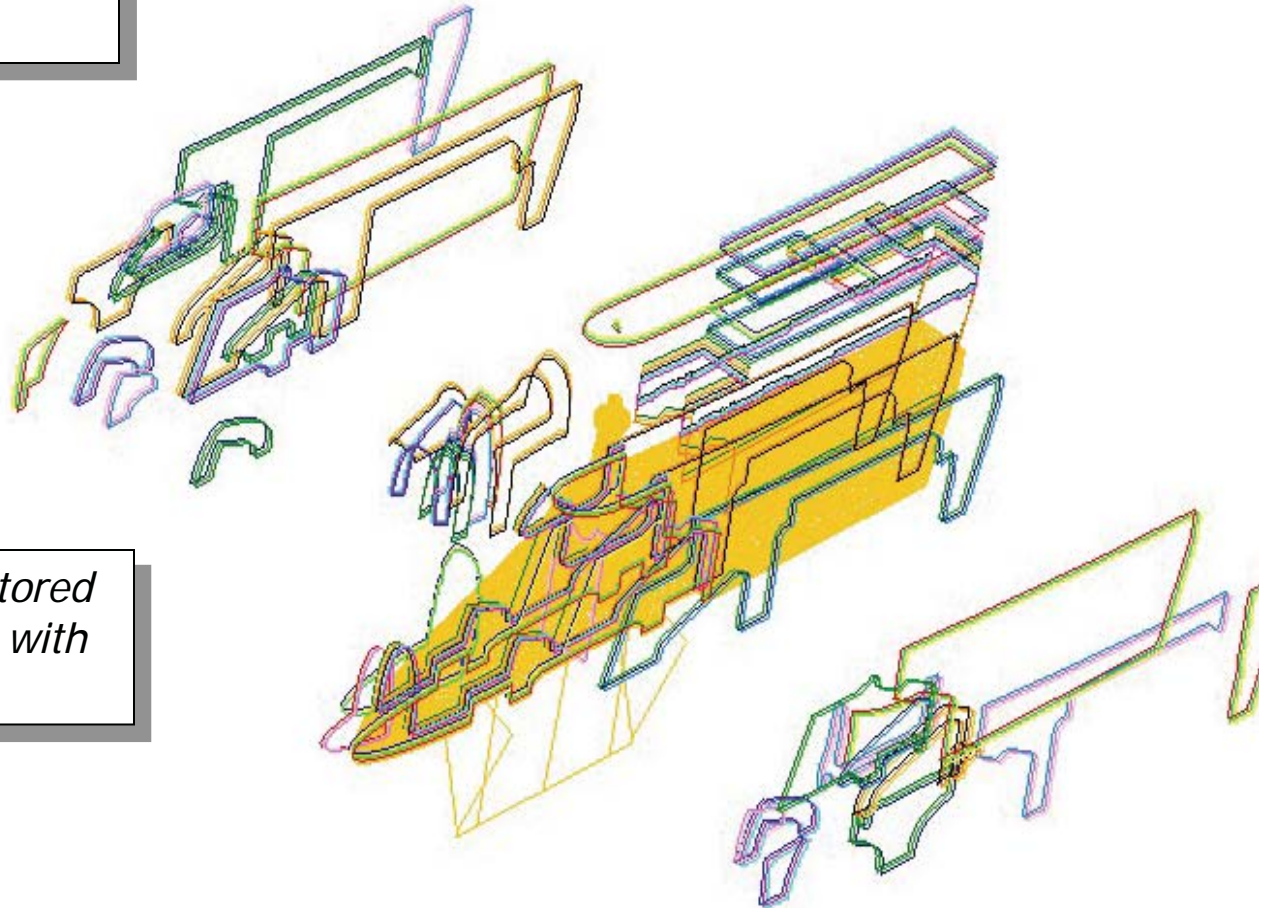
# The iDA method

- 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



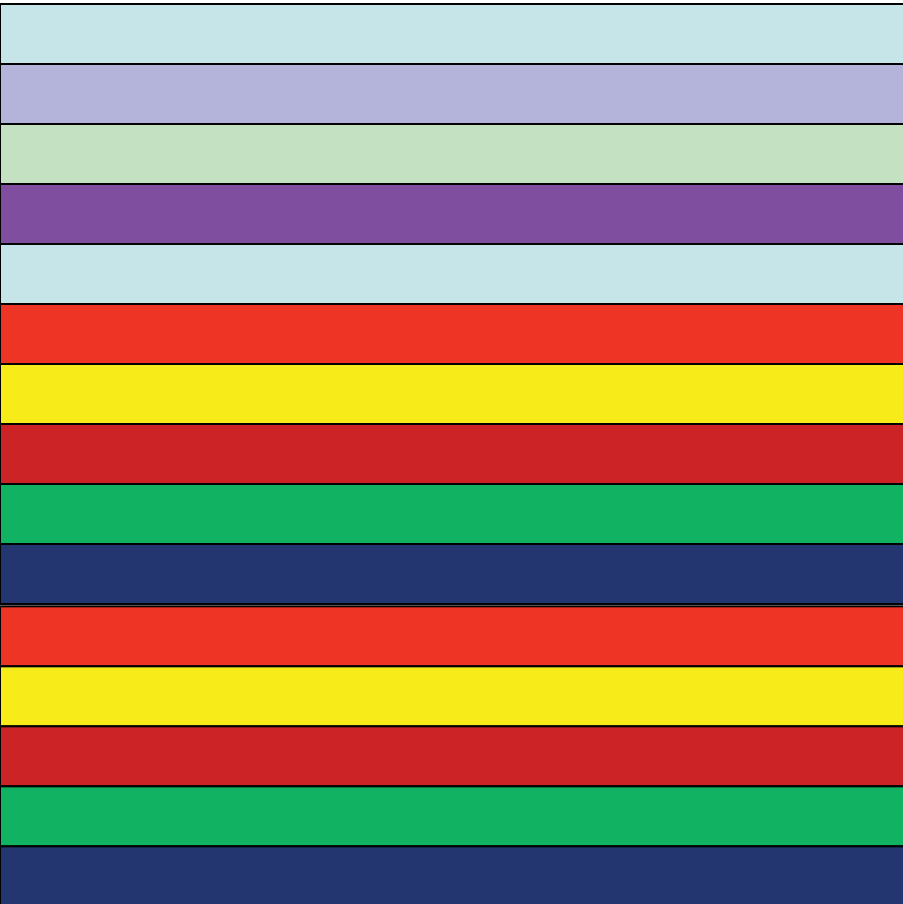
# Manufacturing description in the FEM

*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*

## GLOBAL LAYUP SEQUENCE: the independent plies



PLY NAME	ANGLE	MATERIAL
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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**

