Metodi e strumenti di calcolo per la prototipazione virtuale: l'analisi multibody e multidisciplinare

Adams: Automatic Dynamic Analyis of Mechanical Systems

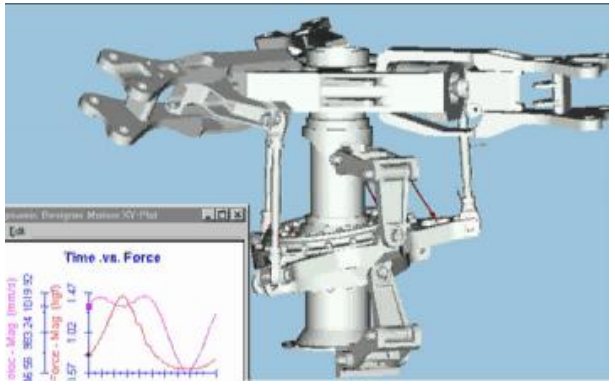
Daniele Catelani

Senior Project Manager MSC Software

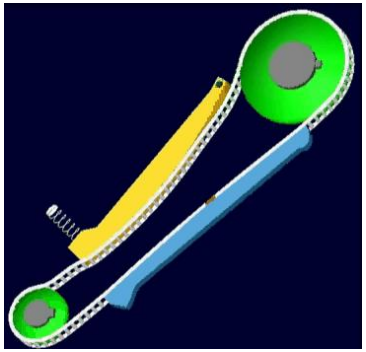
MSC Software

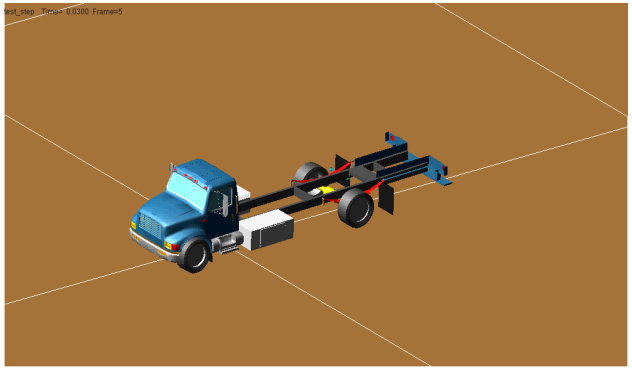
Introduzione alla dinamica dei sistemi *multi-body*

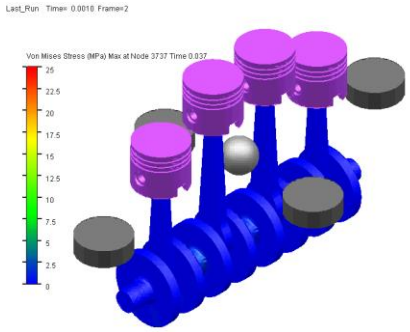
Definizione di sistema *Multi-Body*



- Sistema di parti meccaniche rigide / flessibili
- Interconnesse da giunti rigidi / elastici
- Soggette a qualsiasi sistema di forze
- Compiono grandi spostamenti nello spazio 3D





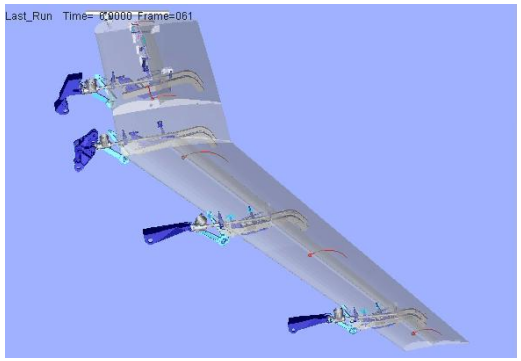


Introduzione alla dinamica dei sistemi *multi-body*

Definizione di sistema *Multi-Body*

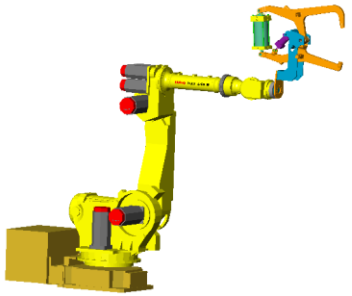
- Dinamica descritta da equazioni differenziali
- Vincoli descritti da equazioni algebriche

➔ Sistema di equazioni DAE non-lineare



Risoluzione di tipo numerico

- Integratori ODE
  (Ordinary Differential Equations)
- Integratori DAE
  (Differential Algebraic Equations)



Introduzione alla dinamica dei sistemi *multi-body*

Basic Concepts

- Rigid Bodies:
  - Use 6 coordinates to represent rigid body location
  - Represent inertia forces in termes of 6 displacements, 6 velocities, 3 angular momenta
- Flexible Bodies:
  - 6 rigid body + m flexible modal coordinates
- Constraints:
  - An algebraic relationship that the generalized coordinates must satisfy
  - The constraint imposes a force that prohibits some motion along/around some direction
  - This force is known as a Lagrange Multiplier (λ)
- Degrees of Freedom:
  - The minimum number of generalized coordinates required to completely specify the configuration of a system
  - System characterized by *n* generalized coordinates *q*, and, *m* constraints, Φ, has $f = (n-m)$ dof
  - n coordinates q, and m variables λ = (n+m) variables

Introduzione alla dinamica dei sistemi *multi-body*

Basic Concepts

- Constraint Classification:
  - Holonomic Constraints: $\Phi(q,t) = 0$
    - Scleronomic Constraints: $\Phi(q) = 0$
      - No explicit dependence on time
    - Rheonomic Constraints: $\Phi(q,t) = 0$
      - Explicit dependence on time
  - Non-holonomic Constraints:
    - Constraint can only be expressed in terms of differentials

rev $\left\langle (\vec{R}_i + \vec{r}_i) - (\vec{R}_j + \vec{r}_j),\quad \hat{z}_i \perp \hat{x}_j,\quad \hat{z}_i \perp \hat{y}_j \right\rangle$

tra $\left\langle (\vec{R}_i + \vec{r}_i) - (\vec{R}_j + \vec{r}_j) \perp \hat{x}_j,\quad (\vec{R}_i + \vec{r}_i) - (\vec{R}_j + \vec{r}_j) \perp \hat{y}_j,\quad \hat{z}_i \perp \hat{x}_j,\quad \hat{z}_i \perp \hat{y}_j,\quad \hat{x}_i \perp \hat{y}_j \right\rangle$

mot $(\vec{R}_i + \vec{r}_i) - (\vec{R}_j + \vec{r}_j) \perp \hat{z}_j - f(t) = 0$

$$\sum A_{ij}(q)\,\dot{q}_i + A_{it} = 0$$

- Redundant Constraints:
  - The constraints $\Phi(q)$ are not independent
  - A redundant constraint cannot impose any reaction force (λ=0)
  - Typically eliminated from equation set

Introduzione alla dinamica dei sistemi *multi-body*

Basic Concepts

- Kinematics:
  - Study of motion of a system without regard to motivating forces
  - All degrees of freedom are prescribed as functions of time
  - Forces cannot affect motion
  - Forces calculated as a consequence of motion
  - Displacement, Velocity, Acceleration and Reaction force solution is algebraic in nature
  - No need to solve differential equations

- Statics:
  - Study of equilibria of a system without regard to inertia forces or velocity dependent forces
  - System velocities and accelerations are zero at each configuration
  - Force affects configuration only
  - Governing equations are algebraic in nature

Introduzione alla dinamica dei sistemi *multi-body*

Basic Concepts

- Dynamics:
  - Study of motion of a system as a consequence of applied forces and inertia forces
  - Forces affect accelerations
  - Accelerations are integrated to velocities
  - Velocities are interated to give displacements
  - 2nd order differential equations are to be solved

- Linear Analysis:
  - Study of the modes of vibration of a system at any specified operating point: $q = q^*, u = u^*$
  - Equations of motion are linearized about operating point to get
    - $M\dot{u} + Cu + Kq = 0$

      $u - \dot{q} = 0$
    - M, C, K are constant matrices
  - Vibration mode shapes and frequencies are analyzed by solving the associated eigenvalue problem

Introduzione alla dinamica dei sistemi *multi-body*

General Overview about Multibody/Xstiff Solver

Formulation of the Equations

Differential Equations (DE) are in Nature of 2nd Order

Order Reduction to DE of 1st Order with additional Velocity Equations

↓

Integration of the Equations

Differential Operators dq/dt are replaced by Difference Operators $\Delta q/\Delta t$, to transform the DE in a Set of Nonlinear Equations

The Nonlinear Equations are solved with a modified Newton Raphson Method

Introduzione alla dinamica dei sistemi *multi-body*

Basic Concepts

- Implementation of Euler-Lagrange-Equations in ADAMS for a Rigid Body :

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \left(\frac{\partial L}{\partial q_i}\right) - Q + \sum_{k=1}^{m}\left(\frac{\partial \Phi_k}{\partial q_i}\right)\lambda_k = 0 \qquad \text{(Eqn.1)}$$

with:

L	=	T-V = kinetic energy of the system - potential energy
q	=	generalized coordinates of the system
Φ	=	constraint function
λ	=	Lagrange-multiplicators
Q	=	generalized external loads
m	=	number of constraint equations
I	=	1,2,..,5,6 (translational and rotational components

Introduzione alla dinamica dei sistemi *multi-body*

Basic Concepts

Equation Formulation: Dynamics

$$\dot{p} - \partial L / \partial q + \phi_q^T \lambda - H^T F = 0 \quad \rightarrow \quad \textit{Differential Equation}$$

$$p - \partial L / \partial \dot{q} = 0 \quad \rightarrow \quad \textit{Momenta Definition}$$

$$u - \dot{q} = 0 \quad \rightarrow \quad \textit{Differential Equation}$$

$$\phi(q,t) = 0 \quad \rightarrow \quad \textit{Constraint Equation}$$

$$F - f(q,u,t) = 0 \quad \rightarrow \quad \textit{Force Definition}$$

Introduzione alla dinamica dei sistemi *multi-body*

Solution of DAE

$$Solve\ the\ DAE:\ G(y,\dot{y},t)=0, y(0)=y_0$$

Phase 1: Predict an initial guess

$$y_{n+1}^{p}=\sum_{i=0}^{k}\frac{h^i y_n^{(i)}}{i!},\quad k=integration\ order$$

$$y_{n+1}=\sum_{i=1}^{k}\alpha_i y_{n-i+1}+h\beta_0\dot{y}_{n+1}$$

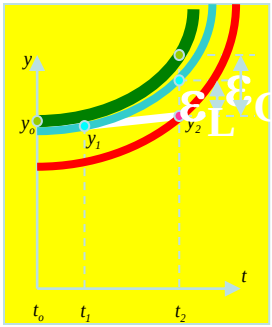
Phase 2: Correct the guess

$$\left[\frac{\partial G}{\partial y}+\frac{1}{h\beta_0}\frac{\partial G}{\partial \dot{y}}\right]\Delta y=-G$$

$$y^{(new)}=y^{(old)}+\Delta y$$

Phase 3: Evaluate quality of solution (accept solution)

$$\|\Delta y\|\le corrector\ \ error\ tolerance$$



Phase 4: Prepare for next step

Introduzione alla dinamica dei sistemi *multi-body*

Basic Concepts

- Displacement, velocities, accelerations, reaction forces: Jacobian matrix evaluation

$$\Phi(q,t) = 0$$

$$\dot{\Phi}(q,\dot{q},t) = \left[\frac{\partial \Phi}{\partial q}\right]\dot{q} + \frac{\partial \Phi}{\partial t} = 0$$

$$\left[\frac{\partial \Phi}{\partial q}\right]\dot{q} = -\frac{\partial \Phi}{\partial t} \quad or \quad \dot{q} = -\left[\frac{\partial \Phi}{\partial q}\right]^{-1}\frac{\partial \Phi}{\partial t}$$

- The constraints are nonlinear algebraic equations
  - Need to use an iterative method to solve for the *q's*
  - Newton-Raphson Method

Introduzione alla dinamica dei sistemi *multi-body*

Basic Concepts

- Newton-Raphson method
  - From initial guess, find solution of non linear system

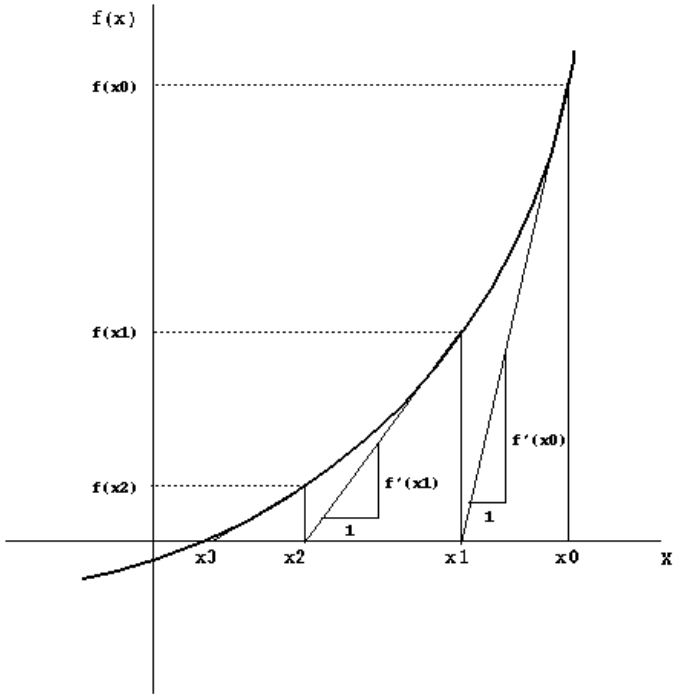
$$f(x) = 0$$

$$x^{(1)} = x^{(0)} - \frac{f(x^{(0)})}{f'(x^{(0)})}$$

$$x^{(2)} = x^{(1)} - \frac{f(x^{(1)})}{f'(x^{(1)})}$$

$$x^{(3)} = x^{(2)} - \frac{f(x^{(2)})}{f'(x^{(2)})}$$

$$\dots$$



Introduzione alla dinamica dei sistemi *multi-body*

Basic Concepts

- Quasi Newton-Raphson method
  - The same derivative is used for several iteration

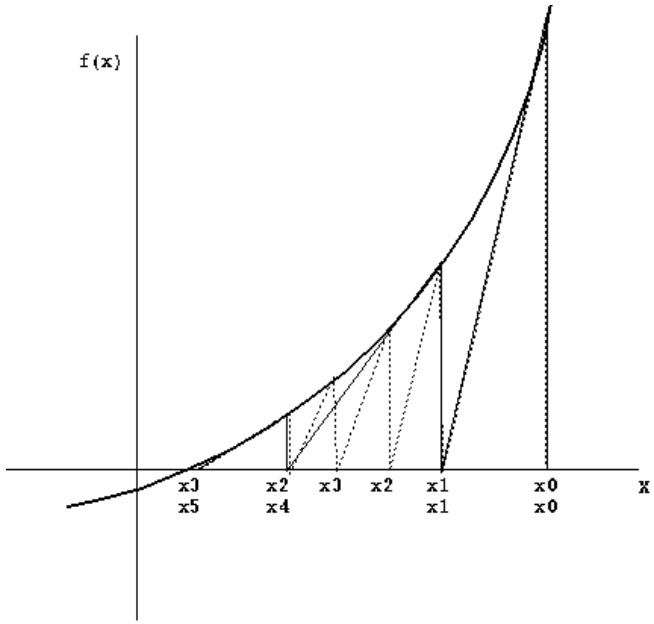
$$x^{(1)} = x^{(0)} - \frac{f(x^{(0)})}{f'(x^{(0)})}$$

$$\dots$$

$$x^{(4)} = x^{(3)} - \frac{f(x^{(3)})}{f'(x^{(0)})}$$

$$x^{(5)} = x^{(4)} - \frac{f(x^{(4)})}{f'(x^{(4)})}$$

$$\dots$$



Introduzione alla dinamica dei sistemi *multi-body*

Definizione di sistema *Multi-Body*

- Corpo Rigido
- Corpo Flessibile
  - lineare (modale)
  - nonlineare

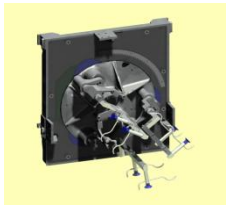
- Vincoli
  - Connessioni
  - Equazioni
  - Leggi di moto
  - Bushing
  - Beam
  - Field

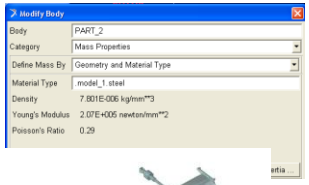
- Forze
  - Elastiche/Viscose
  - Aerodinamiche/Fluidodinamiche
  - Attuazione (elettrica, pneumatica,…)
  - Attrito
  - Contatto
  - Termiche

- Misure f(tempo, frequenza)
  - Spostamenti (CM, punti, origine,…)
  - Velocità (CM, punti, origine,…)
  - Accelerazioni (CM, punti, origine,…)
  - Forze applicate
  - Forze di Reazione
  - Frequenze proprie (modi)

Il codice di calcolo *multi-body*

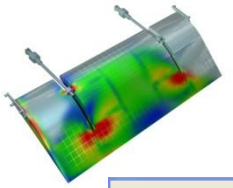
ADAMS
Automated Dynamic Analysis of Mechanical System

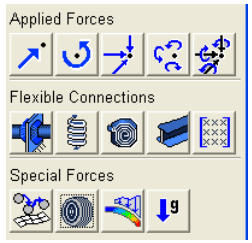


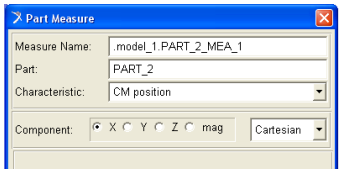


DataSet

❖ Rigid Body	Location, Orientation, Mass, CM, Density Material properties, Initial Velocity, Geometry
❖ Flexible Body	Location, Orientation, Flexible Data, Damping
❖ Marker	Location, Node Id, Orientation, Type
❖ Constraint	Joint (Revolute, Translational, Cylindrica, Planar,…) Jprim (Inplane, Inline, Perpendicular, Orientation,…) Higher Level (Gear, Coupler, Ptcv, Cvcv,…).
❖ Motion	Function (analytical, experimental, user)
❖ Force	Beam, Bushing, Field, SpringDamper, Gravity,Tire… Single Component, Vector, General Force
❖ Data	String, Spline, State Variable, Matrix, Curve, Array,...
❖ Equations	Differential, LSE, GSE, Transfer Function,…
❖ Measures	Position, Velocity, Acceleration, Force, Energy,…
❖ Solver	Dynamics, Equilibrium, Kinematic Parameters,...







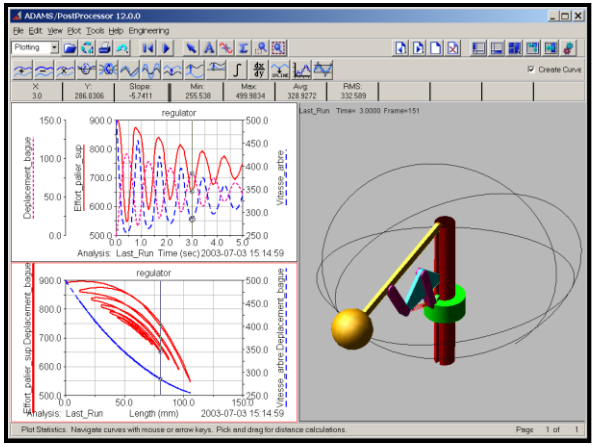
Il codice di calcolo *multi-body*

DEMO

ADAMS
Automated Dynamic Analysis of Mechanical System

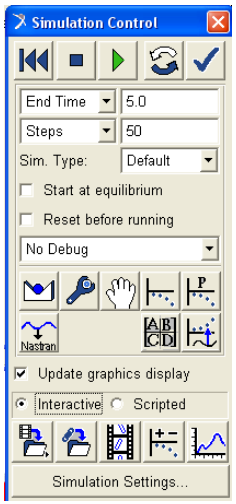
Codice per Elaborazione e risoluzione numerica dei sistemi DAE

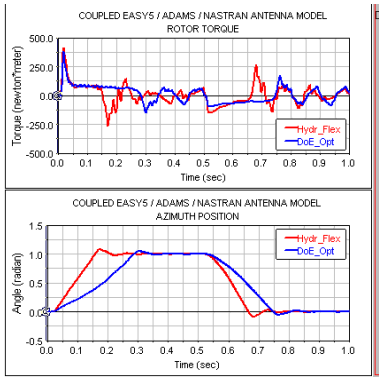
- **Definizione topologia (corpi,giunti,forze…)**
- **Definizione dati inerziali (massa,inerzia…)**
- **Modellazione fenomeni cinematici / dinamici**
- **Modellazione solida (geometria, forme,...)**
- **Definizione output (*measures, requests, obj*…)**

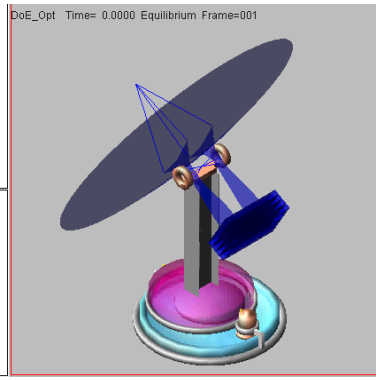


Impostazione Analisi

Postprocessing Risultati





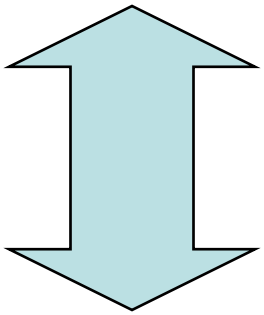


Introduzione alla dinamica dei sistemi *multi-body*

ADAMS

Automated Dynamic Analysis of Mechanical System

VIRTUAL PROTOTYPING DESIGN



GENERAL PURPOSE COMPUTER PROGRAM

Applicazioni dell'Analisi Multibody

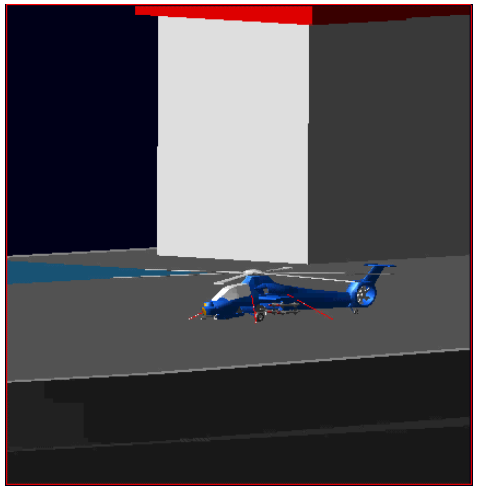
GENERAL PURPOSE COMPUTER PROGRAM

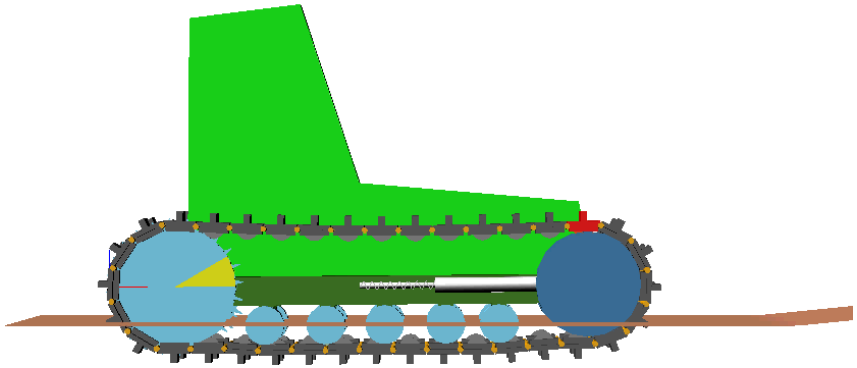
- Approccio Sistematico
- Analisi di qualsiasi Sistema *Multi-Body*
- Qualsiasi campo di applicazione meccanica (generale)
- Indipendente dalla specificità del problema e/o modello