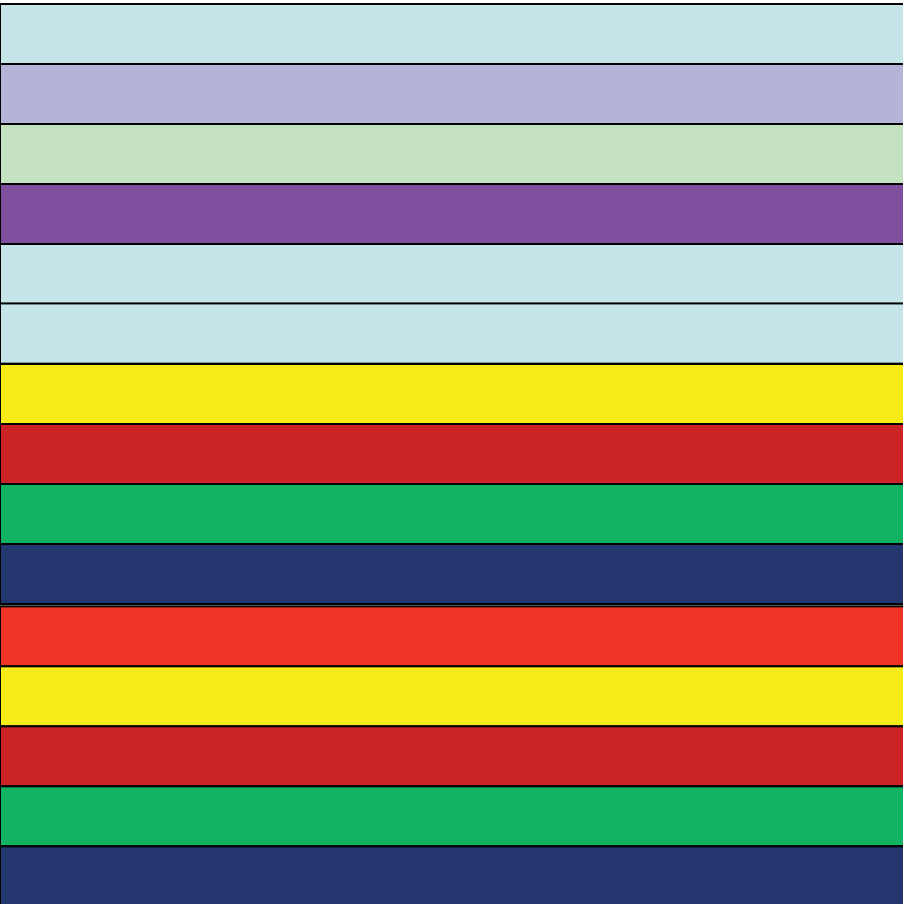


- In the composite design, iDA doesn't consider the parameter like thickness, angles or materials as cardinal numbers, but it manages them as "configuration state"
- A stochastic distance is defined for each design parameter: the ply shape, the angle and the ply material;  
the list table of all these parameters is a "configuration state"
- The Euclid distance between the configuration state and the user desired performance is automatically 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

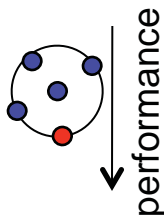
	PLY NAME	ANGLE	MATERIAL
	Ply_shape_#1000	angle=45°	Mat=A
	Ply_shape_#1010	angle=0°	Mat=B
	Ply_shape_#1012	angle=90°	Mat=A
	Ply_shape_#1020	angle=0°	Mat=C
	Ply_shape_#1000	angle=45°	Mat=C
	Ply_shape_#2040	angle=45°	Mat=A
	Ply_shape_#2045	angle=0°	Mat=B
	Ply_shape_#2044	angle=0°	Mat=A
	Ply_shape_#1072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

## 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
<del>Ply_shape_#2040</del>	<del>angle=0°</del>	<del>Mat=A</del>
Ply_shape_#2045	angle=0°	Mat=A
Ply_shape_#2044	<del>angle=0°</del>	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°	<del>Mat=A</del>
Ply_shape_#2044	angle=0°	Mat=A
Ply_shape_#1072	angle=0°	Mat=A
Ply_shape_#1045	angle=0°	Mat=A



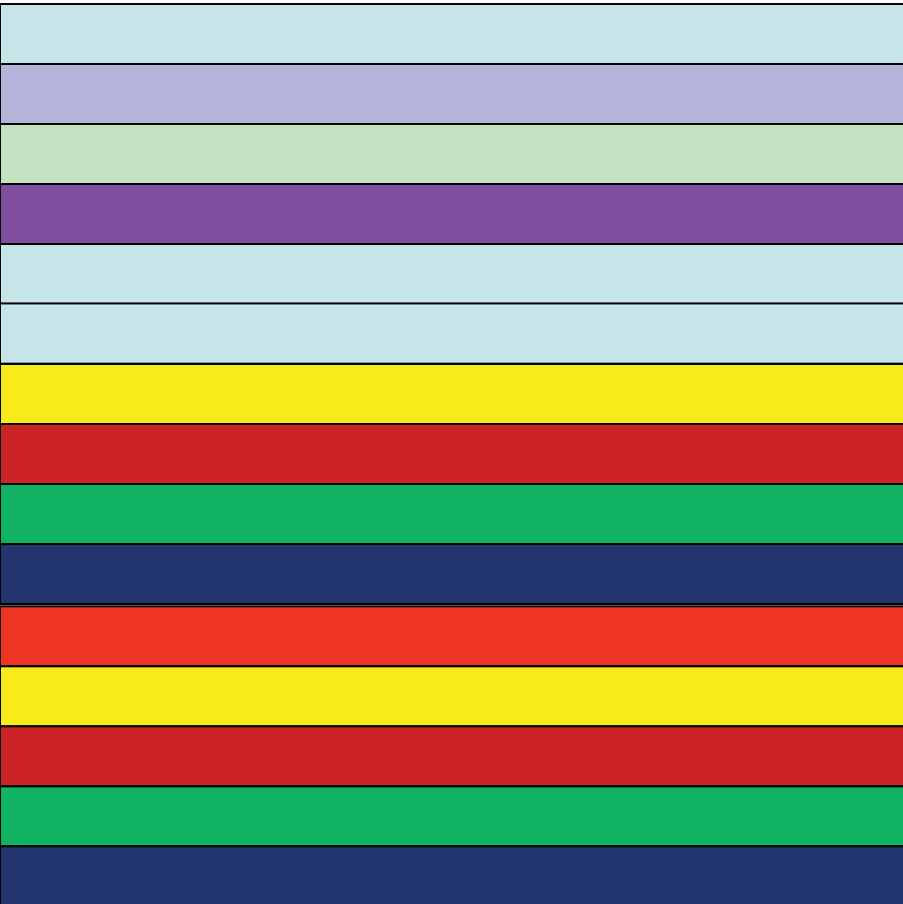
**STEP -1- : first design exploration**

- 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

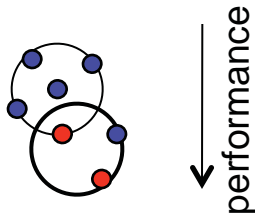
	PLY NAME	ANGLE	MATERIAL
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	Ply_shape_#1010	angle=0°	Mat=B
	Ply_shape_#1012	angle=90°	Mat=A
	Ply_shape_#1020	angle=0°	Mat=C
	Ply_shape_#1000	angle=45°	Mat=C
	Ply_shape_#2040	angle=45°	Mat=A
	Ply_shape_#2045	angle=0°	Mat=B
	Ply_shape_#2044	angle=0°	Mat=A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