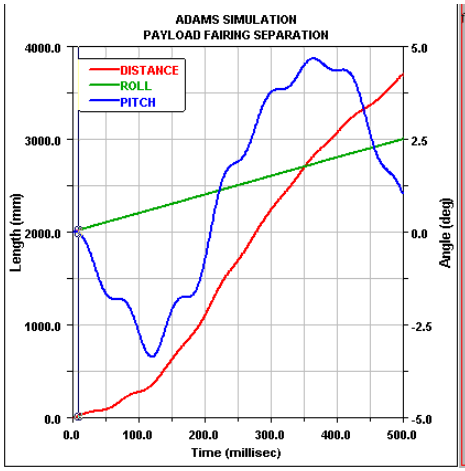
SPECIAL PURPOSE COMPUTER PROGRAM

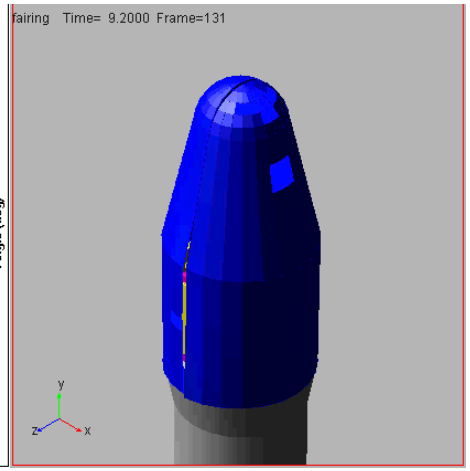
- Approccio specifico (dedicato)
- Analisi di particolare (definito) sistema
- Singola applicazione
- Impossibilità di estensione a nuove problematiche

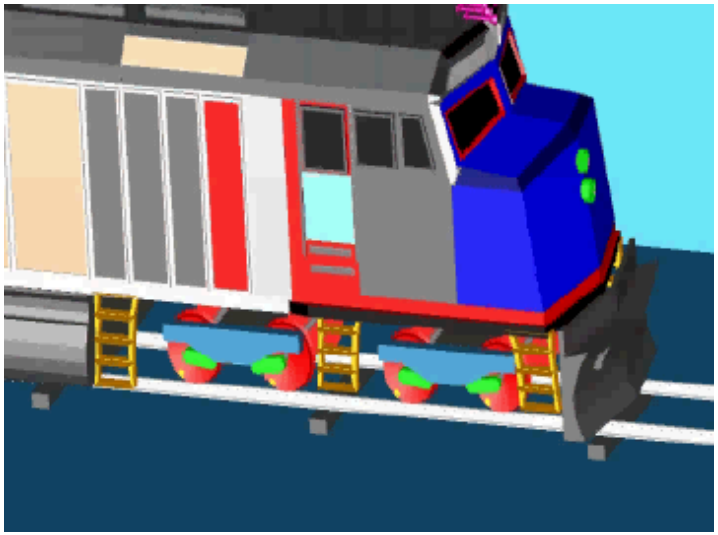
Applicazioni dell'Analisi Multibody

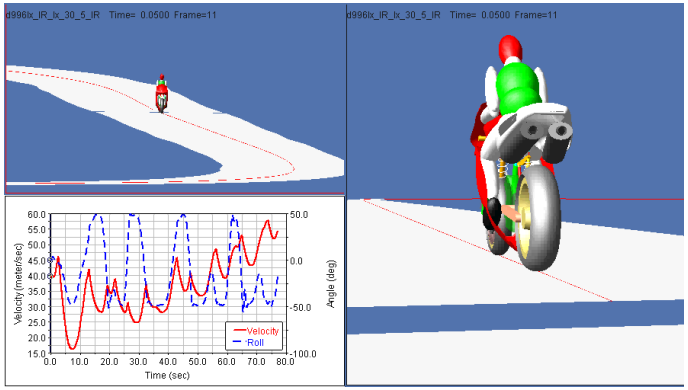


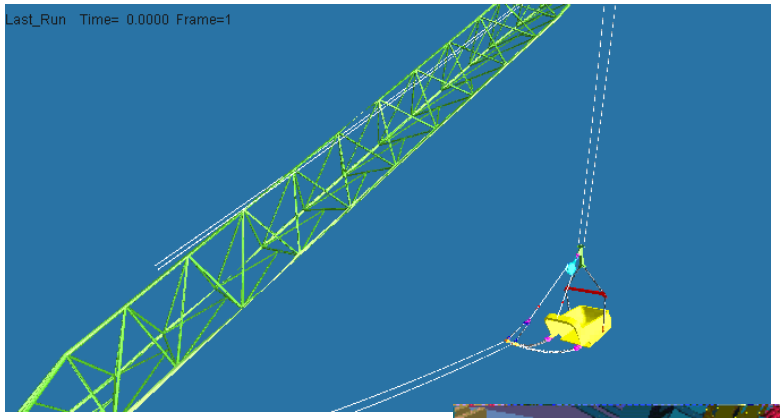









d996lx_IR_lx_30_5_IR Time= 0.0500 Frame=11
d996lx_IR_lx_30_5_IR Time= 0.0500 Frame=11
Velocity (meters/sec)
Angle (deg)
Time (sec)
Velocity
Roll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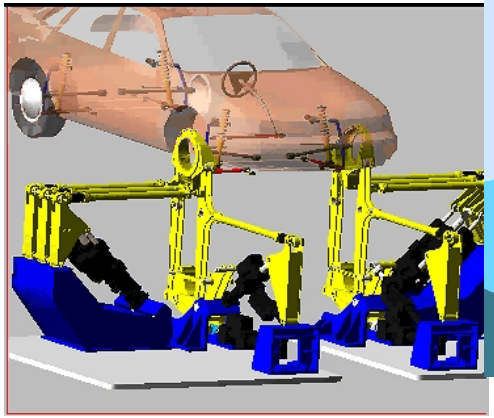

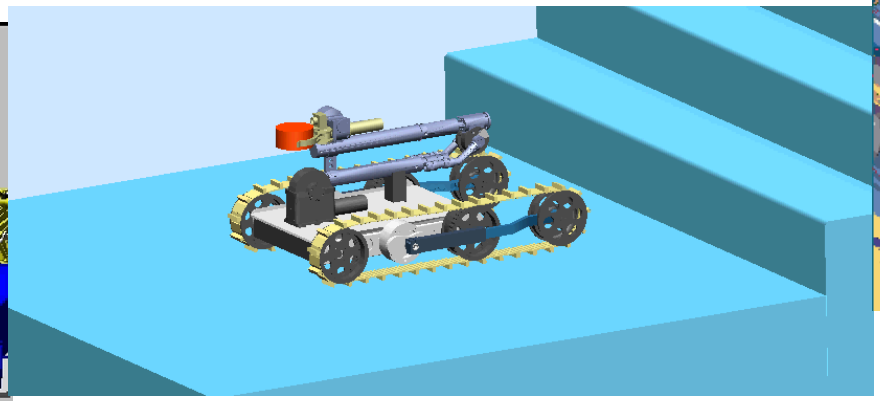

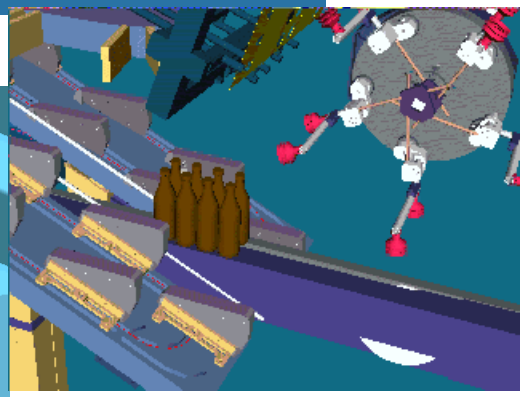

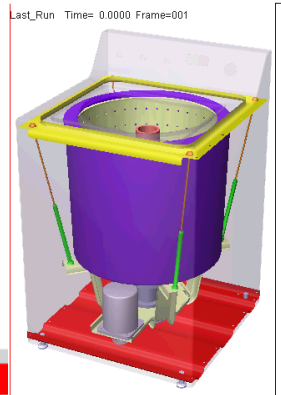
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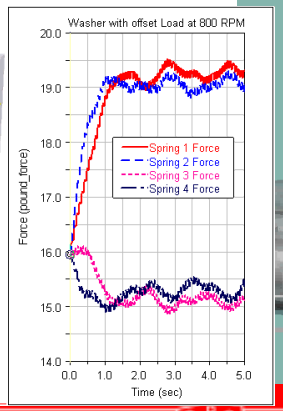
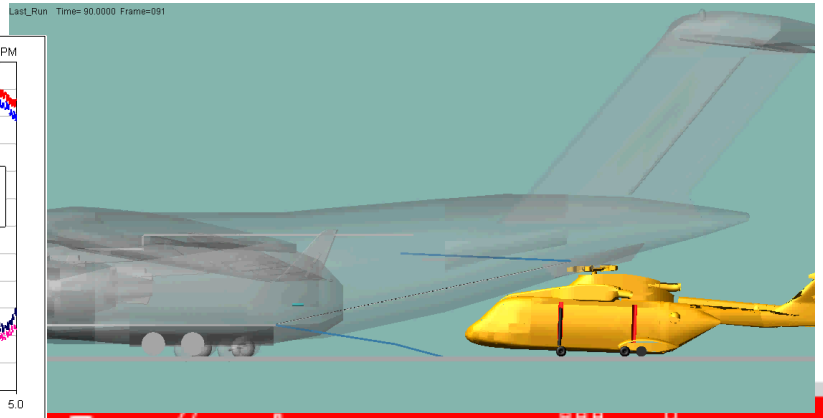

Washer with offset Load at 800 RPM
Force (pound_force)
Time (sec)
Spring 1 Force
Spring 2 Force
Spring 3 Force
Spring 4 Force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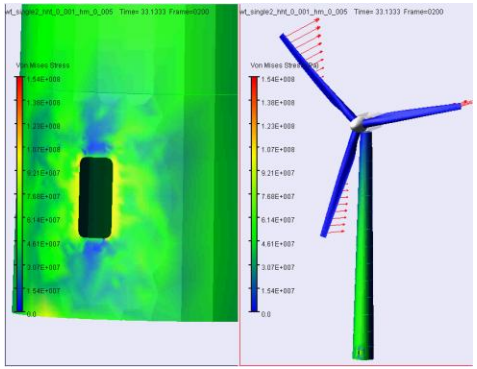


Applicazioni dell'Analisi Multibody

GENERAL PURPOSE COMPUTER PROGRAM

Origine

- Esigenza di analizzare sistemi complessi soggetti a grandi
- spostamenti (traslazioni e rotazioni) ➔ equazioni fortemente non lineari
- Esigenza di modellare fenomeni complessi e difficilmente riproducibili
- Esigenza di superare studio semplificato (linearizzazione, riduzione equazioni)
- Necessità di utilizzare il Computer ➔ sviluppo del Computer
- Necessità della progettazione: riduzione costi, riduzione *time-to-market*, riduzione rischi connessi alla costruzione di prototipi reali
- Possibilità di applicare tecniche di ottimizzazione e *Design of Experiments*
- Possibilità di esplorare (a rischio nullo) situazioni catastrofiche: ricostruzione incidenti, simulazione *CRASH*, ecc.

Applicazioni dell'Analisi Multibody

GENERAL PURPOSE COMPUTER PROGRAM

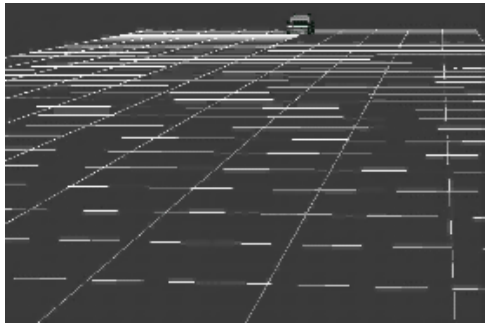
Scopo

- Permettere la ***Simulazione*** di un generico sistema Multi-Body:
  Verifica
- Effettuare l'analisi dinamica al ***variare dei parametri progettuali:***
  Ottimizzazione
- Diventare ***Strumento di Progettazione:***
  Predizione
- Attuare la ***Prototipazione Virtuale:***
  Validazione/Certificazione

Applicazioni dell'Analisi Multibody

GENERAL PURPOSE COMPUTER PROGRAM

Progetto



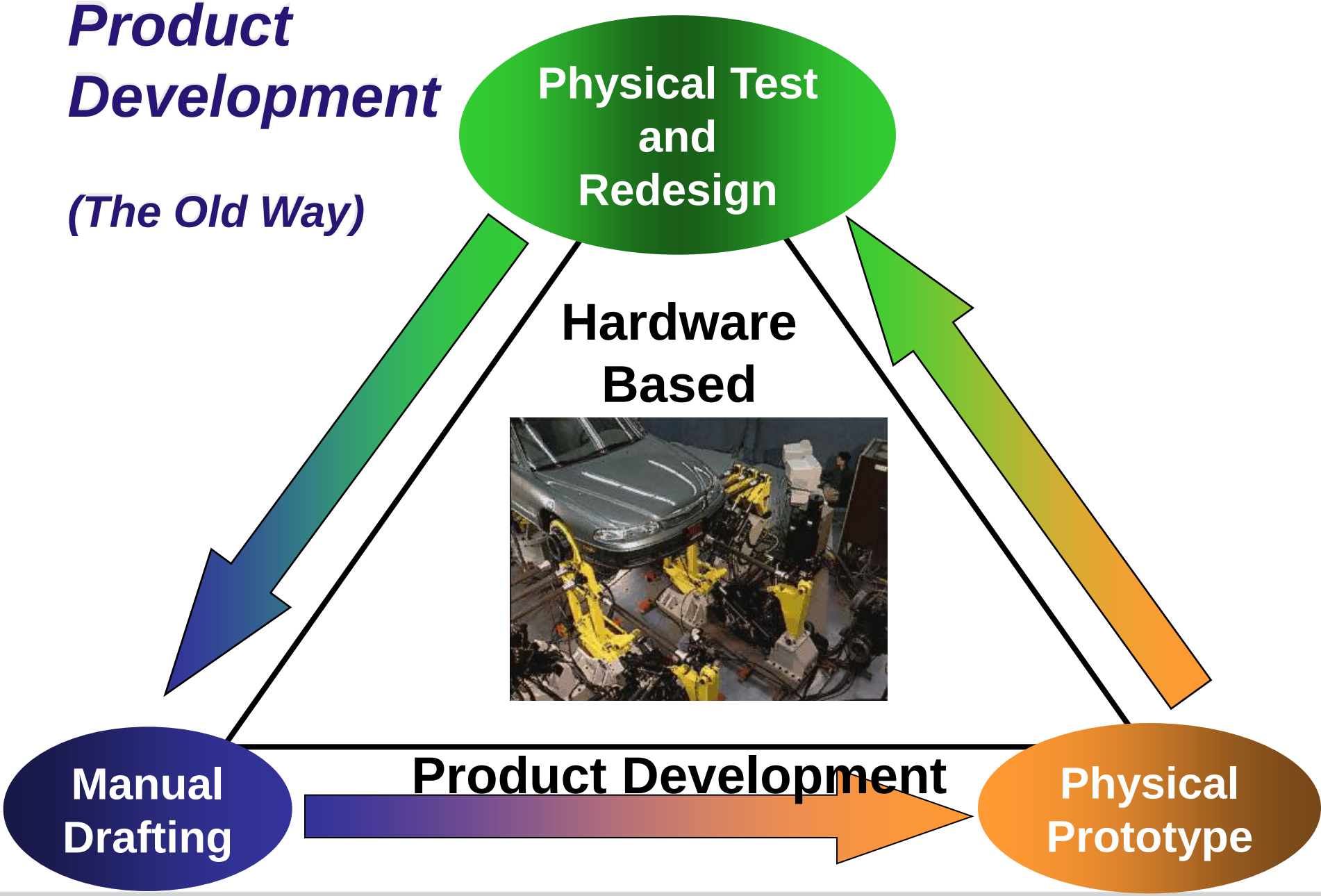
- ❖ **Studio di fattibilità**
- ❖ **Valutazione delle prestazioni**
- ❖ **Analisi di sensitività**
- ❖ **Ottimizzazione**

- ❖ **Confronto con risultati sperimentali**
- ✓ **Verifica e iterazione**

- ❖ **Certificazione e produzione**

Product Development

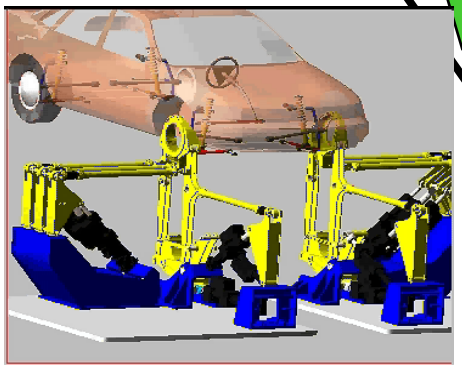
(The Old Way)



Product Development

(The New Way)

Functional Virtual Prototyping



Virtual Product Development

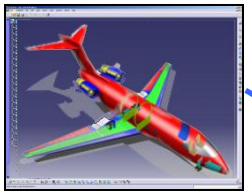
3D CAD

Digital Mock-up

Integration Platform

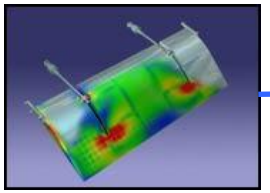
Import models and data from CAD, In-house models, and other MSC products

3D CAD

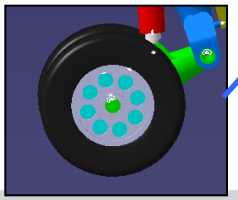


MSC.EASY5

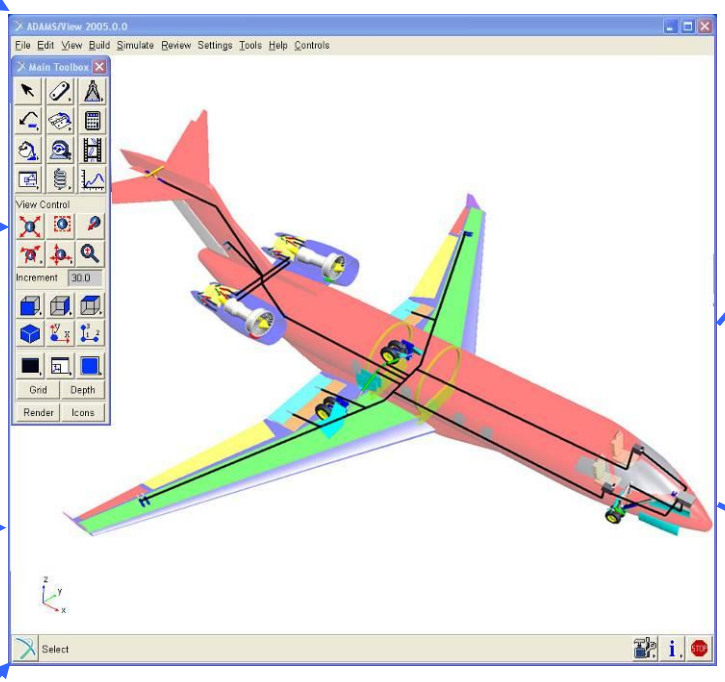
MSC.Nastran



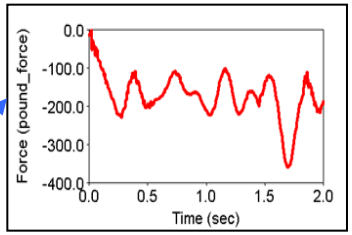
In House Tire Models



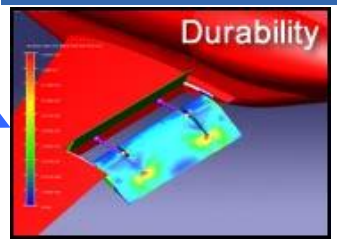
CFD Models



Detailed Loading Conditions for MSC.NASTRAN



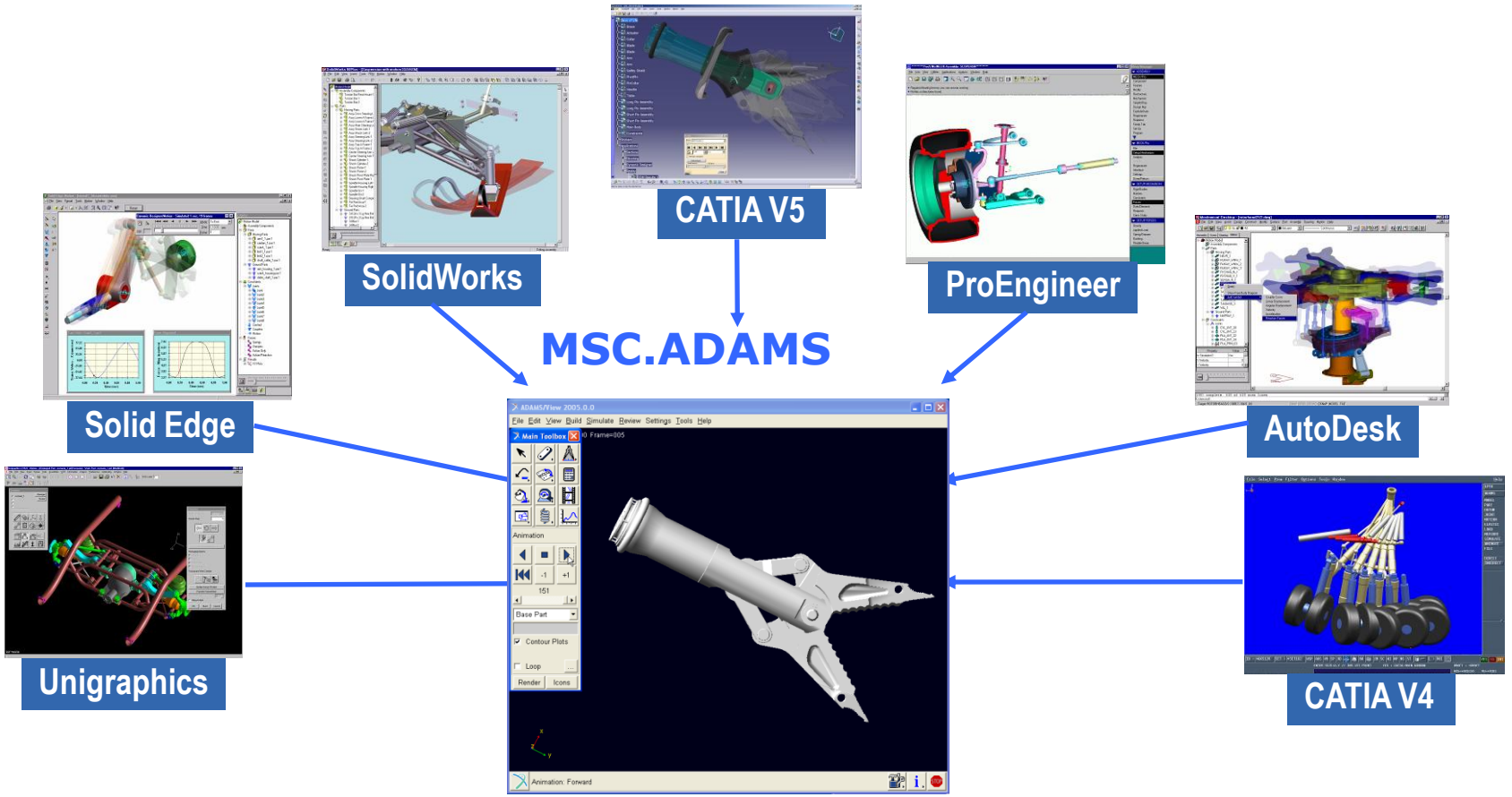
Stress time Histories for MSC.Fatigue



Export data for detailed stress simulation and durability analysis

Supported CAD Integration

Suppliers and Customers use different CAD systems.