## GLOBAL LAYUP SEQUENCE: the independent plies



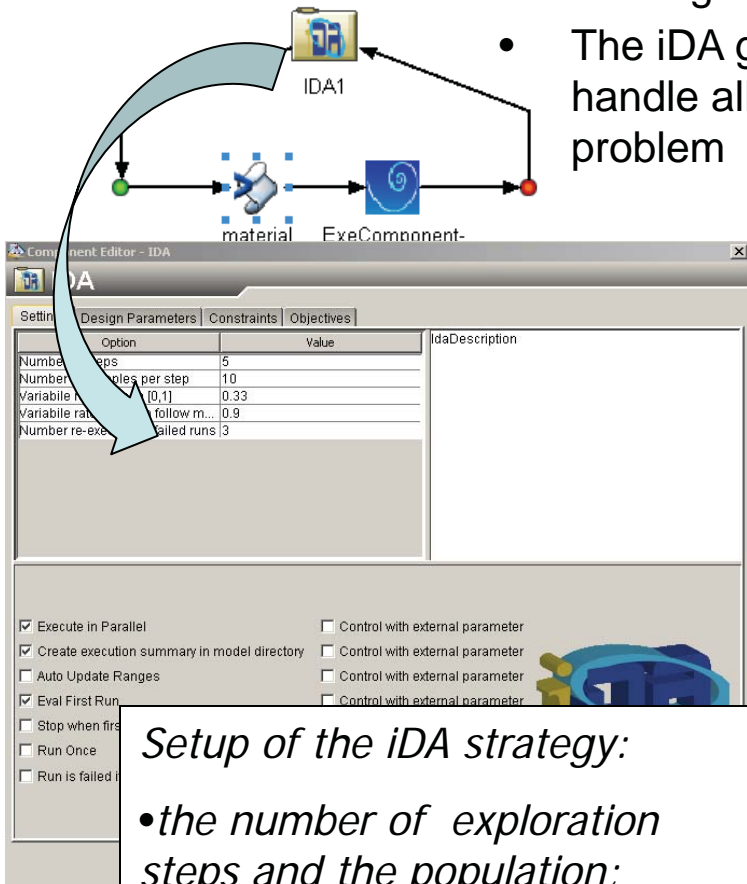
## PLY NAME ANGLE MATERIAL

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
<b>Ply_shape_#1000</b>	angle=0°	Mat=A
Ply_shape_#2045	angle=0°	Mat=A
Ply_shape_#2044	<b>angle=45°</b>	Mat=A
Ply_shape_#1072	angle=0°	Mat=A
Ply_shape_#1045	<b>angle=90°</b>	Mat=A
Ply_shape_#2040	angle=0°	Mat=A
Ply_shape_#2045	angle=0°	<b>Mat=C</b>
Ply_shape_#2044	angle=0°	Mat=A
Ply_shape_#1072	angle=0°	Mat=A
Ply_shape_#1045	angle=0°	Mat=A



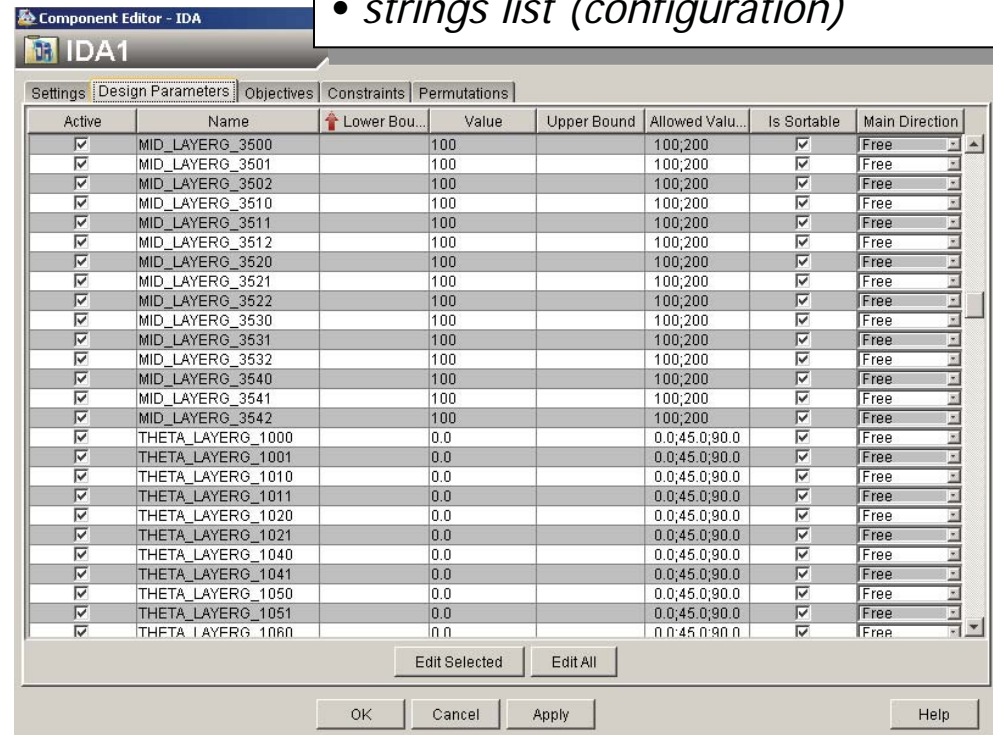
**STEP -2- : next step design exploration**

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



*Setup the iDA design parameter, allowed parameter can be:*

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



*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*



- **The composite weight is the 70% of the total wing pylon weight**
- **The total amount of parameters involved are 990 :**
  - 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:**