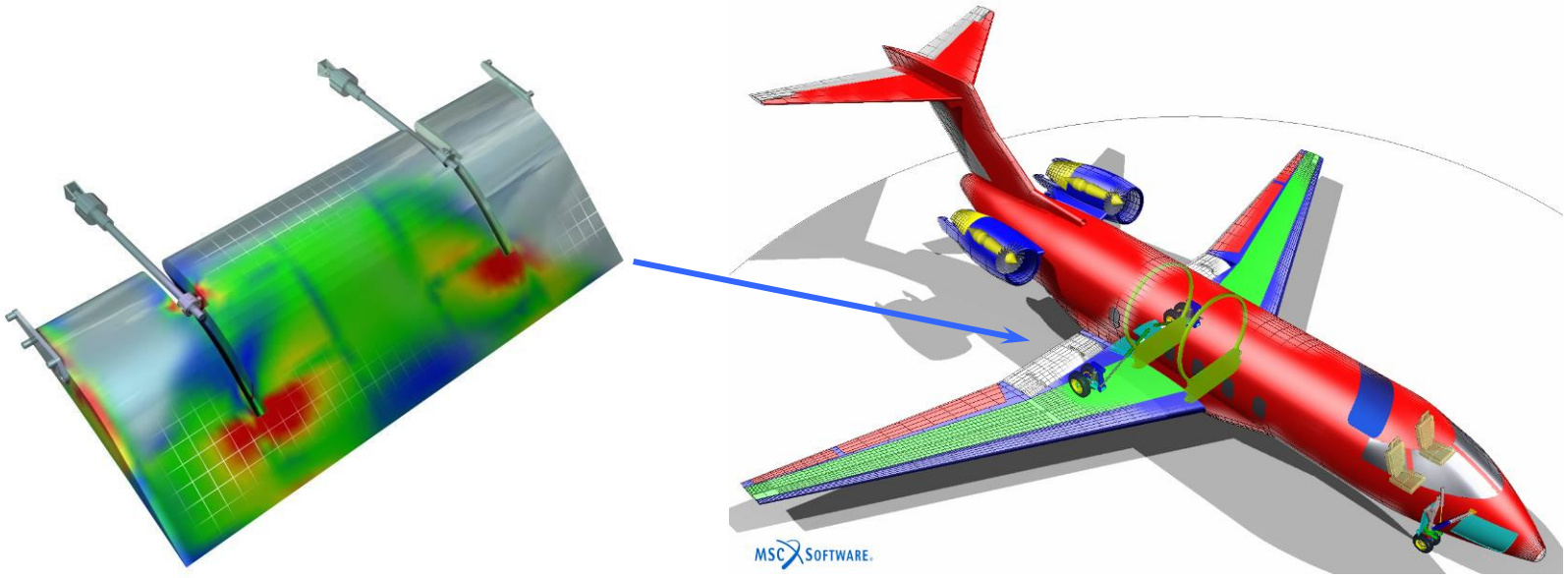


ADAMS can import data from all major CAD systems.

ADAMS/Flex

Adding Flexibility To Your VPD Process

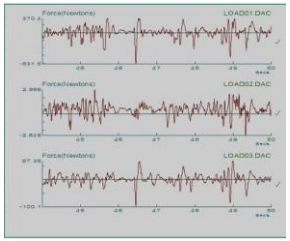
- Transfer data to and from several FE applications.
- Tightly integrated with MSC.Nastran, MSC.Marc and Patran.
- Supported by all MSC.ADAMS industry specific products.

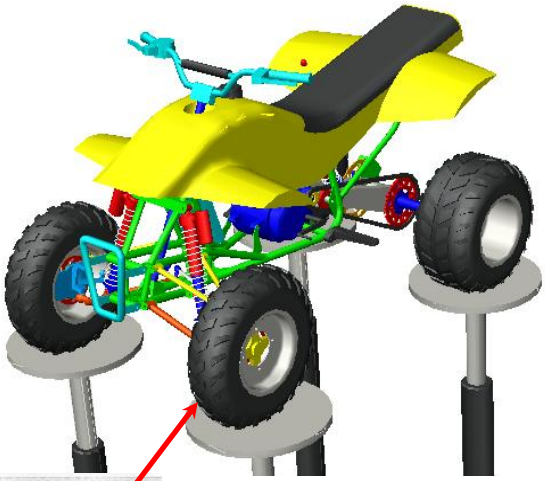


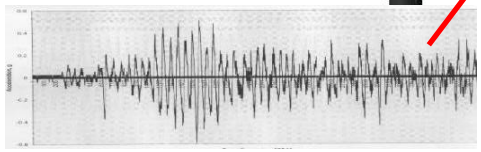
ADAMS/Durability

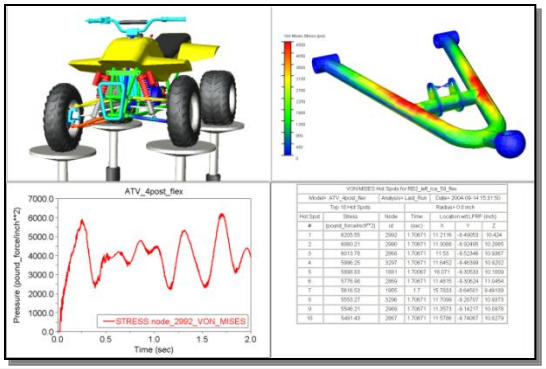
Construct virtual test lab inputs and outputs

- Import physical test data
  - MTS Systems RPC® III file
  - nCode International DAC file
- Efficient spline interpolation
- Add virtual measurements like strain gauges
- Stress Recovery
- Data exchange with FE or fatigue programs for life prediction

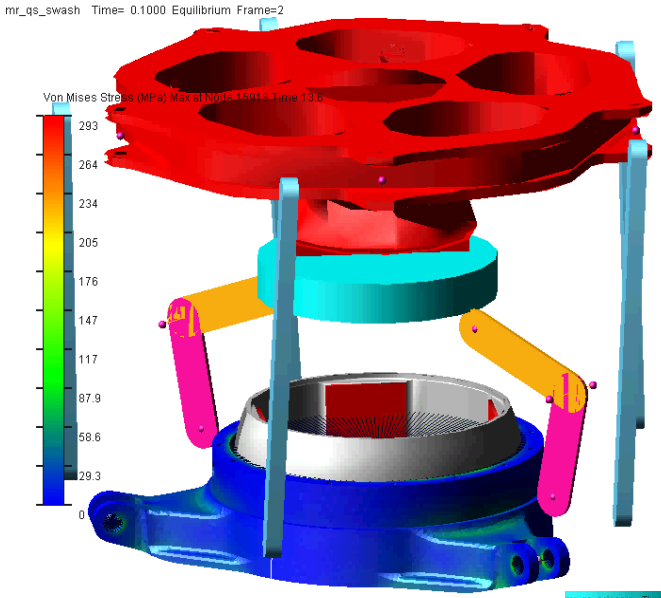








Esempi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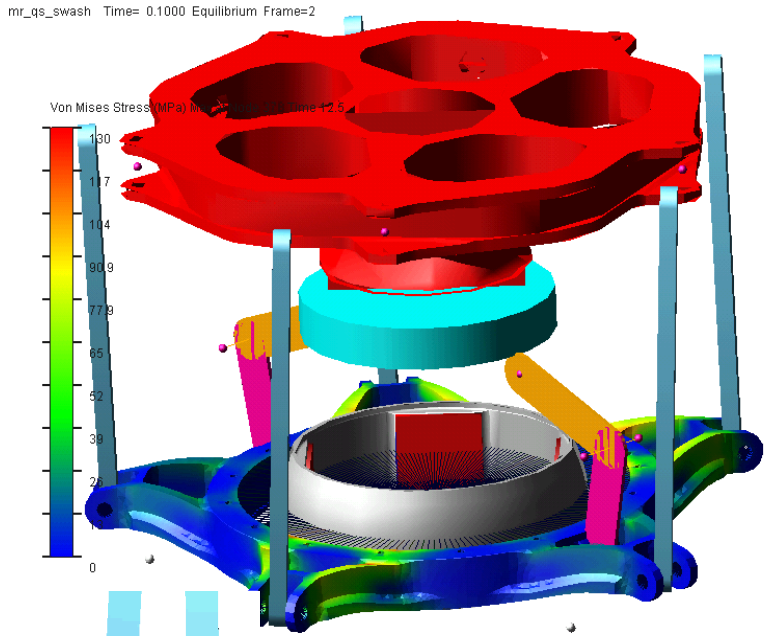
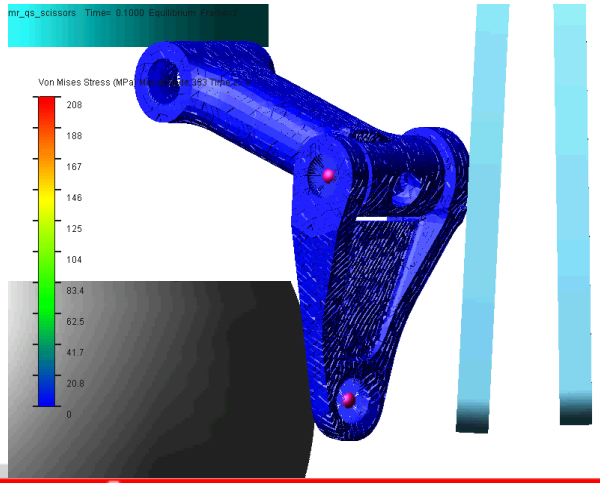
Von Mises Stress (MPa) Max at Node 15918 Time 13.6
293
264
234
205
176
147
117
87.9
58.6
29.3
0

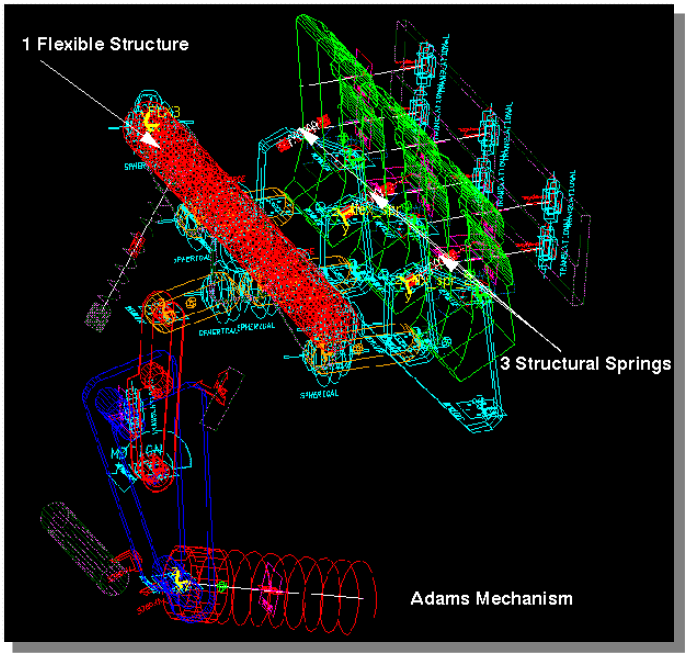

mr_qs_swash Time= 0.1000 Equilibrium Frame=2
Von Mises Stress (MPa)
130
117
104
90.9
77.9
65
52
39
0

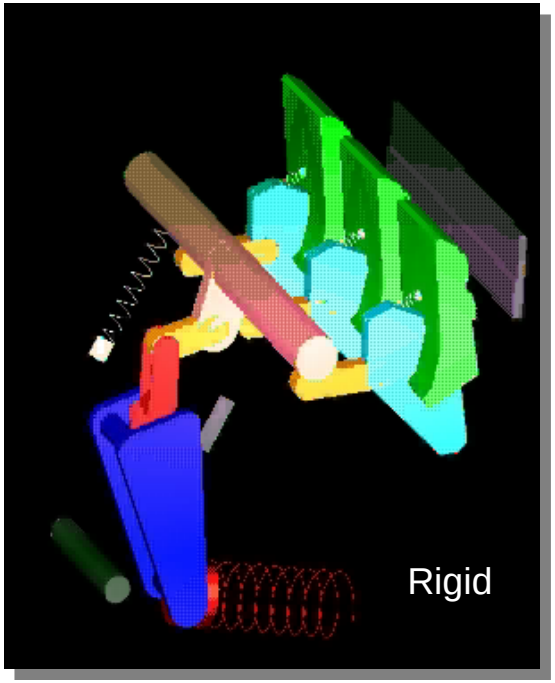

208
188
167
146
125
104
83.4
62.5
41.7
20.8
0

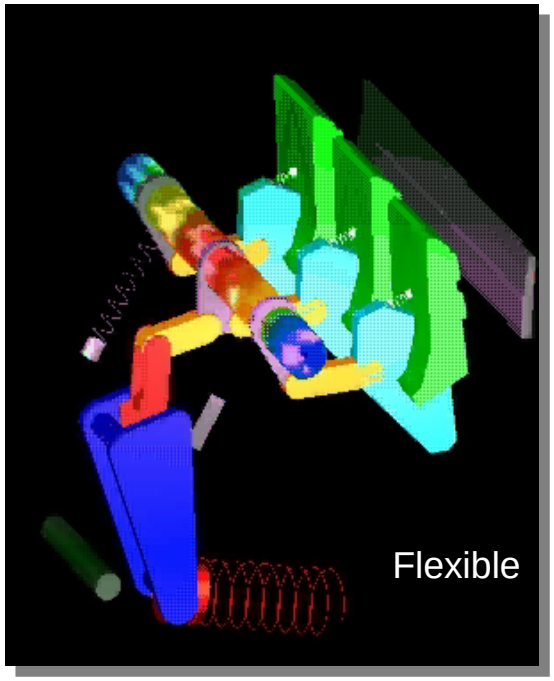
Low Voltage Circuit Breaker

Courtesy of ABB Research

- Simple geometry
- Structural Springs including Mass
- Very rapid dynamics
- Rigid vs Flexible Results

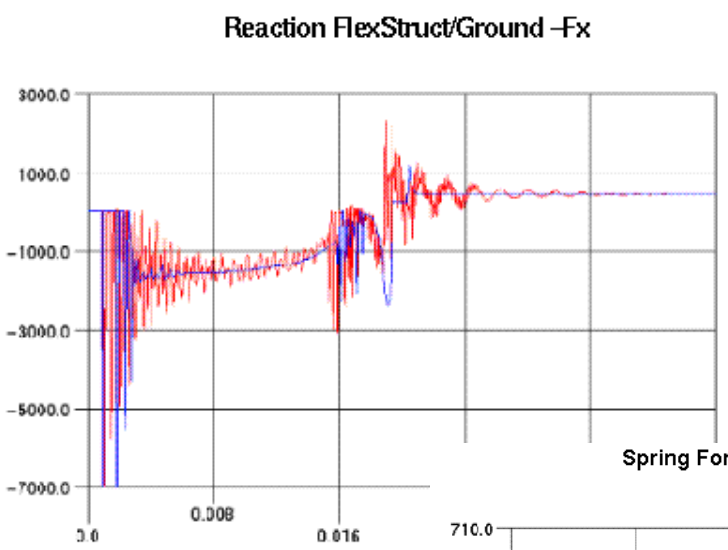


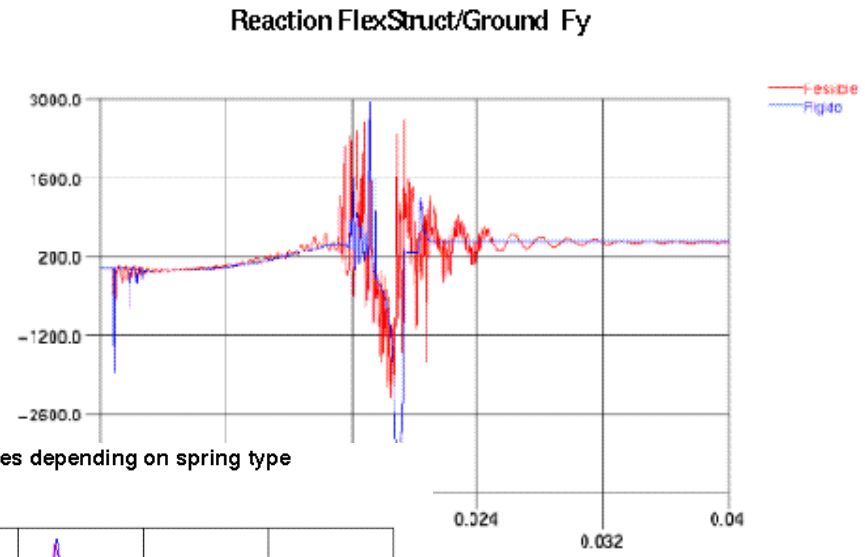




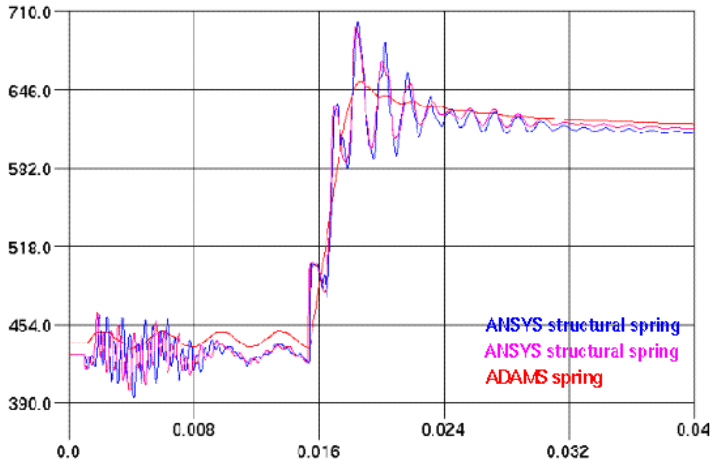
Low Voltage Circuit Breaker

Courtesy of ABB Research





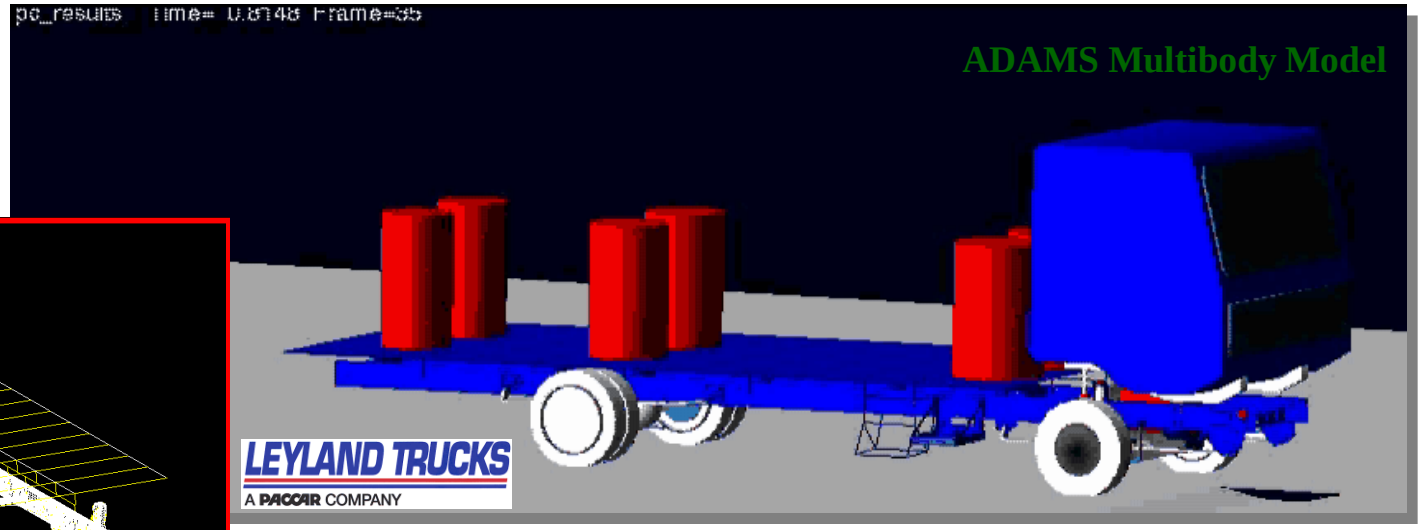
Spring Forces depending on spring type

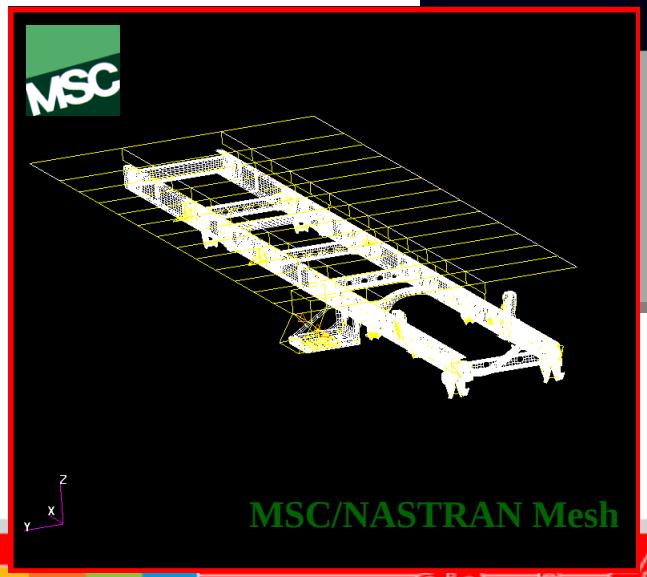


Pothole passing with a Truck - 1

Courtesy of Leyland Trucks

- Pothole-passing manouver of a full-vehicle truck model including a flexible frame
- Rigid vs. Flexible frame comparison of vertical accelerations at the driver's seat
- Automatic Stress distribution calculation for the most critical dynamic loading condition



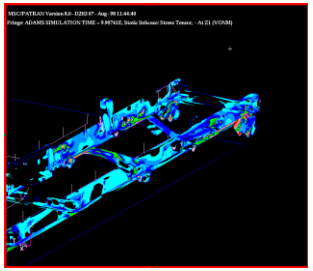


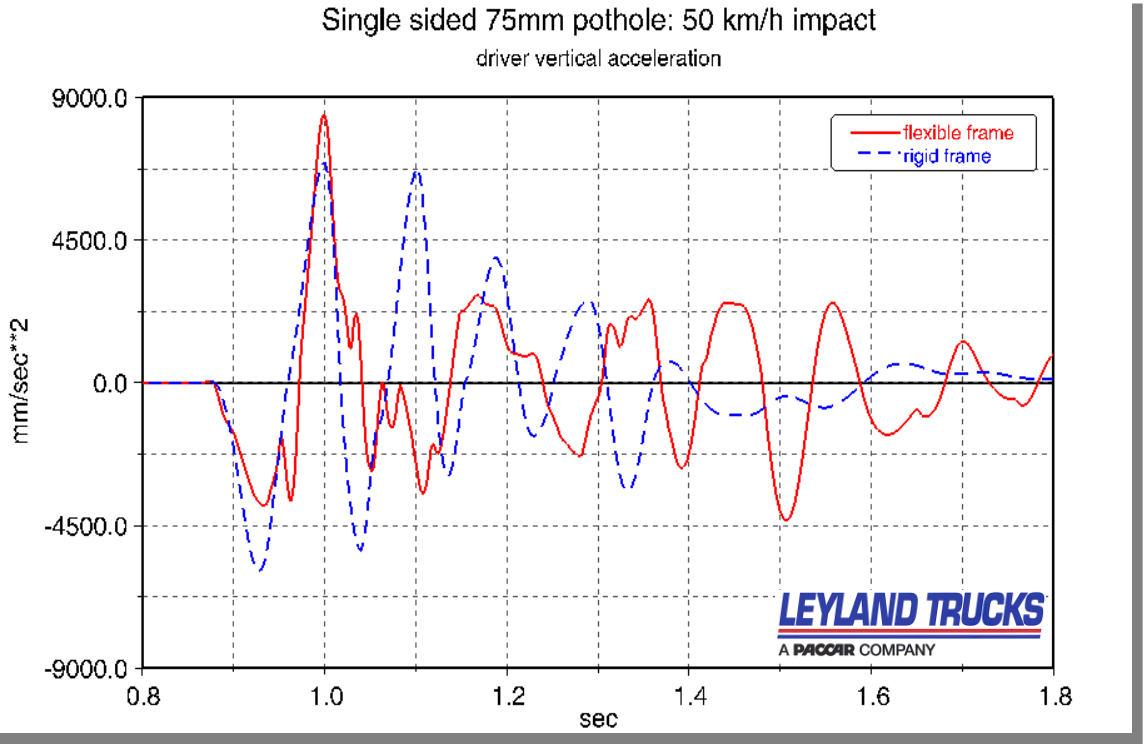
Leyland

Pothole passing with a Truck - 2

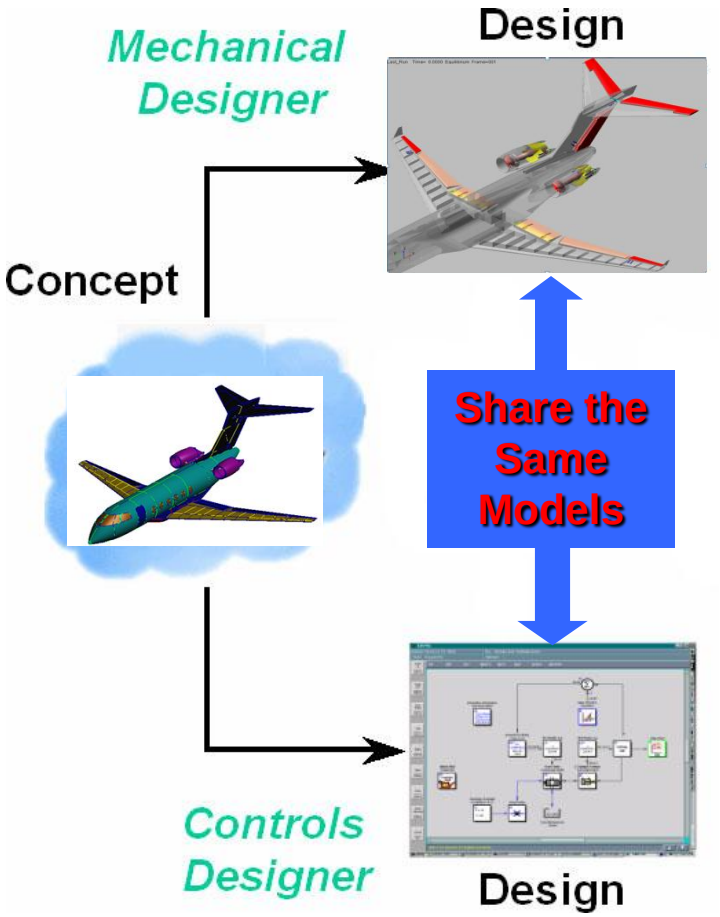
Courtesy of Leyland Trucks

- Simulation Results in ADAMS
  - Vertical Acceleration at driver's seat
  - Different response between rigid and flex frame representation
  - The most significant feature of the different response in terms of acceleration plot is the vertical component shown here
  - With rigid frame the front wheel strike creates a shock which dies away progressively
  - With flex frame the initial shock begins to attenuate, but then increases once more as the rear wheel impact shock propagates along the frame - this impact shock can be felt by the driver when the vehicle is driven over such a disturbance. Rigid body models fail to predict this effect

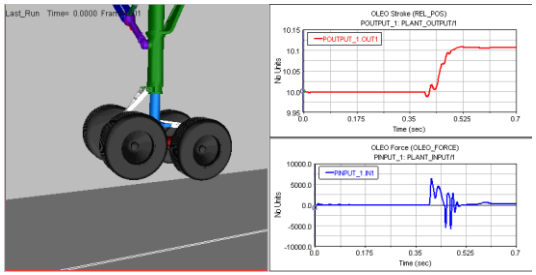


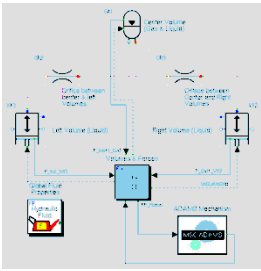


ADAMS/Controls



Systems Engineer's need higher fidelity control models for more accurate results.



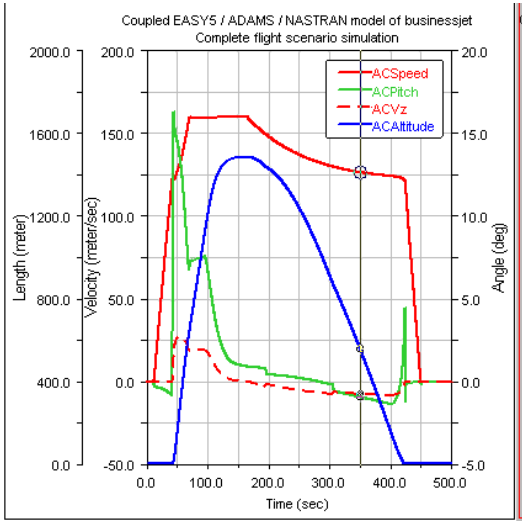


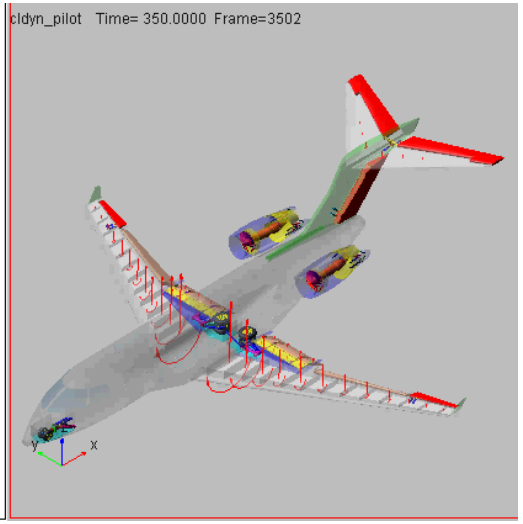
Simultaneously understand the operation of your mechanical and control systems

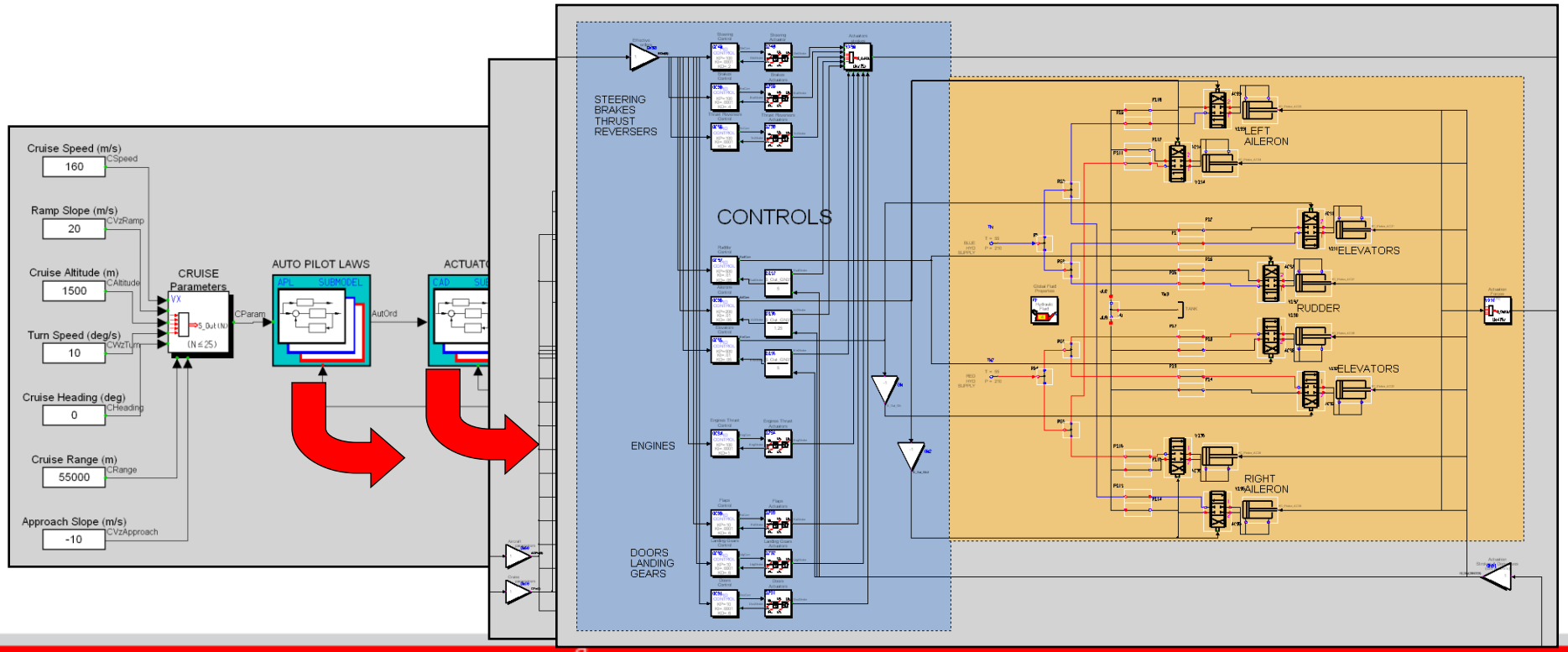
Control Engineer's need realistic Vehicle models to accurately test their control designs.

Improve collaboration between your controls engineers and your systems engineers

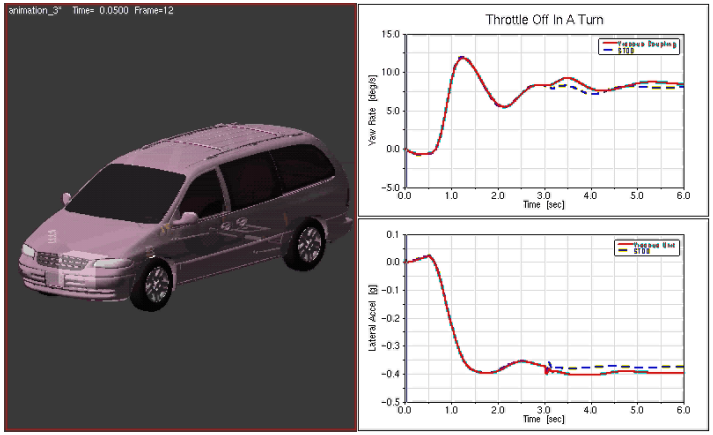
Business jet

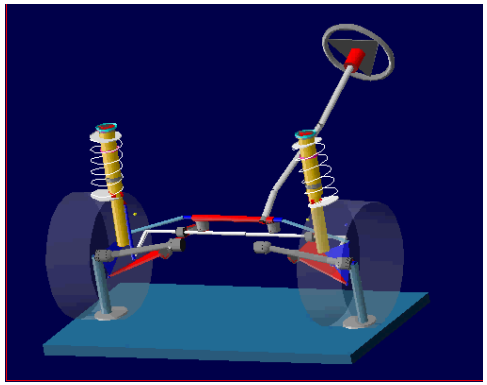


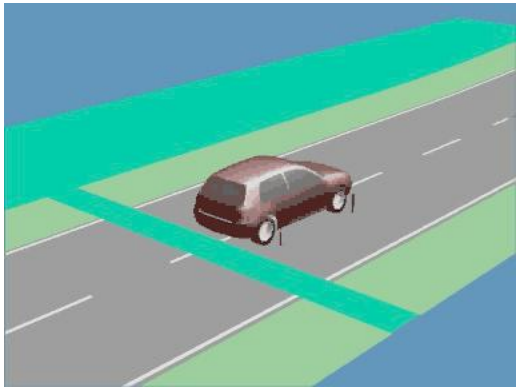


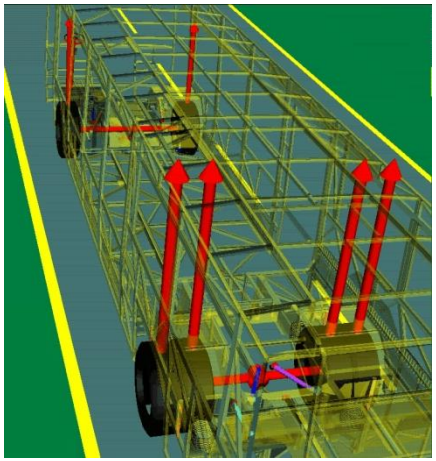


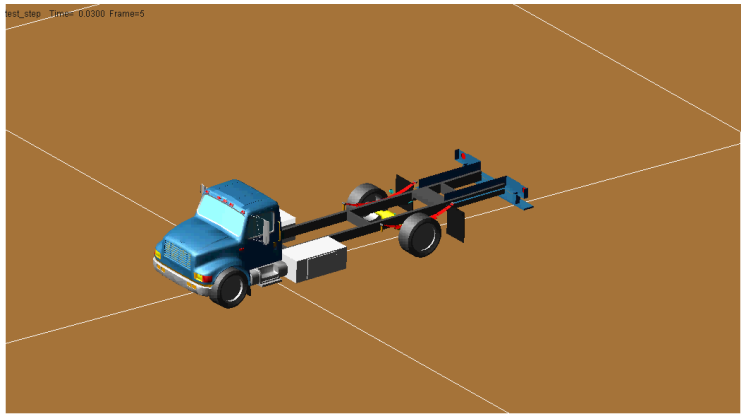
Car


animation_3* Time= 0.0500 Frame=12
Throttle Off In A Turn
Yaw Rate [deg/s]
Time [sec]
Lateral Accel [g]
Time [sec]

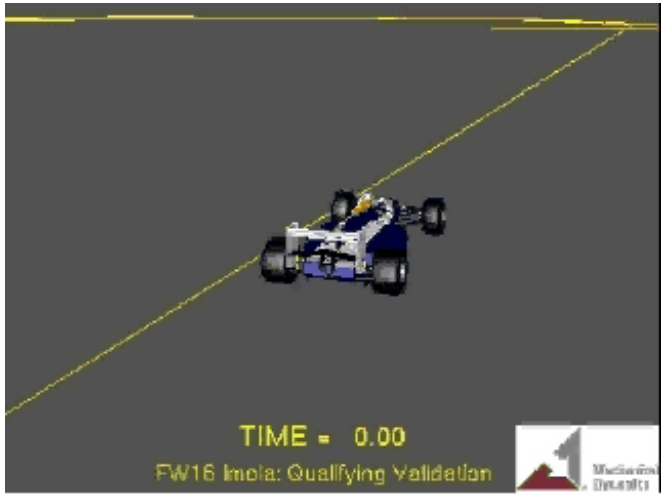


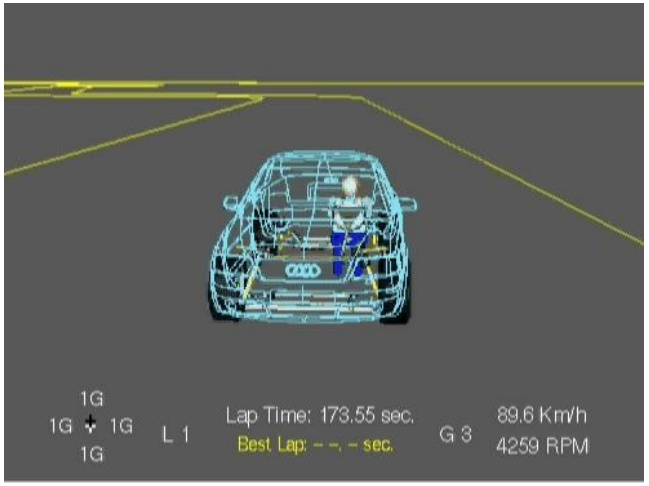


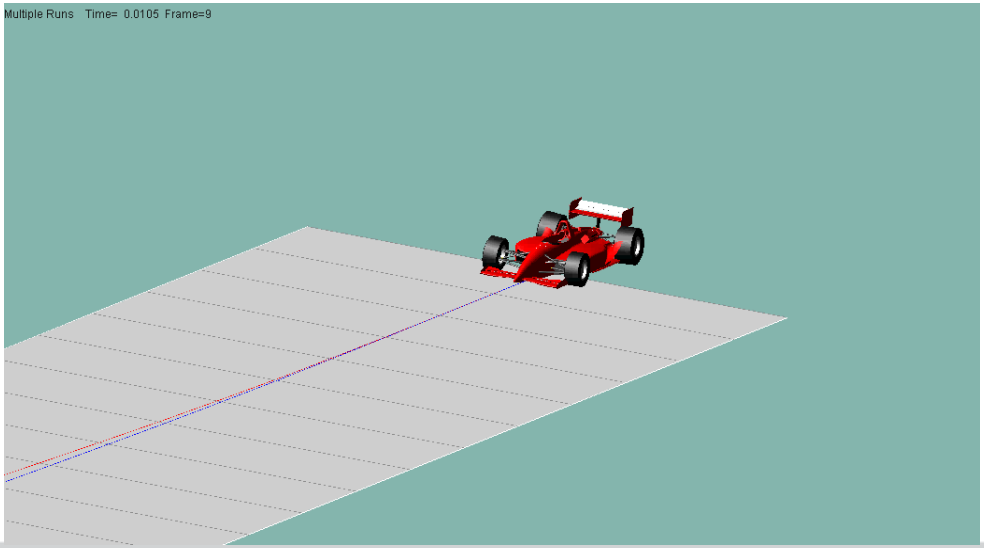



test_step Time= 0.0300 Frame=5

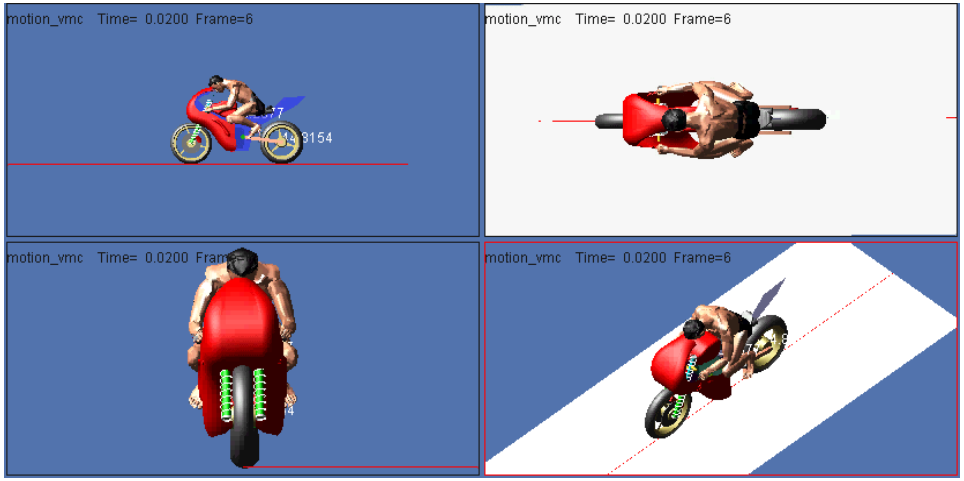
Motorsport

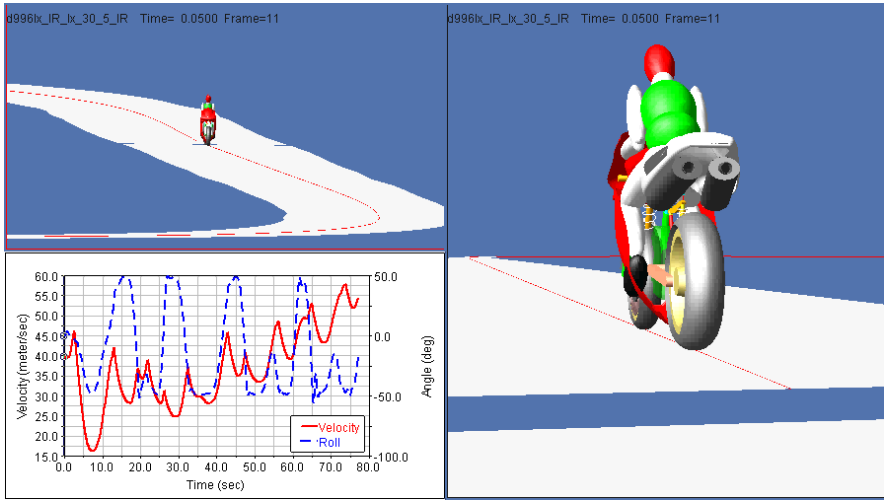

TIME = 0.00
FW16 Imola: Qualifying Validation

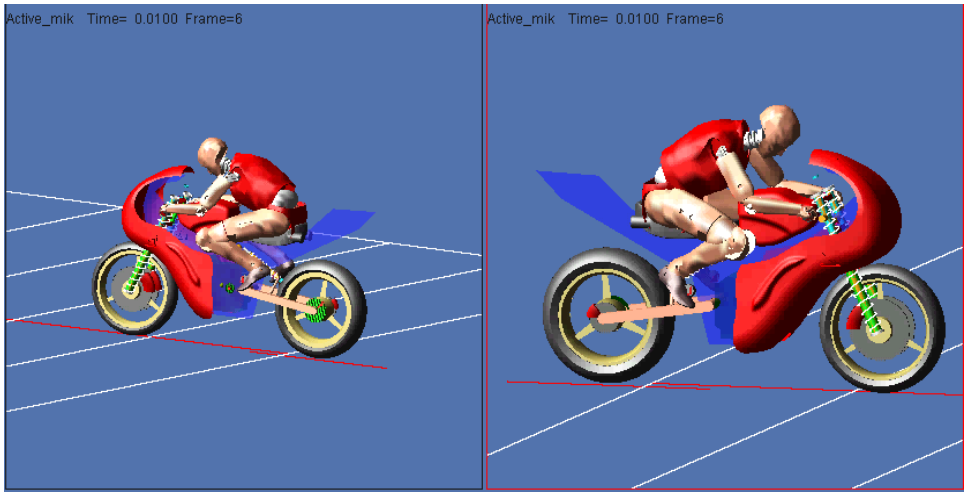

1G
1G 1G
1G
L 1
Lap Time: 173.55 sec.
Best Lap: - -. - sec.
G 3
89.6 Km/h
4259 RPM


Multiple Runs Time= 0.0105 Frame=9

Motorcycle


motion_vmc Time= 0.0200 Frame=6
motion_vmc Time= 0.0200 Frame=6
motion_vmc Time= 0.0200 Frame=6
motion_vmc Time= 0.0200 Frame=6


d996lx_IR_lx_30_5_IR Time= 0.0500 Frame=11
d996lx_IR_lx_30_5_IR Time= 0.0500 Frame=11
Velocity (meter/sec)
Angle (deg)
Time (sec)
Velocity
Roll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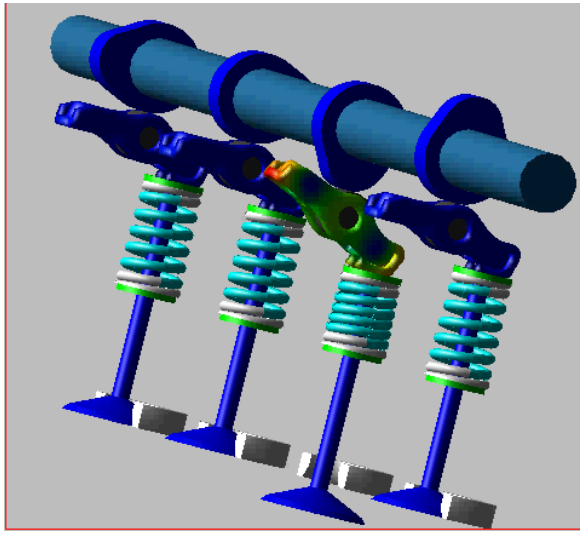
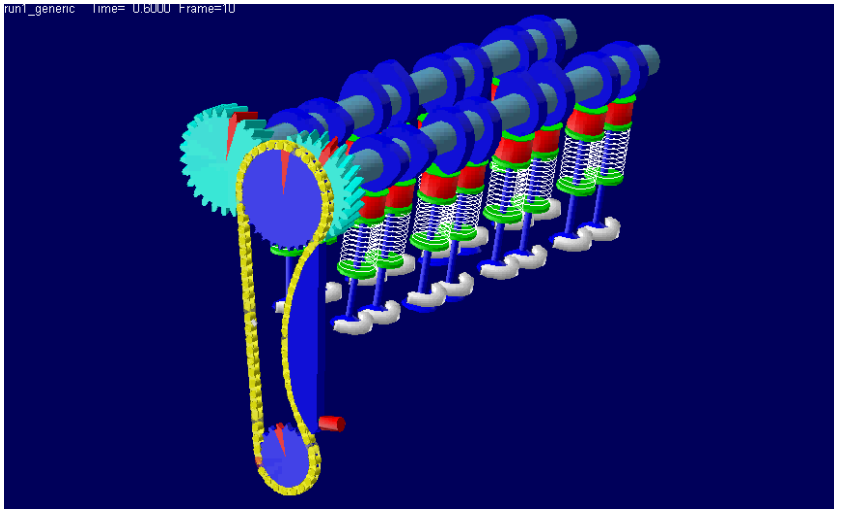
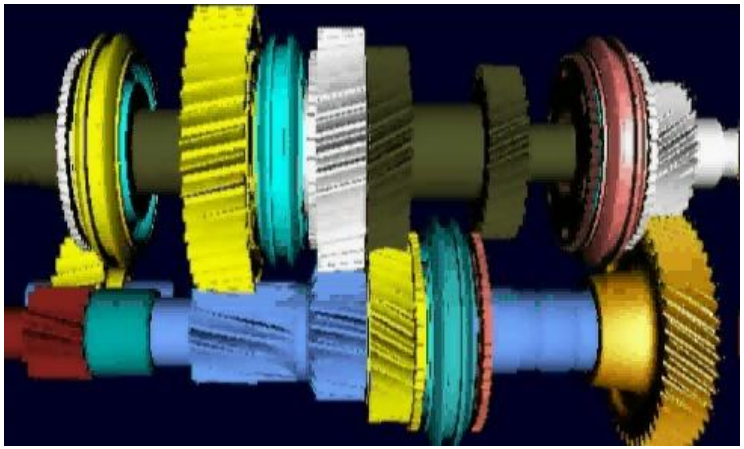
Active_mik Time= 0.0100 Frame=6