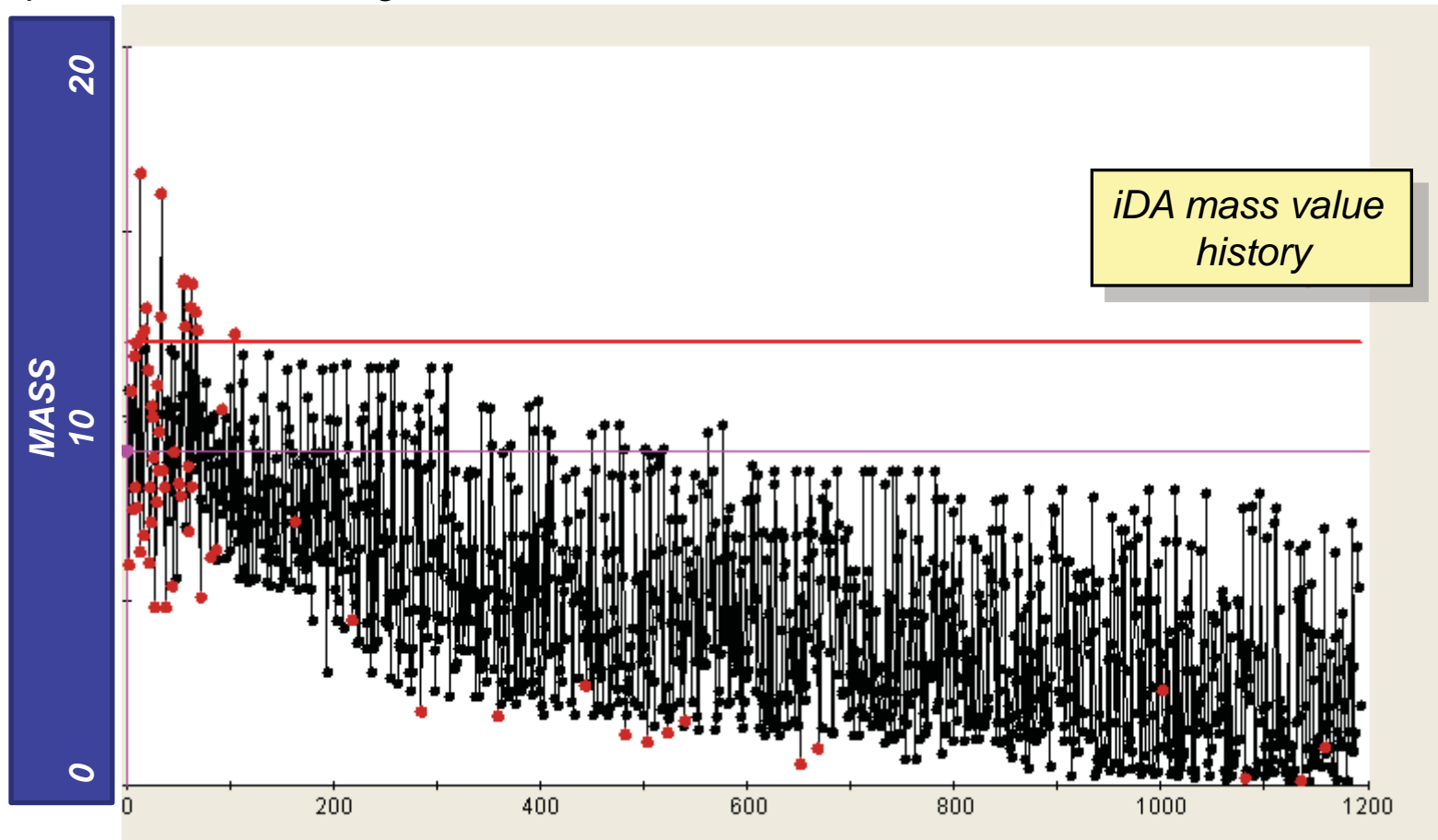
Reduce the wing pylon mass of the model:  
 $\text{mass} < \text{actual weight}$