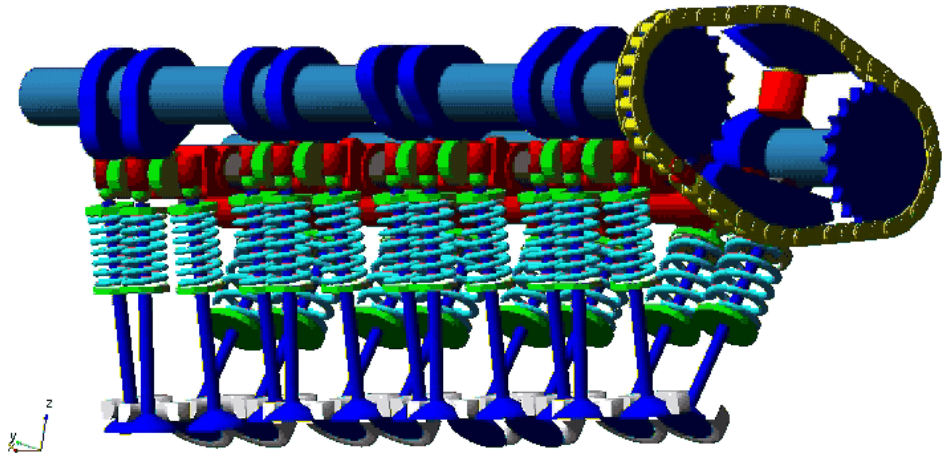

EUROSPORT

Engine & Driveline



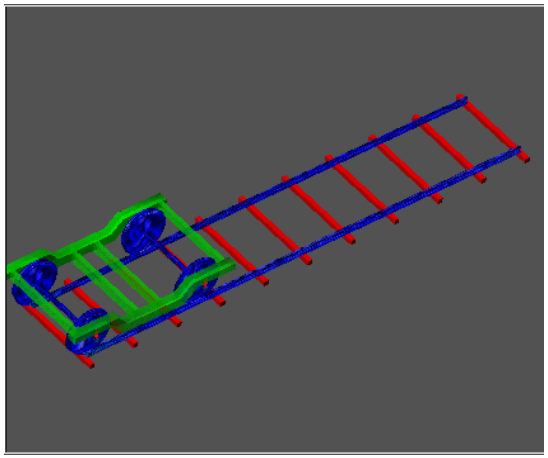


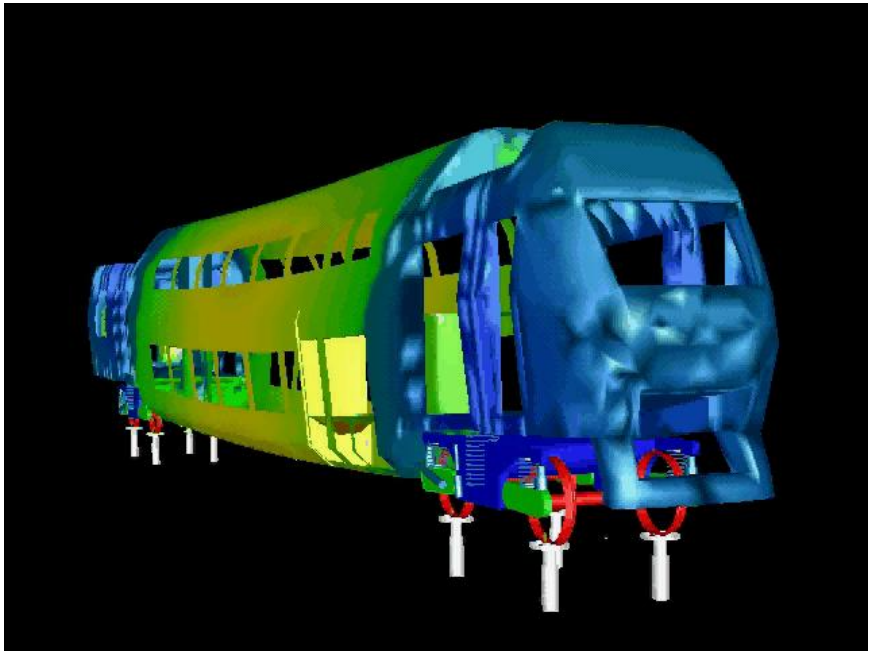


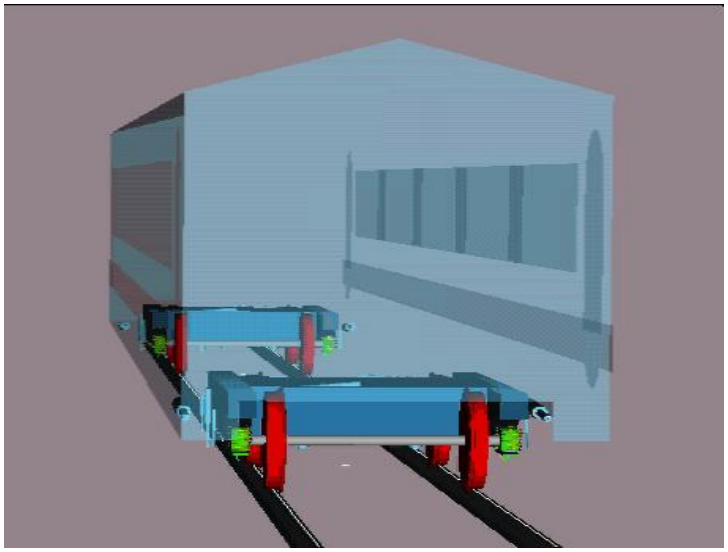


erstellt von Dirk Steinborn, N/ET-122, AUDI AG

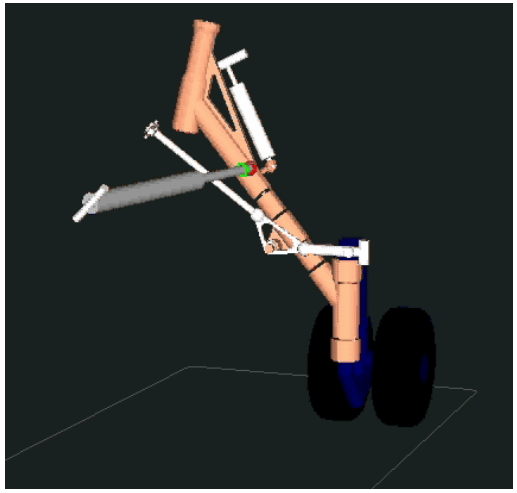
Rail

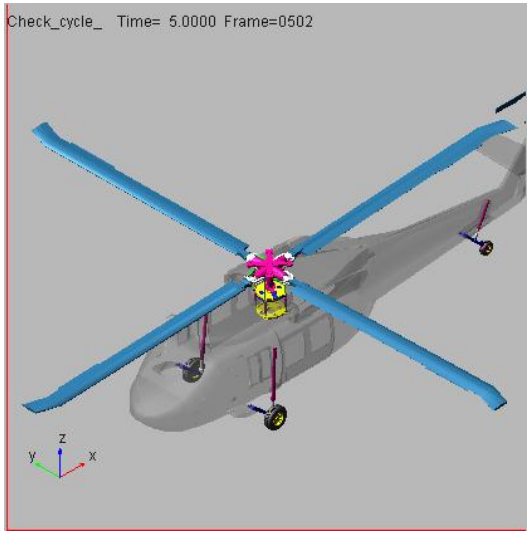


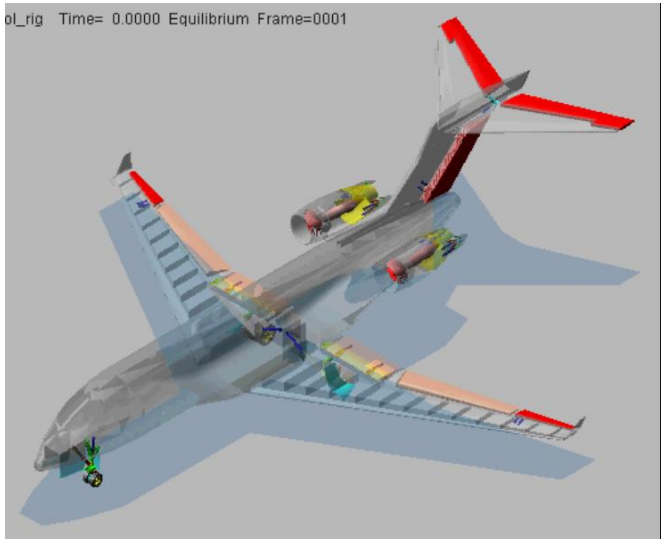


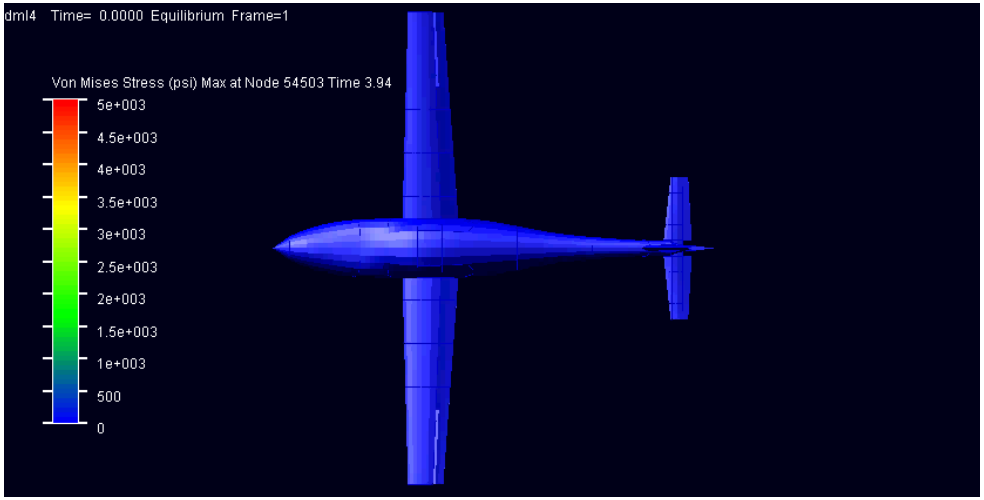


Aircraft

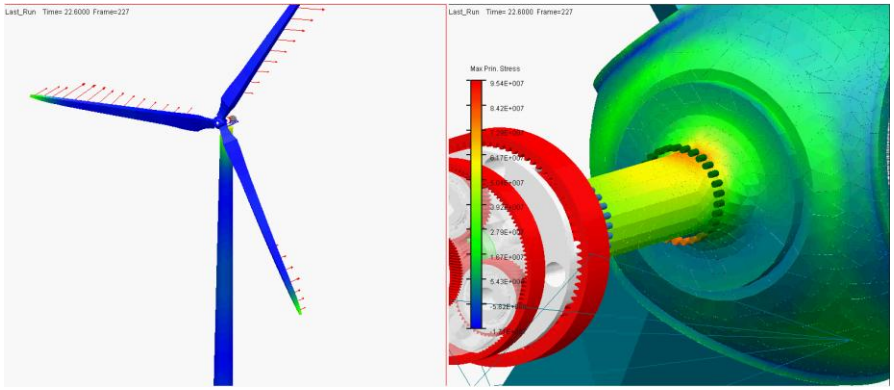


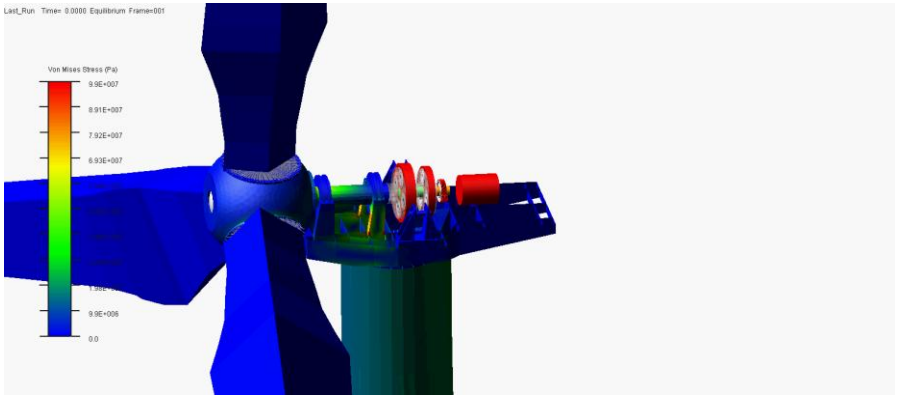

Check_cycle_ Time= 5.0000 Frame=0502
z
y
x

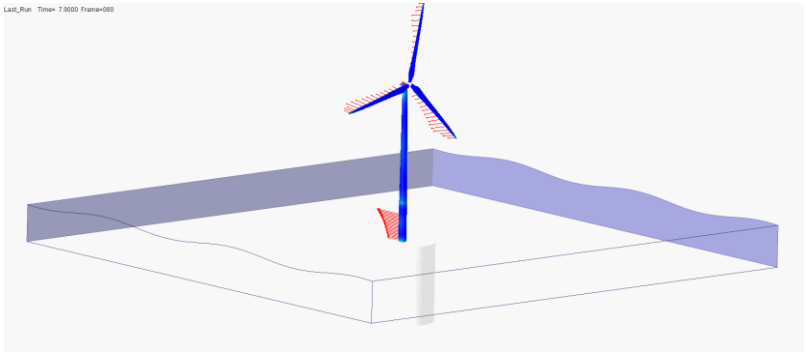

ol_rig Time= 0.0000 Equilibrium Frame=0001

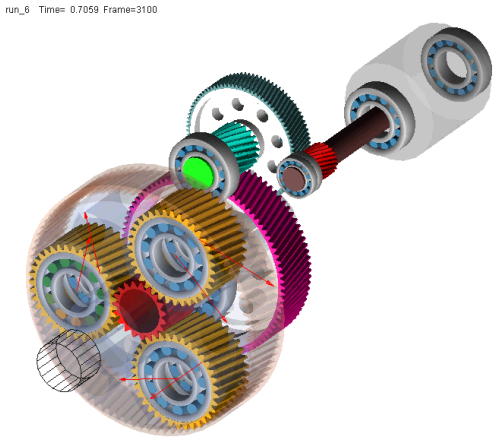

dml4 Time= 0.0000 Equilibrium Frame=1
Von Mises Stress (psi) Max at Node 54503 Time 3.94
5e+003
4.5e+003
4e+003
3.5e+003
3e+003
2.5e+003
2e+003
1.5e+003
1e+003
500
0

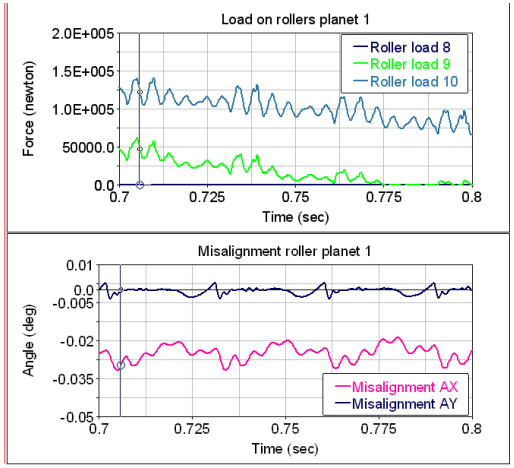
Wind Energy



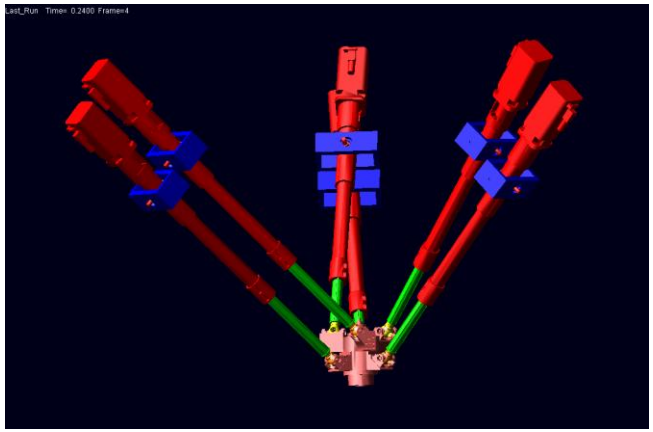


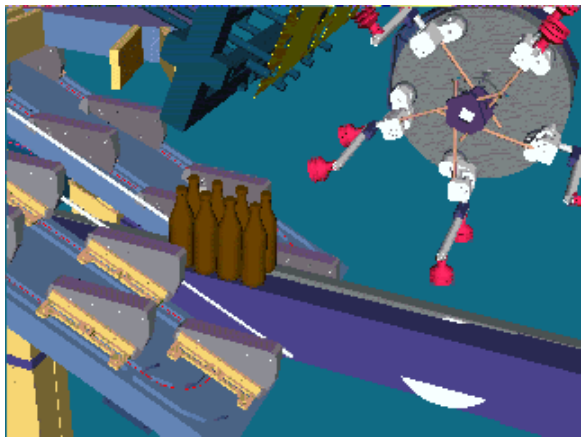


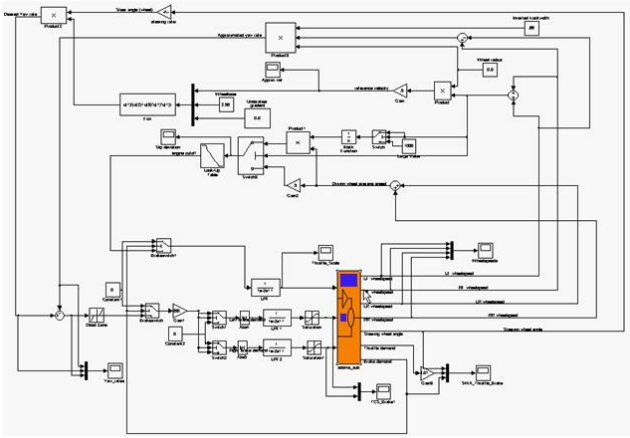


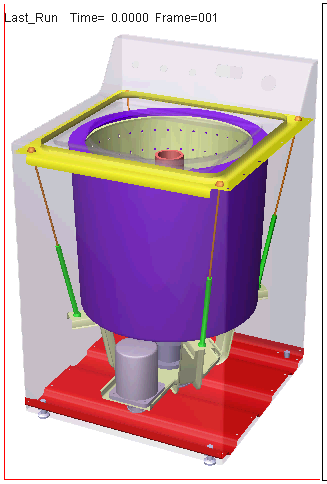

Load on rollers planet 1
Force (newton)
2.0E+005
1.5E+005
1.0E+005
50000.0
0.0
0.7
0.725
0.75
0.775
0.8
Time (sec)
Roller load 8
Roller load 9
Roller load 10
Misalignment roller planet 1
Angle (deg)
0.01
0.0
-0.005
-0.02
-0.035
-0.05
0.7
0.725
0.75
0.775
0.8
Time (sec)
Misalignment AX
Misalignment AY

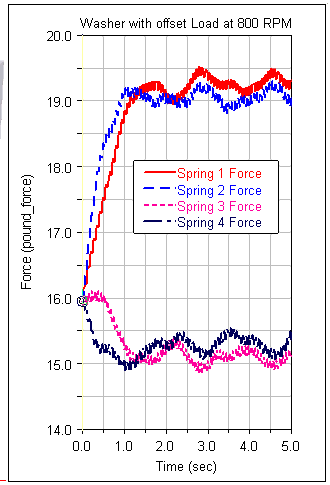
Machinery, Packaging & Robot











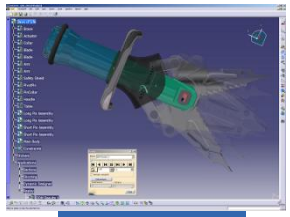
Design Process

"IDEAL" DESIGN PROCESS

Technical Specifications

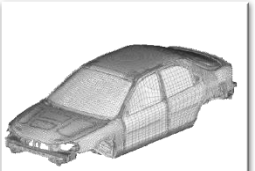
- Weight
- Payload
- Speed
- Resistance
- Life
- Cost

CAD MODEL



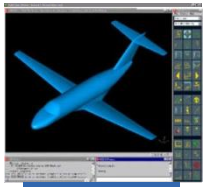
CATIA V5

FE MODEL



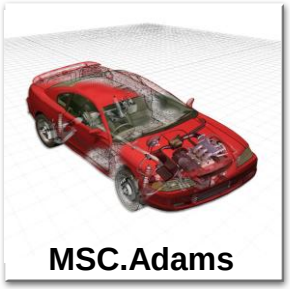
MSC.Nastran

MSC.Patran

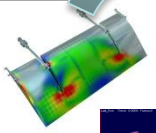


CAD

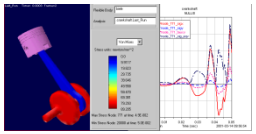
MULTIBODY MODEL



MSC.Adams

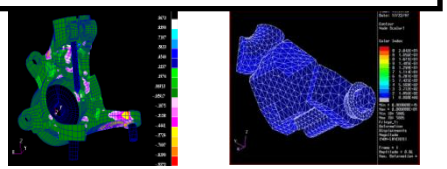


Adams/flex



Adams/Durability

FATIGUE MODEL



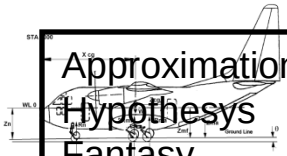
MSC.Fatigue

Certification & Product

“REAL” DESIGN PROCESS: from Specs to Pre-Design

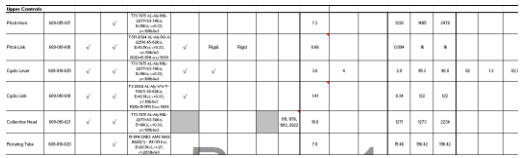
Technical Specifications

SKETCHED MODEL

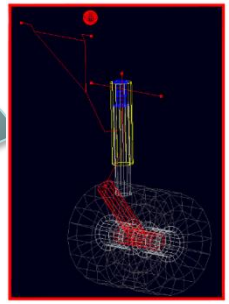


- Approximations
- Hypothesys
- Fantasy
- Previous Data
- Experimental Data

K (stiffness) & M (mass) data



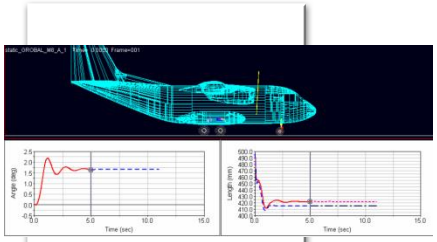
Stick FE MODEL



MSC.Nastran

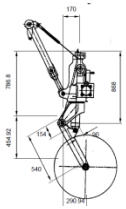
MSC.Patran

MULTIBODY MODEL



MSC.Adams

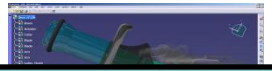
Preliminary Design



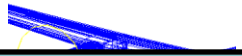
“REAL” DESIGN PROCESS: from Pre-design to Detailed Design

Technical Specifications

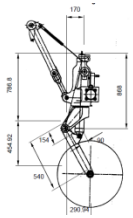
DETAILED MODEL



FE MODEL



Preliminary des



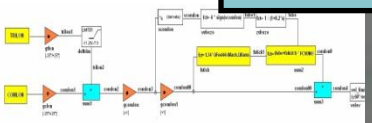
ALL DEPts work together
Concurrent Engineering
Logic Process Flow
All data available
Project history (pedigree)

nalysis

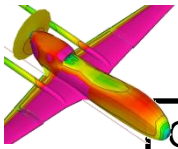
tic Analysis

Nastran MSC.Pat

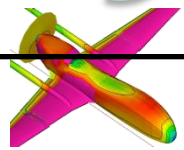
Control



CFD



CFD

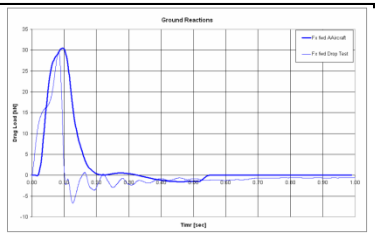


“REAL” DESIGN PROCESS: from Detailed design to Certification and Product

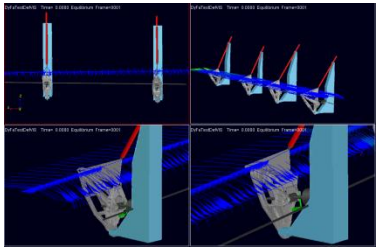
Technical Specifications

Detailed Model

Certification/Validation



Experimental vs Virtual test

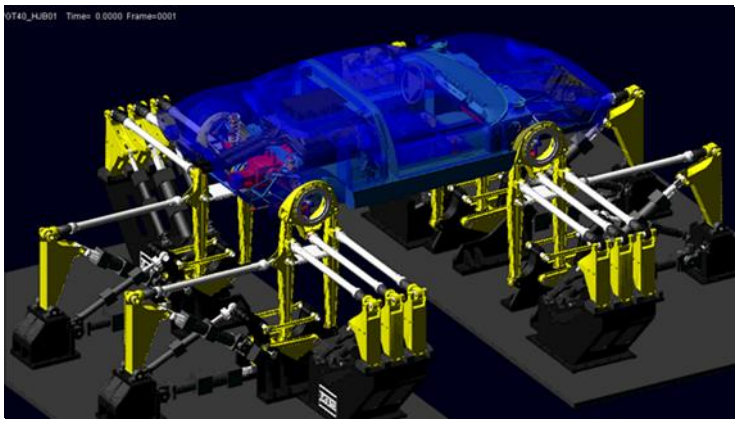


Product

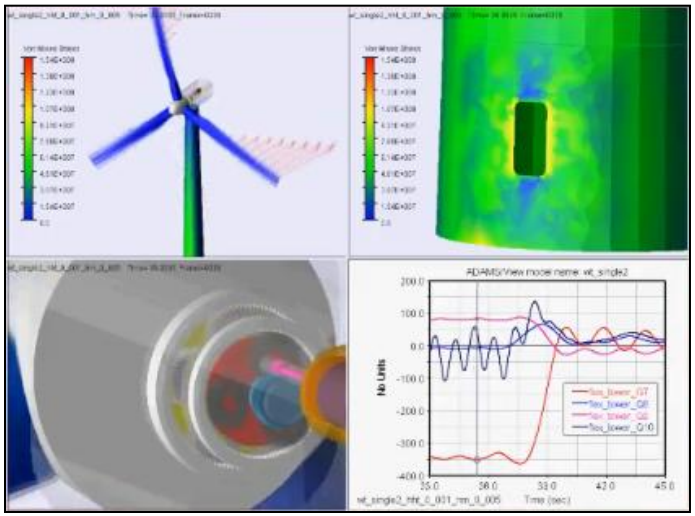
L’analisi multidisciplinare

Multidiscipline Parts & Systems

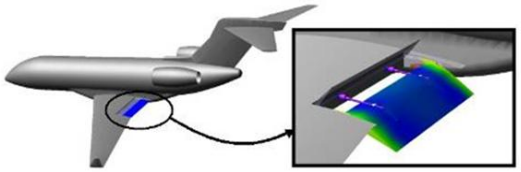
Controls-MBD-FE Integration

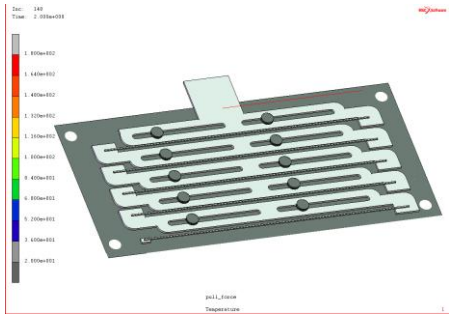


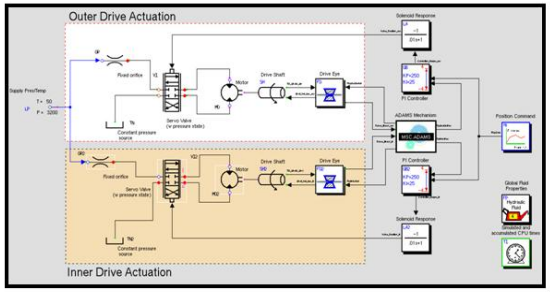
MBS + Fatigue

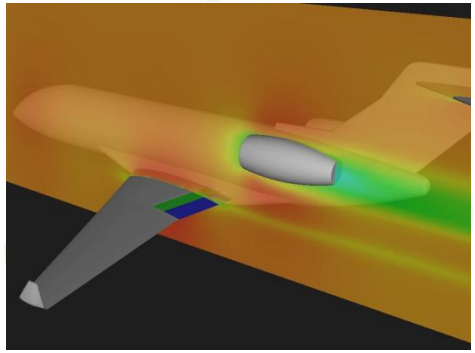


MBS + CFD + Fatigue









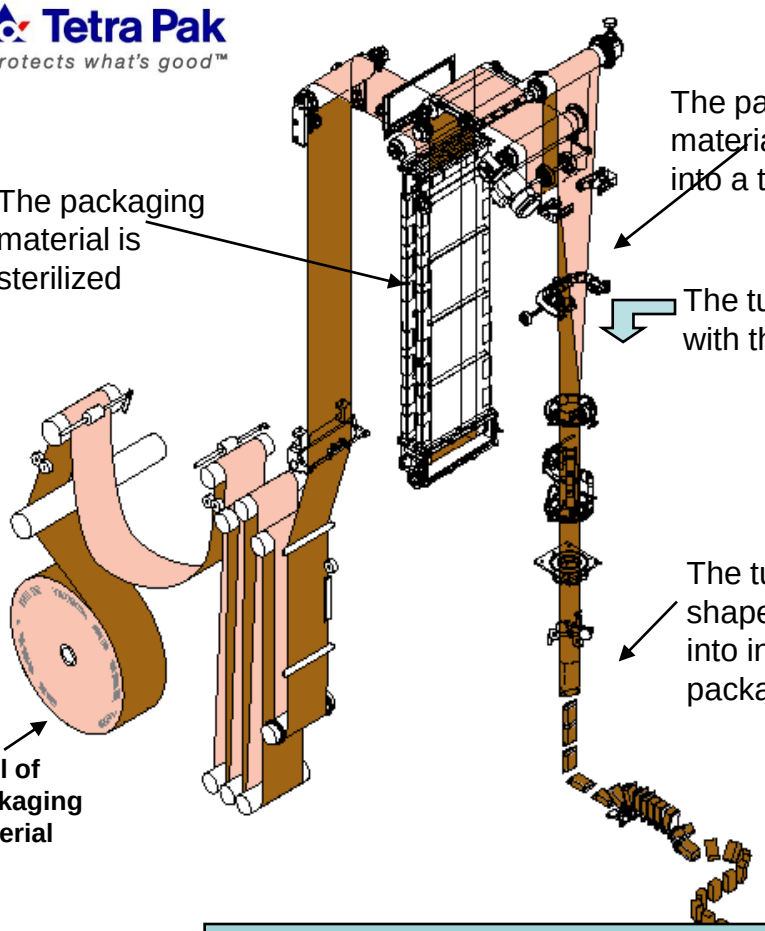
MBS + CFD + Fatigue + EE + Controls

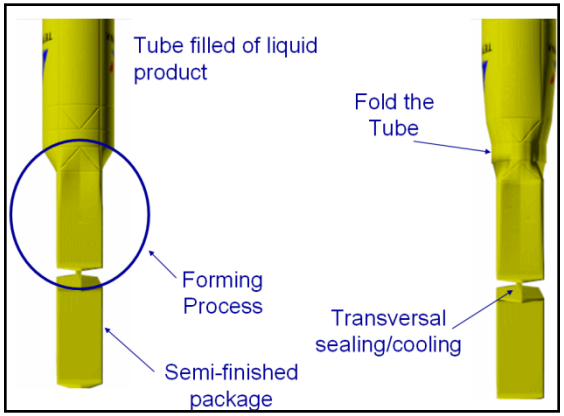
Tetra Pak A3 Flex
Multibody and Hydraulic Co-Simulation

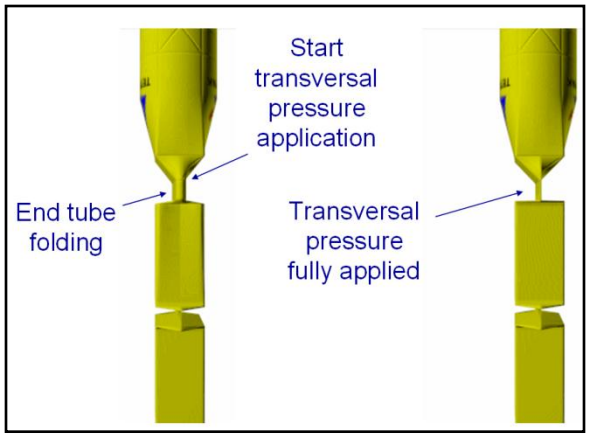
Courtesy by TetraPak

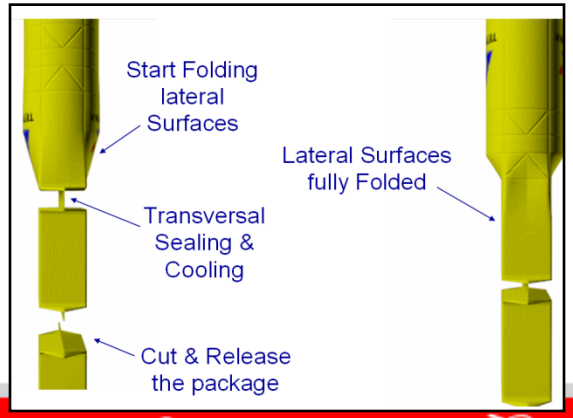
The Package Forming Process

Tetra Pak
protects what's good™





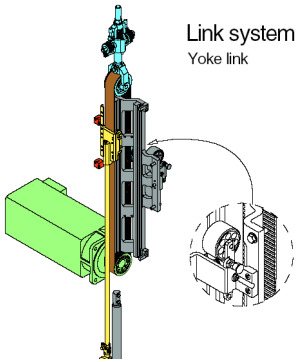


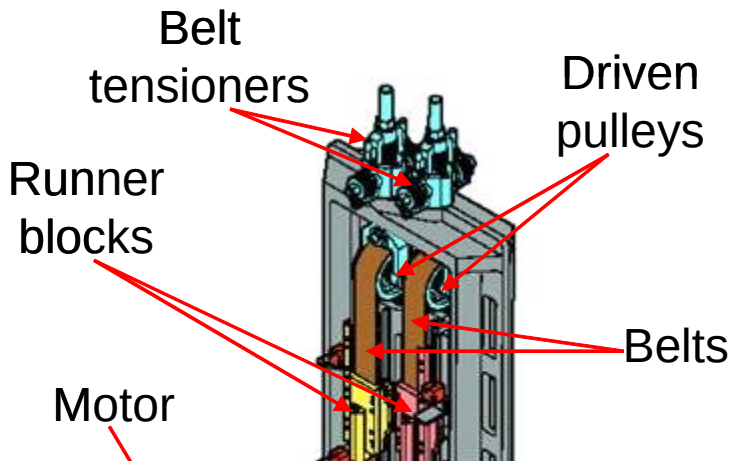


Competition requirements:

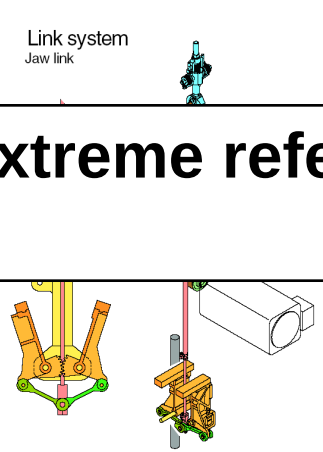
- **high production speed**
- **high precision**
- **minimun number of rejections**
- **lower cost**

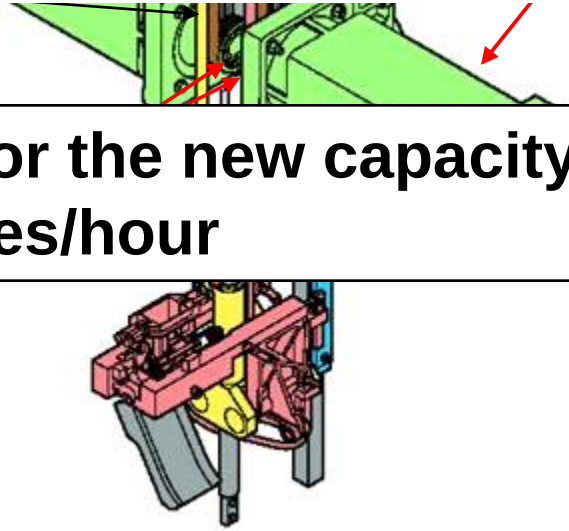
Tetra Pak A3 Flex Drive Unit





Due to belt elasticity the motion transmitted by the motor through the belt/pulley to the runner blocks will be affected by an error. An error below 1 mm is acceptable.

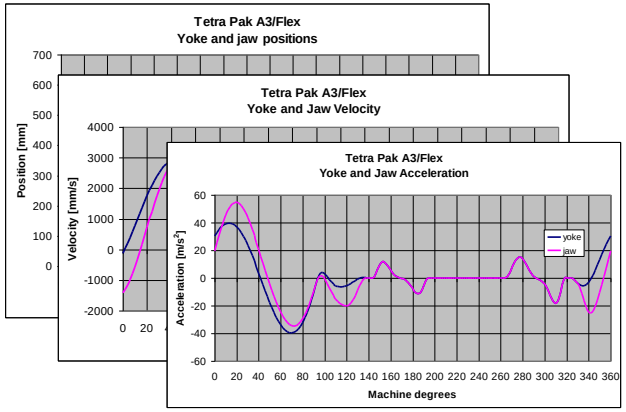


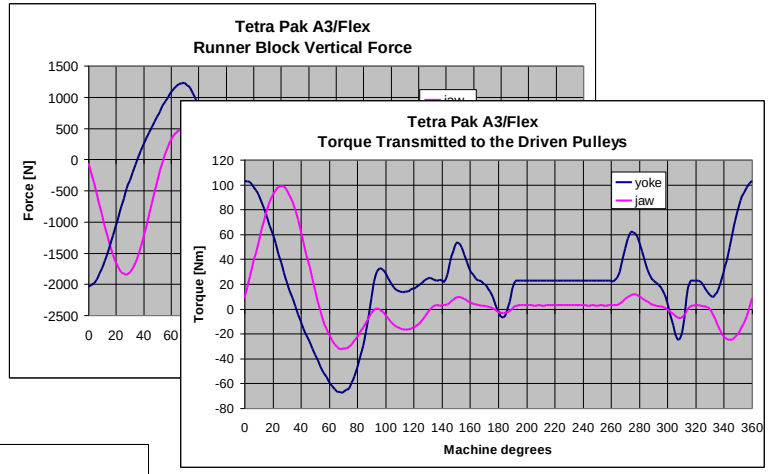


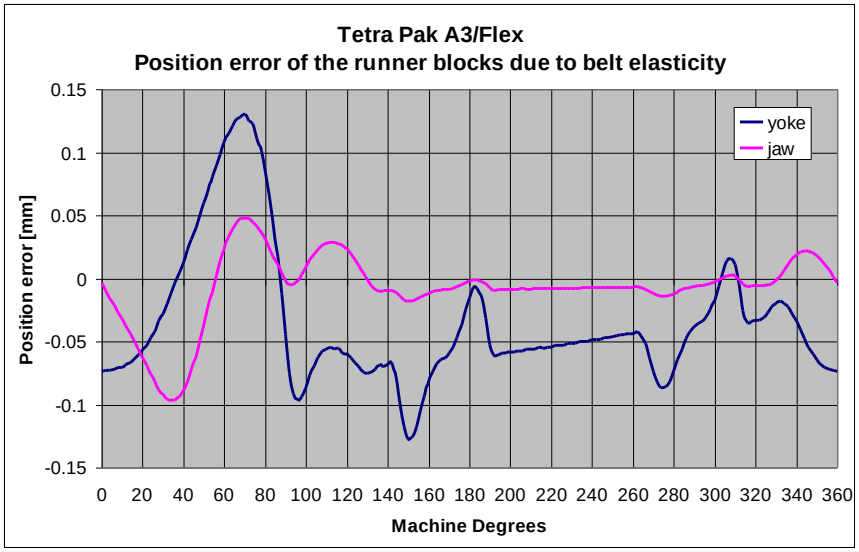
Extreme reference values for the new capacity of 8000 packages/hour

System Requirements

Cyclic behaviour (8000 p/h, cycle time = 0.9 sec.)







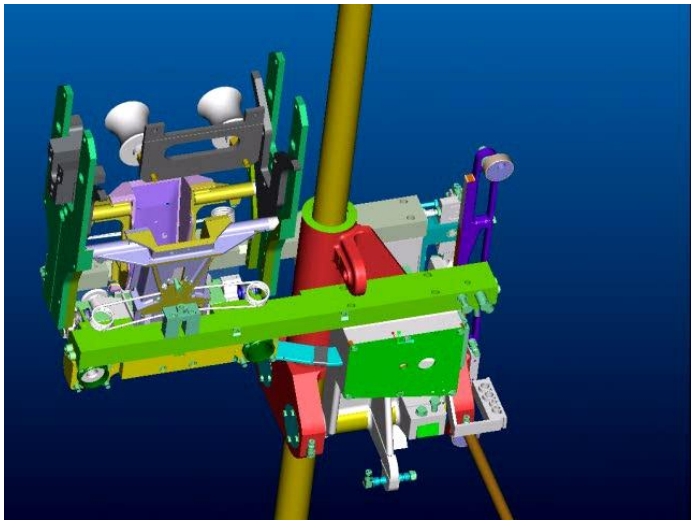
To satisfy requirements:

- **innovative technologies**
- **innovative process**
- **extension use of simulation**

Tetra Pak A3/Flex:Multibody simulation

Tetra Pak
protects what's good™

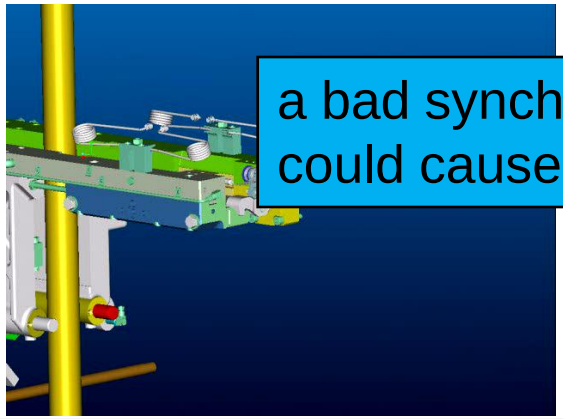
Drive Unit & Jaw System



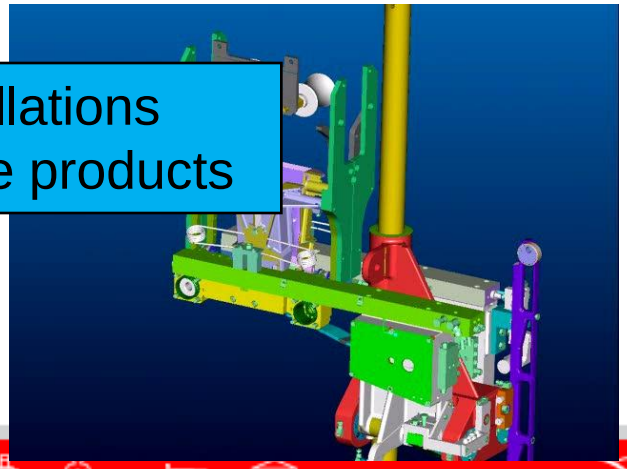
The multibody model of the entire mechanism has been implemented :

- To evaluate all the dynamic effects
- To prevent a not correct way of working of this machine
- To verify the correctness of movement of the different components as the Jaw system
- To verify the correctness of the spring stiffness
- To evaluate the influence due to the different required volume of production.

Transversal Pressure Application

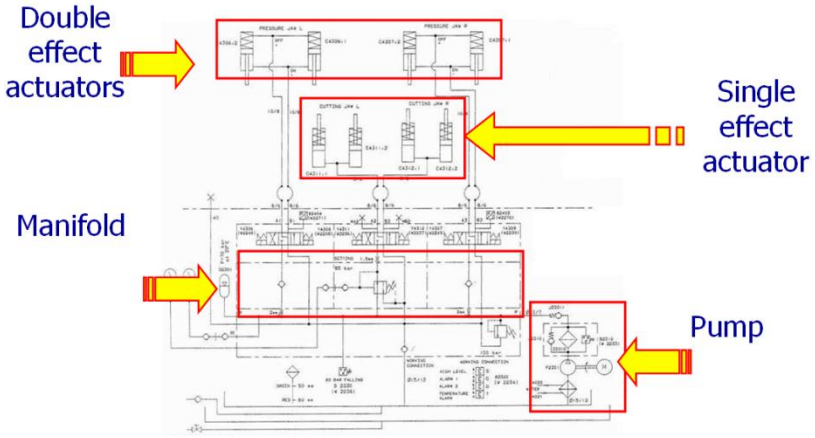


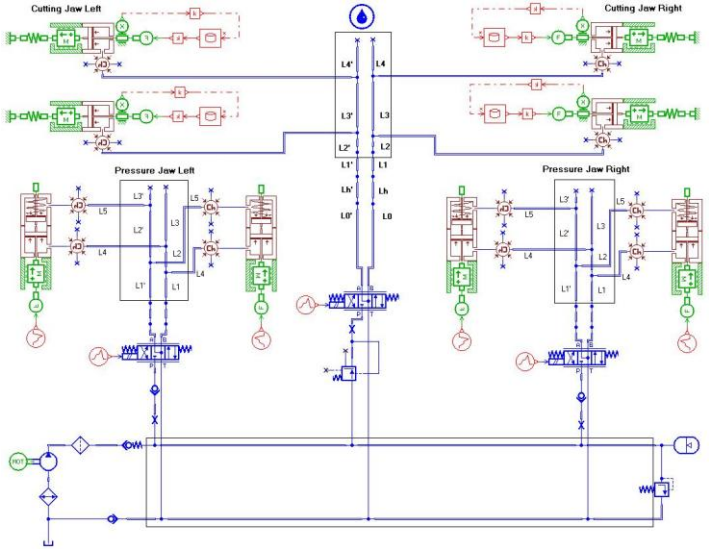
Fold Lateral Surfaces



a bad synchronism or oscillations could cause damage to the products

Tetra Pak A3 Flex: Hydraulic Circuit Simulation



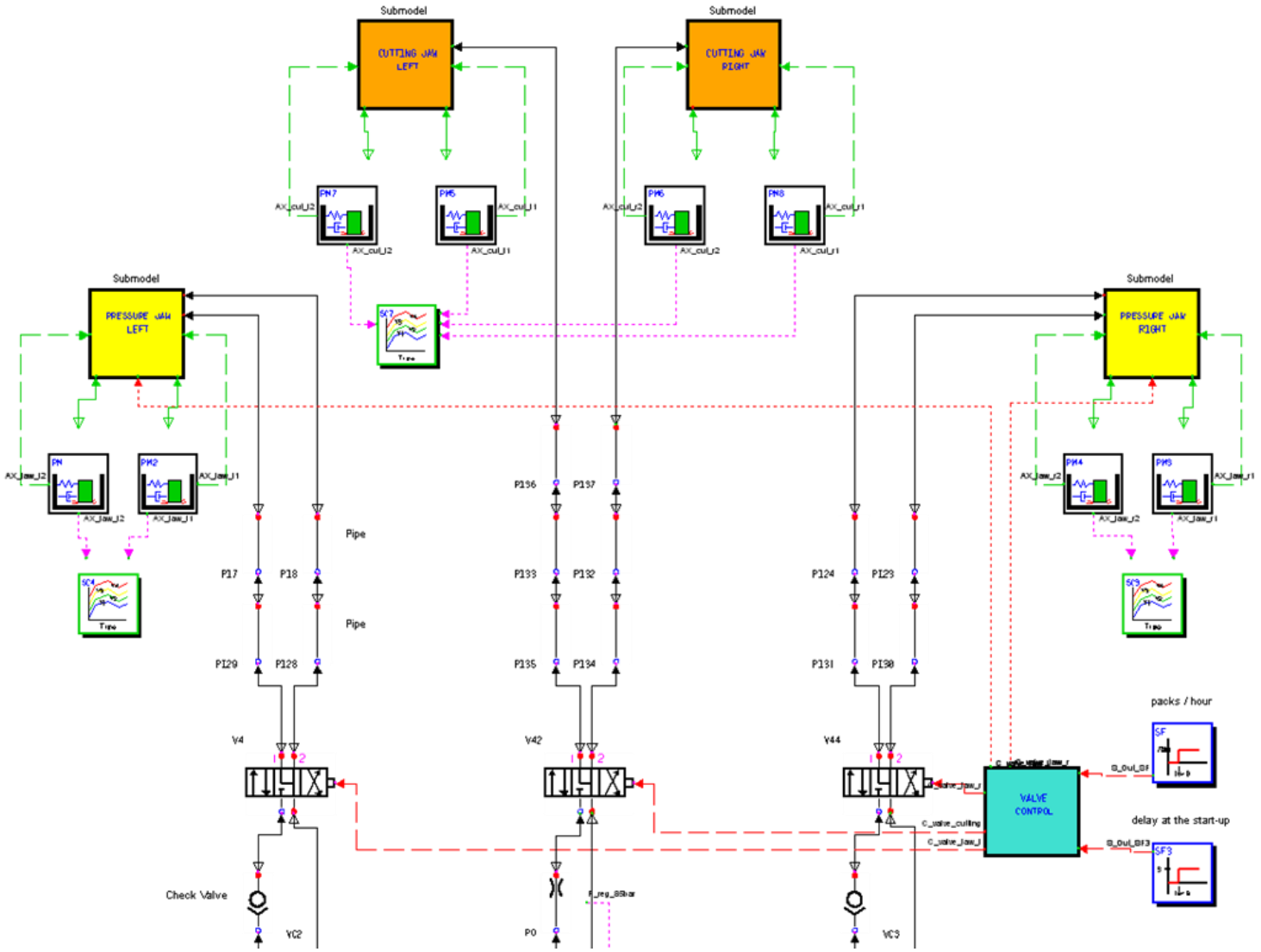


This machine presents also a hydraulic system
- to ensure the hooks closure
- to ensure the activation of the cut components
- to consider in the correct way the influence of the response and the physical delay due to the fluid behavior

A model of the hydraulic system has been implemented in MSC.Easy5.