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

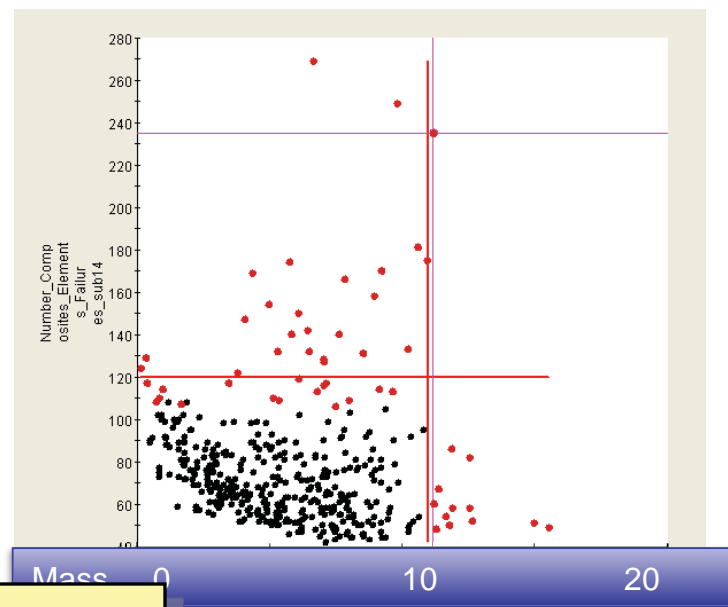
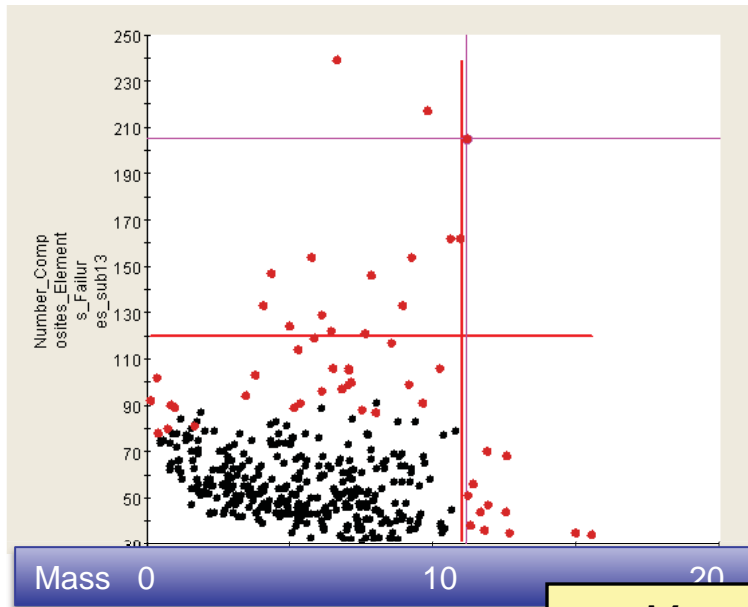
it has been introduced a counter of the element failing the criteria:  
the constrains are to **reduce** the element with  $\text{F.I.} > 1$

  - (critical element are allowed only at the pins location)

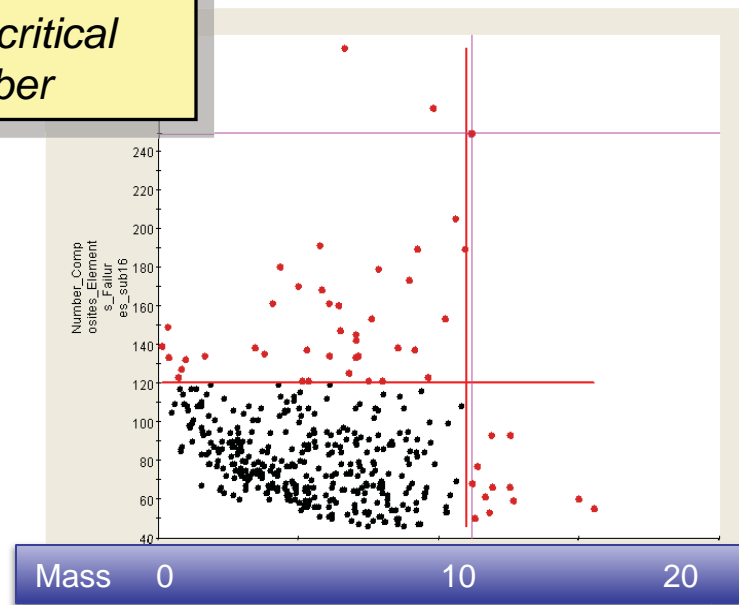
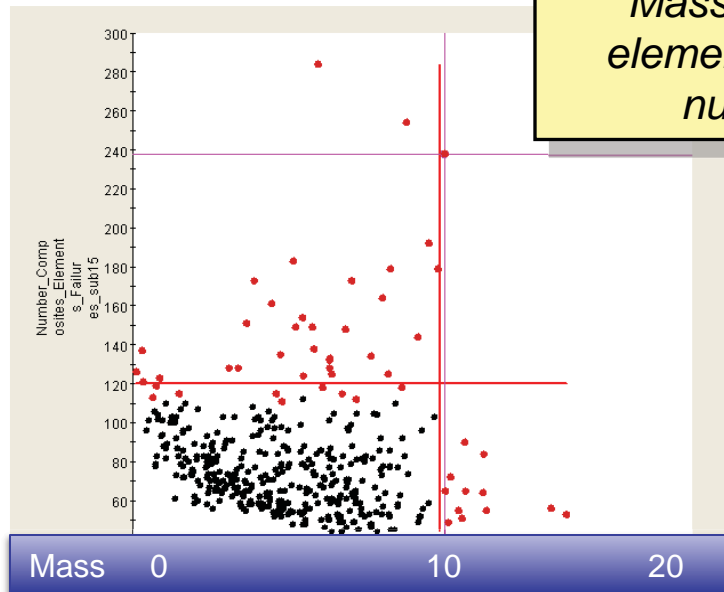
- 1200 function evaluations have been needed to reduce weight and achieve the desired target of mass and strength, starting from a heavy structure
- The final mass reduction has been of 4% of the wing pylon composite structure respect the actual design