Tetra Pak A3 Flex: Hydraulic Circuit Simulation

Tetra Pak
protects what's good™

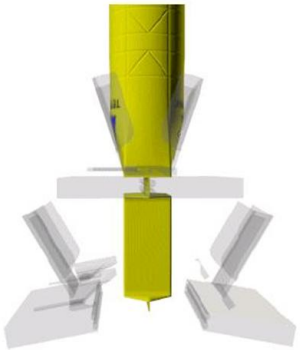


Tetra Pak A3 Flex:

Multibody + Hydraulic CoSimulation

Tetra Pak
protects what's good™

Double effect actuators:
- Pressure Jaw -

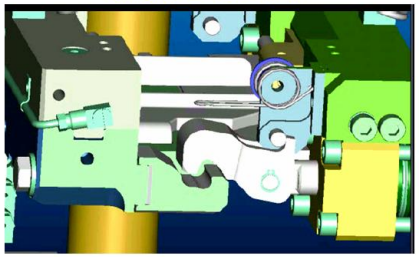


Function

Closing/opening hooks

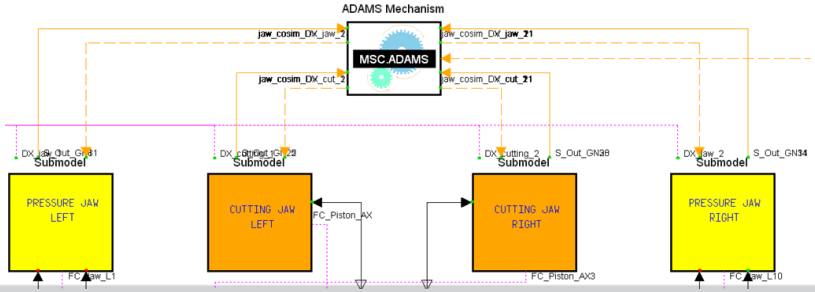
Design variables

Pressure = 100 bar
Stroke = 7.2 mm



Parameters to optimize:
- Section area
- Elastic module of flexible pipes
- Volumes
- Axisimmetry of hydraulic circuit
- Pressure oscillation of cutting jaw

The merge (cosimulation) of different competence has been done on a multidisciplinary field to obtain results as closer as possible to the reality.



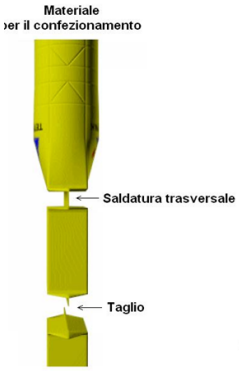
Single effect actuators:
- Cutting Jaw -

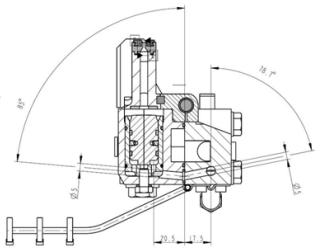
Function

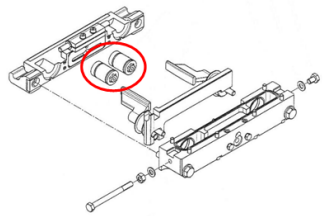
Package cutting

Design variables

Pressure = 85 bar
Stroke = 4 mm



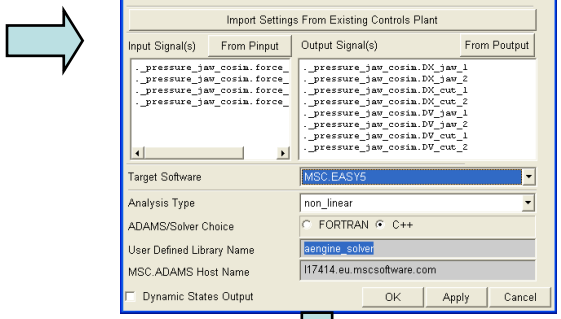




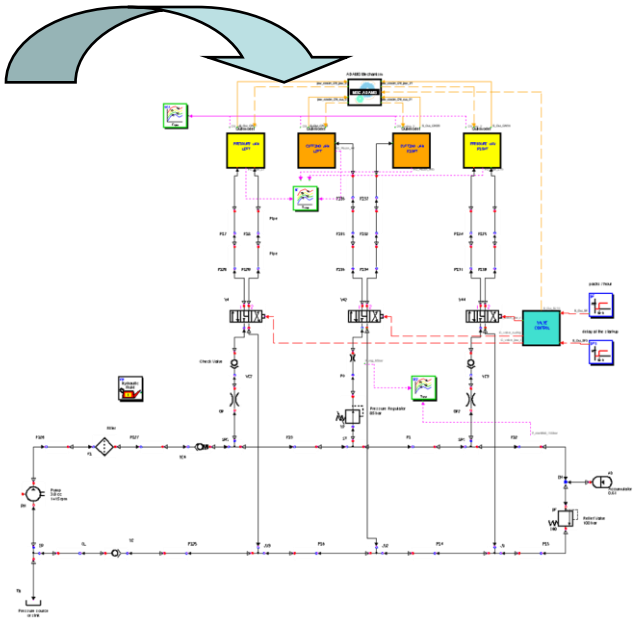
Tetra Pak A3 Flex:

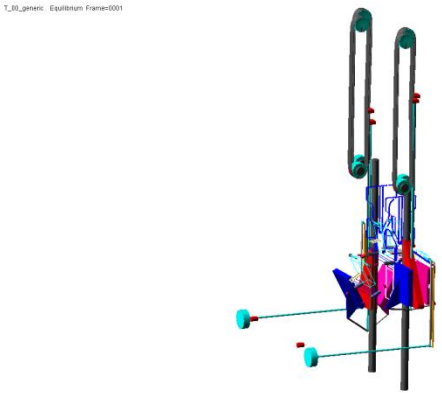
Multibody + Hydraulic CoSimulation

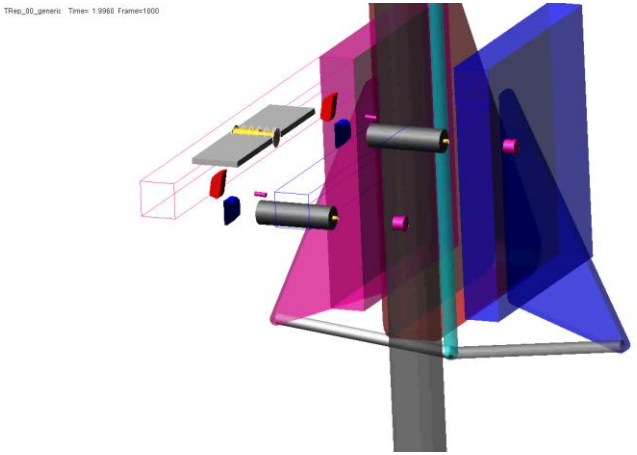
8 Input (actuator) channels;



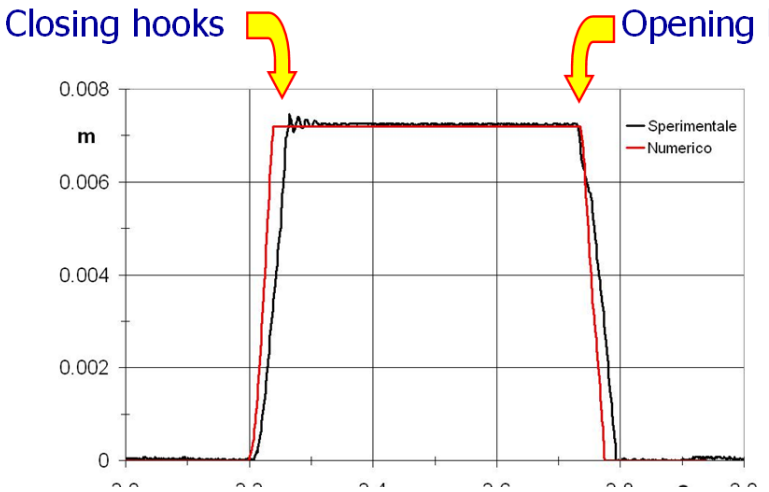
16 output channels:







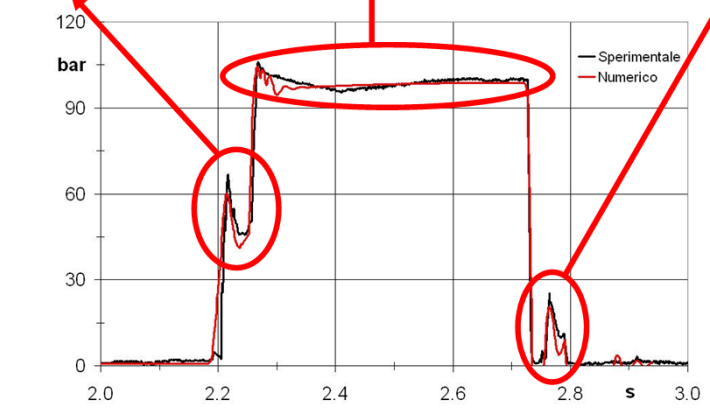
Comparison numeric-experimental data (7000 P/h)



Tank contribution

Friction

Passive chamber pressurization



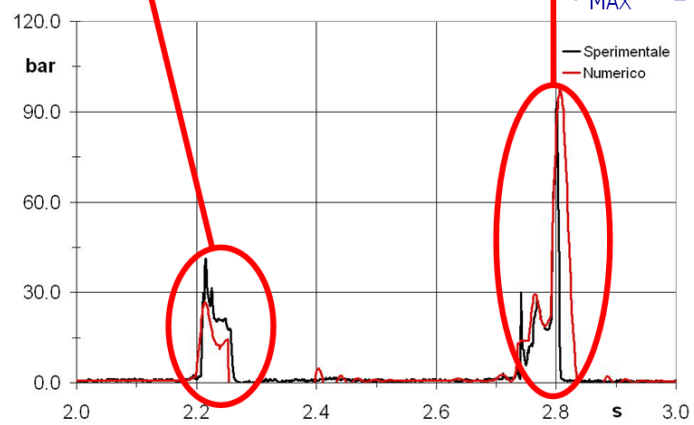
Chamber pressure - Pressure Jaw

Results show the importance of considering these two systems together, because the behavior of the hydraulic actuators are influenced by the movement of the jaw system and the dynamic of the entire system could be compromised by a bad actuation of the hydraulic system.

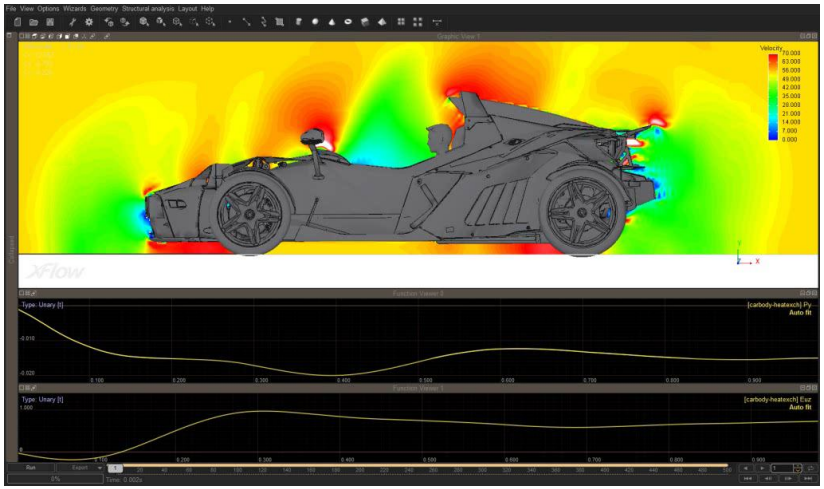
Passive chamber pressurization

Pressure for opening hooks

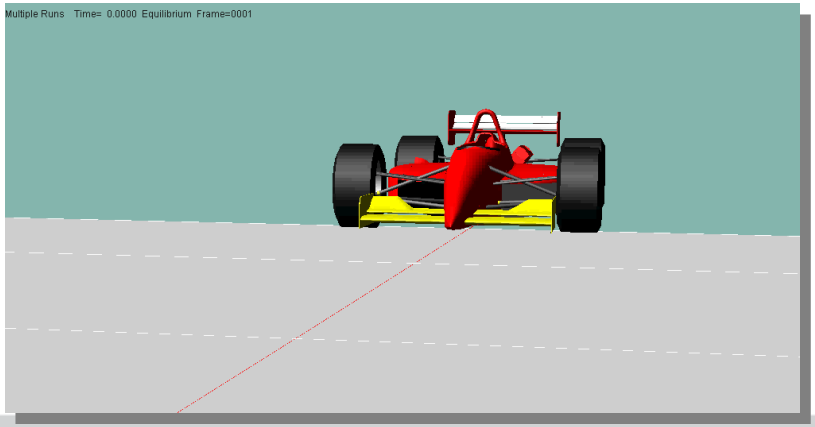
P_{MAX} < 100 bar



Chamber pressure - Pressure Jaw



CFD-FEM-Multibody Integrated Simulation for System-Level Dynamic Performance Including Aerodynamic Profiles



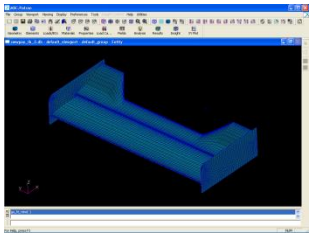

PETIT LE MANS
Road Atlanta
BRASELTON, GA

Front Wing Behavior

- F1 race
  - High-performance wing profiles consistently deform under static aerodynamic load
  - Inertial effects are superimposed
  - The dynamic performance of the profile is coupled to the performance of the chassis mechanical components
- How to take this effect into account into the simulation?

Multibody – Flexibility Effect

Design/Create Fe model

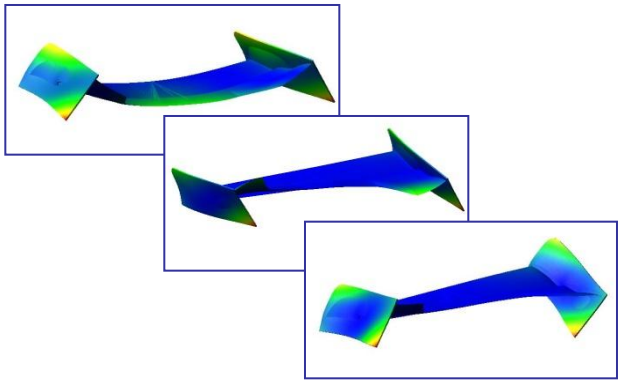


Craig-Bampton Component Mode Synthesis method

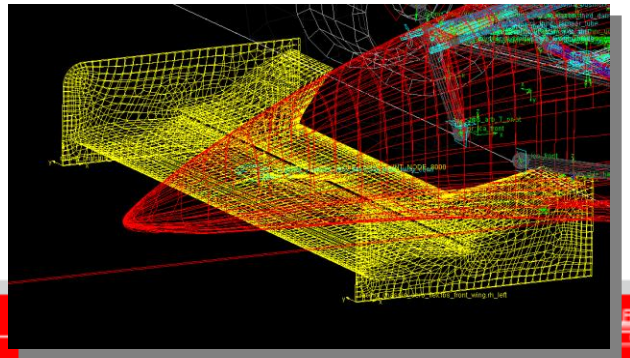
-STATIC CORRECTION MODES

-- NORMAL MODES

Calculate and Reduce flexibility



Integrate within MBS model



Modal
Neutral
File

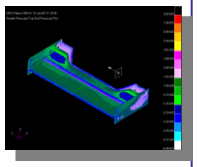
Multibody – Aerodynamic Effect

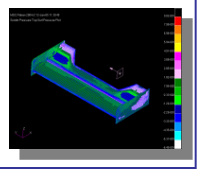
MSC.Patran modeling

CFD solver

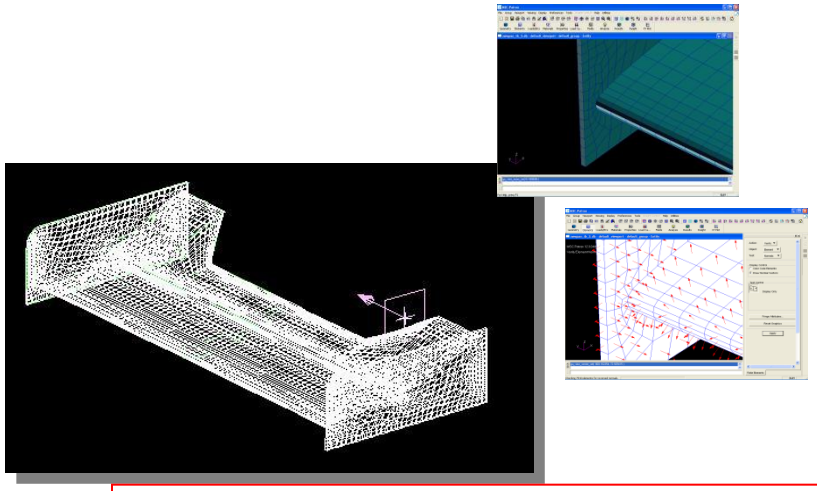
Pressure mapping

PLOAD4* 100	1772	1.435710043E-1
PLOAD4* 100	1773	9.546549618E-2
PLOAD4* 100	1774	-8.901300281E-2
PLOAD4* 100	1775	-1.059615090E-1
PLOAD4* 100	1776	-1.078199968E-1
PLOAD4* 100	1777	-1.358184814E-1
PLOAD4* 100	1778	-1.872119904E-1
PLOAD4* 100	1779	-1.678085029E-1
PLOAD4* 100	1780	-1.432814896E-1
.....		



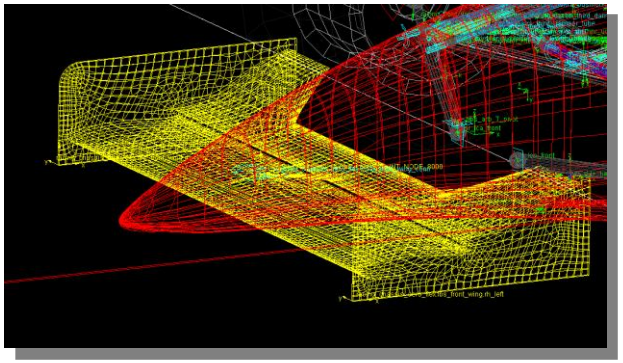


MSC.Nastran modal analysis (CMS) with applied pressure distribution (PLOAD4) projected onto modal base through modal loads f(RH, alpha)



Modal Neutral File (MNF) generation

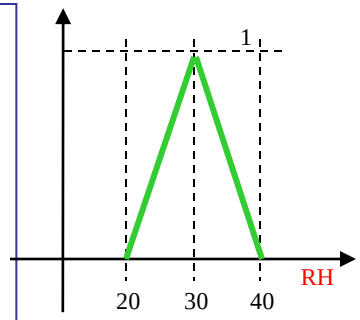
Integration into full-vehicle MB model



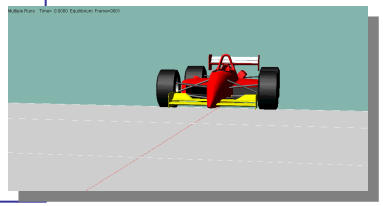
Coupling CFD and FEM

- **CFD stationary states:**
  - **Rigid body states**
    - **RH**
    - **Side slip**
    - **Angle of attack**
  - **Deformed shapes**
    - **Selected according to sensitivity**
    - **Each shape requires 2 CFD runs (+/-) since up/downwards deformation leads to different pressure distributions**
    - **Modal pressure applied as delta with respect to undeformed shape**
- **Each aero pre-calculation leads to an independent aero map**
- **Superposition effects criterion is used (assumption of linearity)**

Ride Heights:
-20mm
-10mm
30mm (BASE)
+10mm
+20mm



Side Slip:
-5deg
0deg (BASE)
+5deg

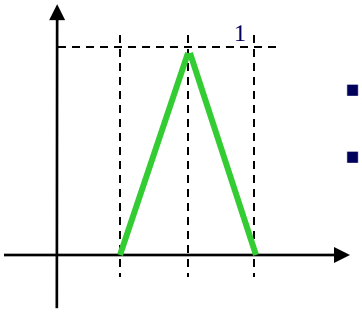


Angle of Attack:
-2deg
0deg (BASE)
+2deg

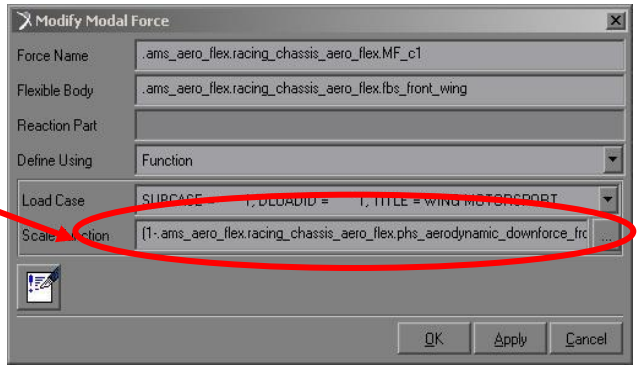
Deformation:
first bending +/-
first torsion +/-
second torsion +/-

Coupling CFD/FEM/MB

MFORCE



- Scaling factor expresson:
- F(time, states)



Aero Map Scaling factors

FUNCTION OF:

- Angle of attack
- ride height
- Side slip
- Yaw
- Roll
- Deformation
- ...

and

D

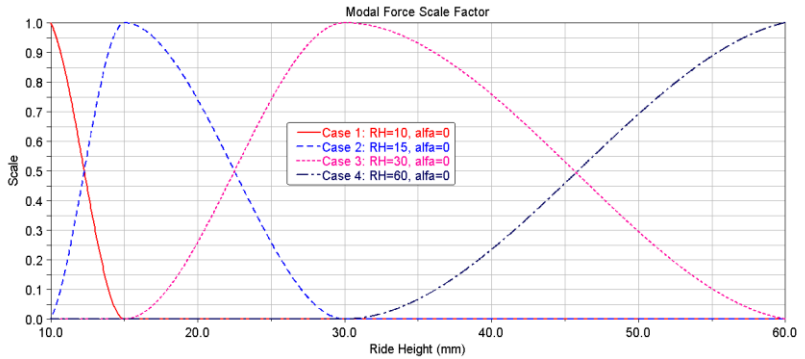
- Angle of attack
- Side slip
- Yaw
- Roll
- Deformation
- ...

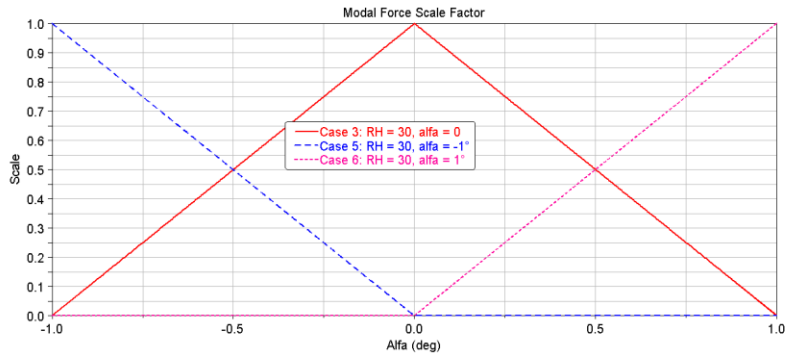
/DT

D^2

- Angle of attack
- Side slip
- Yaw
- Roll
- Deformation
- ...