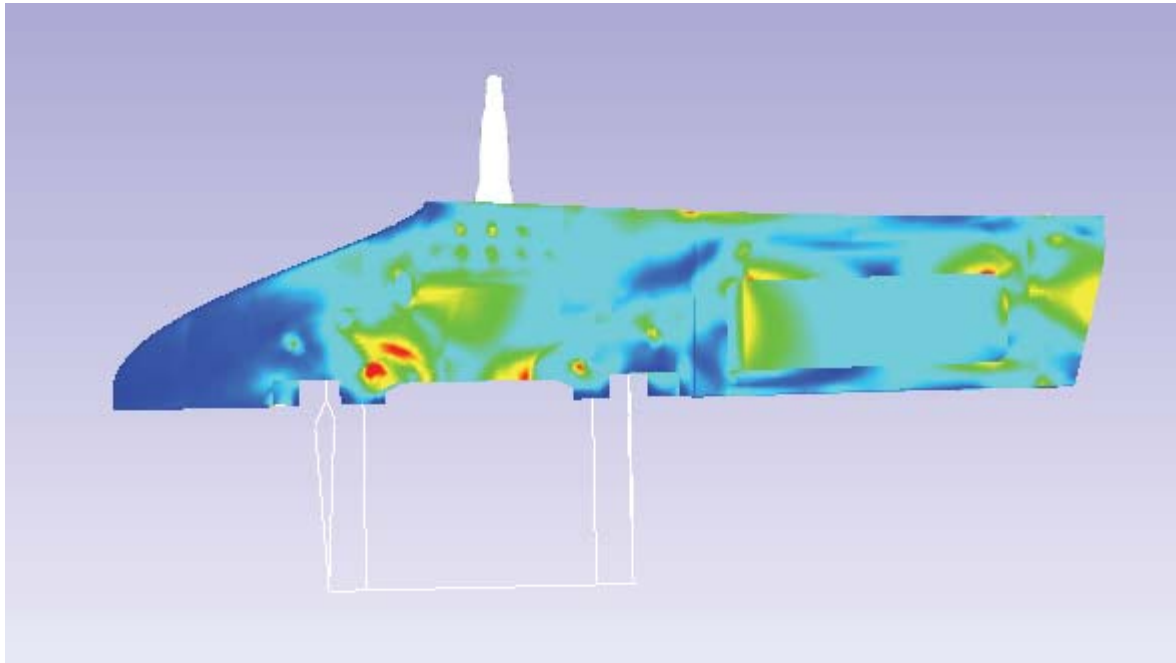
# Results



*Mass versus  
element critical  
number*



# Results



*Critical element location within the most  
“heavy” load condition*

# 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