$/DT^2$

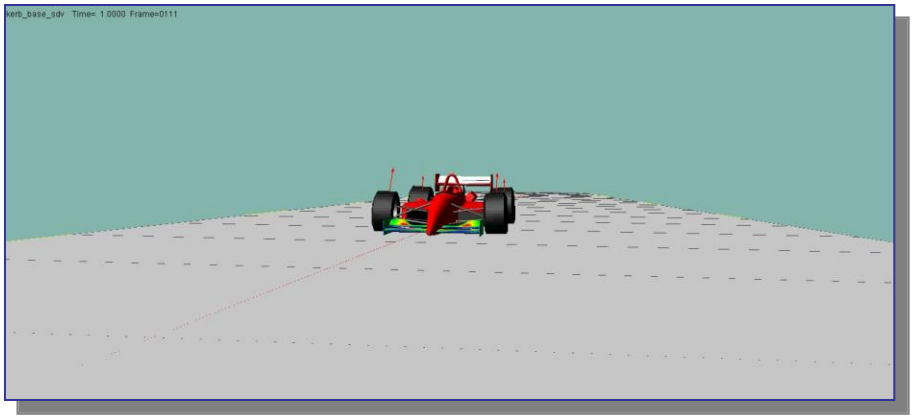




STEADY UNSTEADY

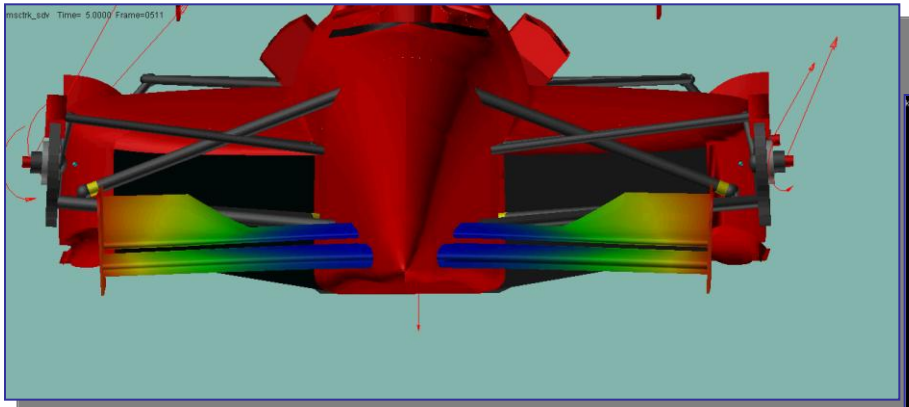
The Multibody Model as Integration Platform

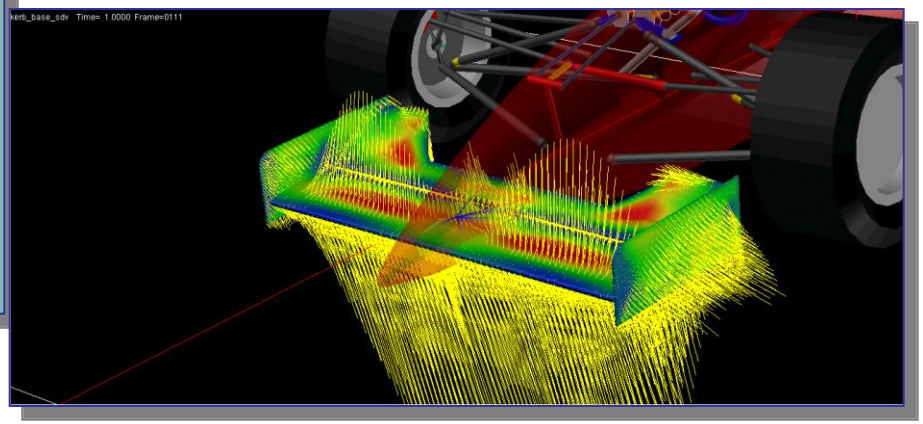
- **Full Vehicle simulation**
  - Vehicle Setup in dedicated GUI
  - Track generation from GPS or telemetry, with added kerbs defined geometrically
  - High-performance tires
  - Closed loop driver model
    - Lap time Calculation
  - Flexible front wing, including
    - Modal flexibility
    - Modal pressure



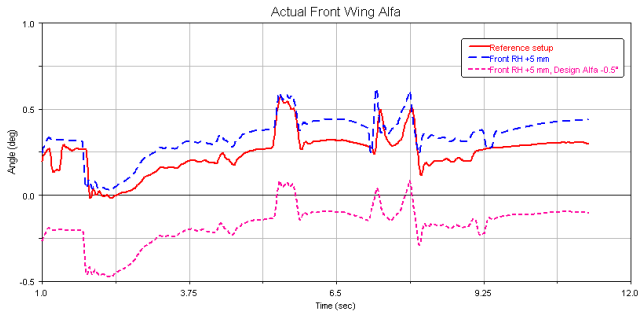
- **High-speed chicane maneuver**
  - Velocity about 200 km/h

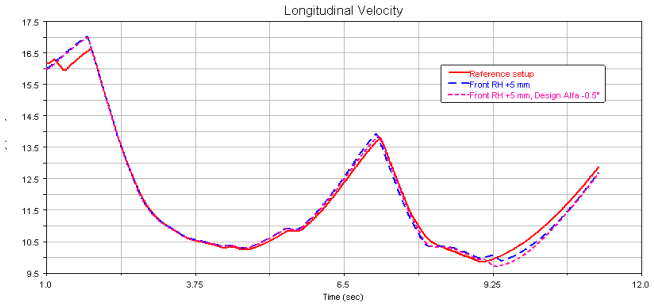
The Multibody Model as Integration Platform



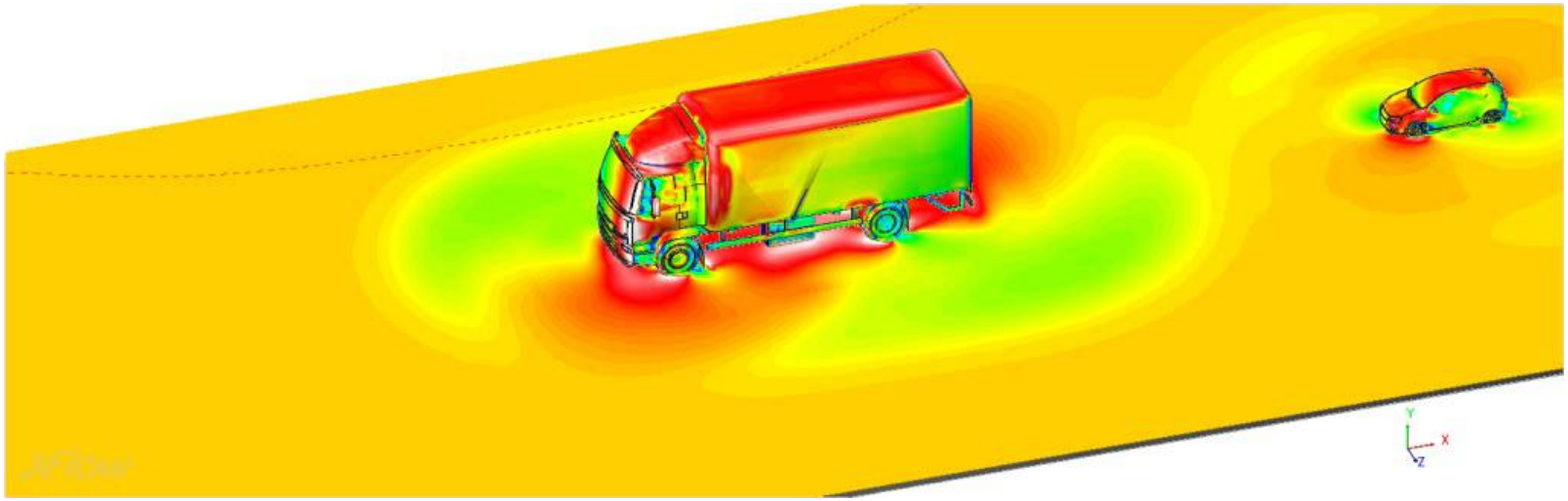


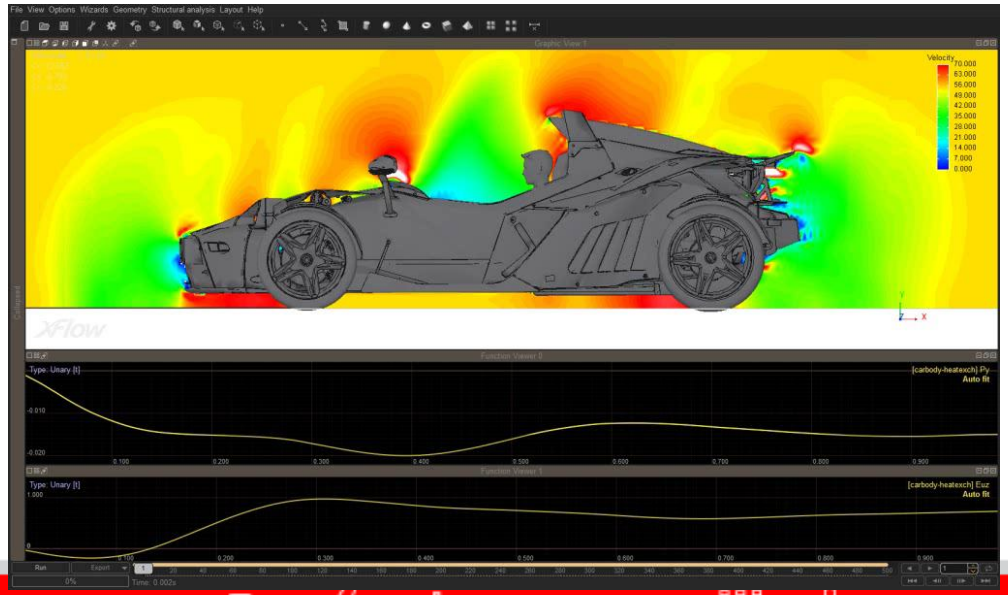
- **Front Wing Performance Comparison**
  - RH and alpha influence speed and lateral acceleration
  - Changes in downforce influence damper reactions





Next frontier: CFD fully integrated with Multibody





UAV Sky-Y flight loads: a Multi-Disciplinary approach

Daniele Catelani (MSC)

G.M. Carossa, E. Baldassin, R. Digo, E. Marinone, O. Valtingojer (Alenia Aeronautica)

MSC Software

Virtual Simulation of Helicopter Ship Deck Operation: Blade Sailing

Courtesy by AgustaWestland

Purpose: simulate VIRTUALLY the condition that an helicopter could experience on a ship deck

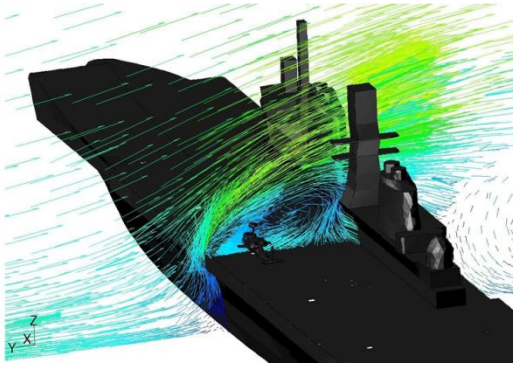
Reasons:

- Increase number and combinations of Ship Trials simulated conditions

In Order to:

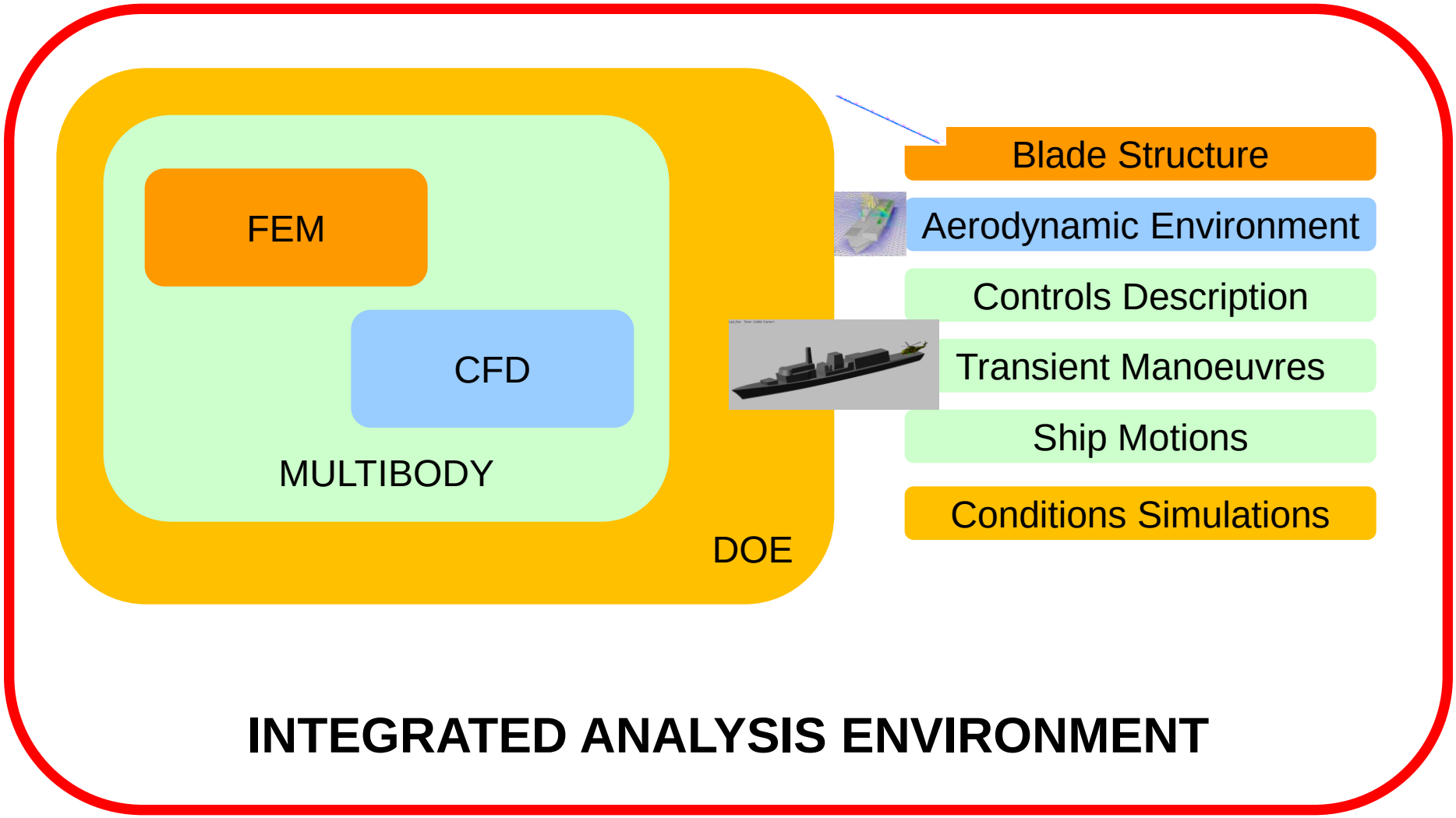
- Reduce risk of damage during Ship Trials
- Reduce duration of Ship Trials
- Reduce Cost

Note: Ship deck environment is VERY DIFFERENT from Ground one, in terms of wind and dynamic movement of the ship



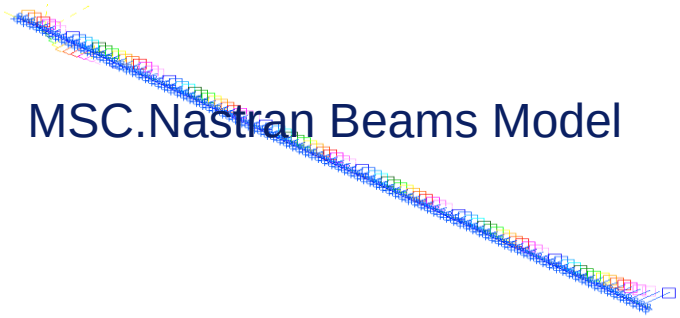
More Than Words

Multidisciplinary Problem

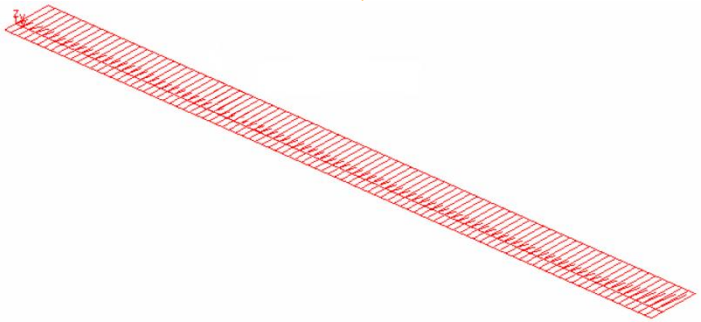


Blade Structure: FEM / ADAMS Flex

MSC.Nastran Beams Model

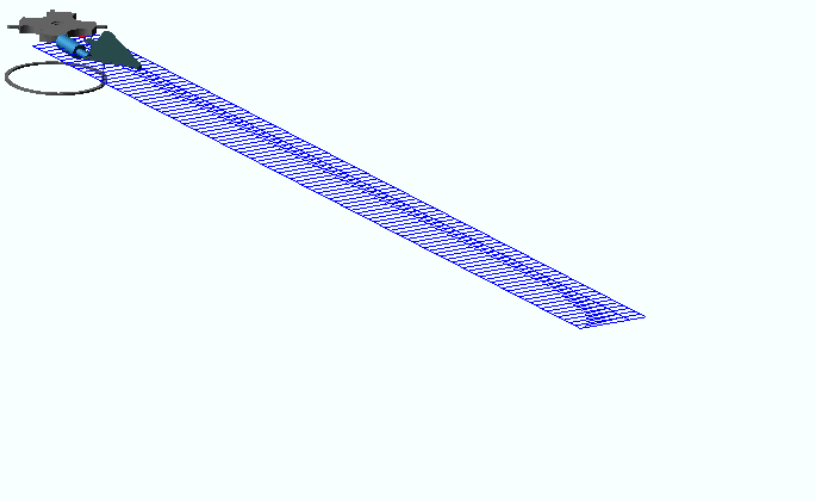


Component Mode Synthesis



Inertia

Structural Stiffness



Centrifugal Stiffness

=

Centre Mass

+

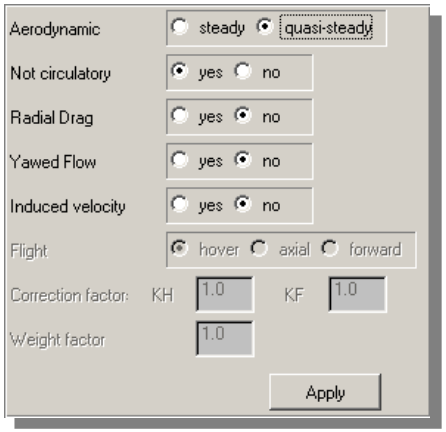
Elastic Deflection

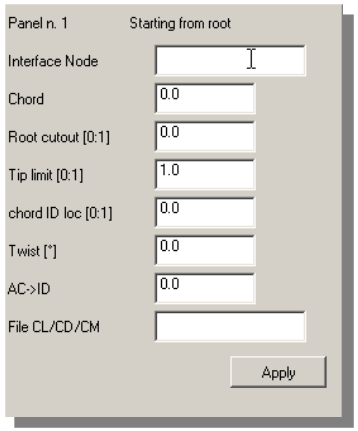
Aerodynamic Environment

Blade Aerodynamic Forces → Complex Routine

Rotor Aerodynamic Field

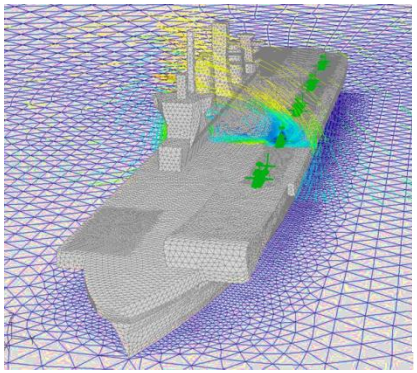
- panel method
- steady/unsteady flow
- Inflow effect
- axial/hovering/forward flight

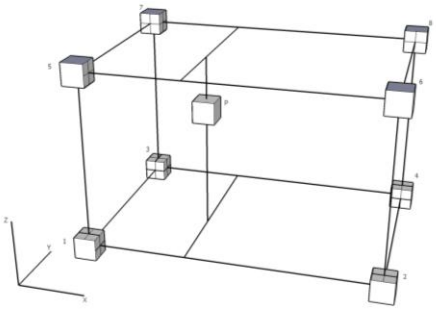




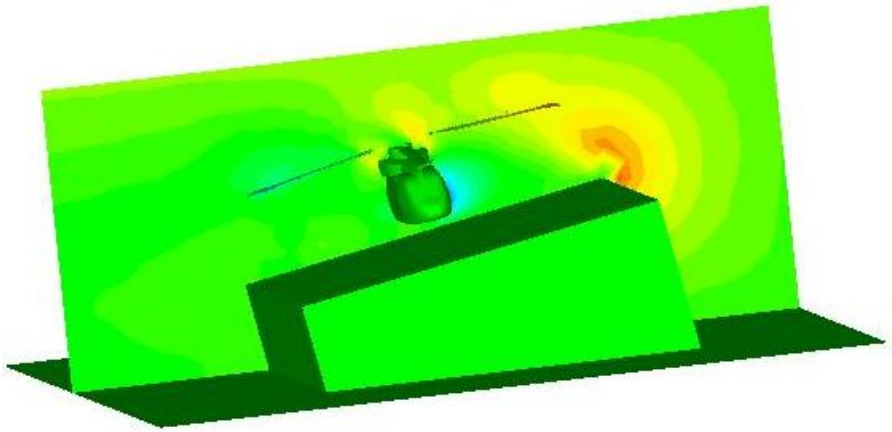
Wind Non Uniform Field

- CFD Based
- 3D Interpolation





CFD Based Aerodynamic



CFD Analysis

Wind Components on Grid Points

3D Interpolation

Non Uniform Wind Velocity Field

Ship Motion

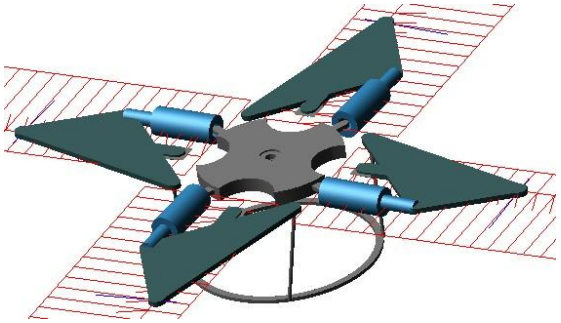
Rotor Motions

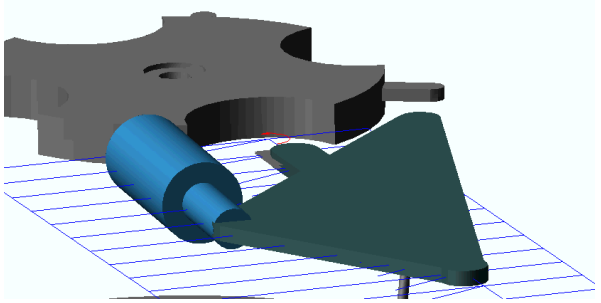
Wind Additional Components

Aerodynamic Forces

MultiBody

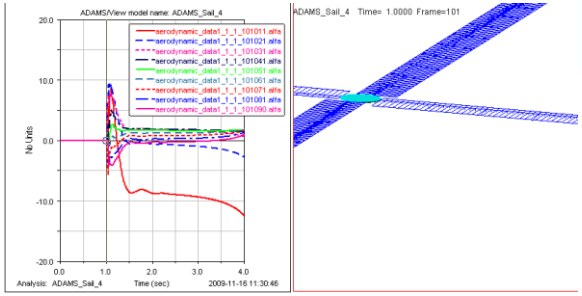
Submodel



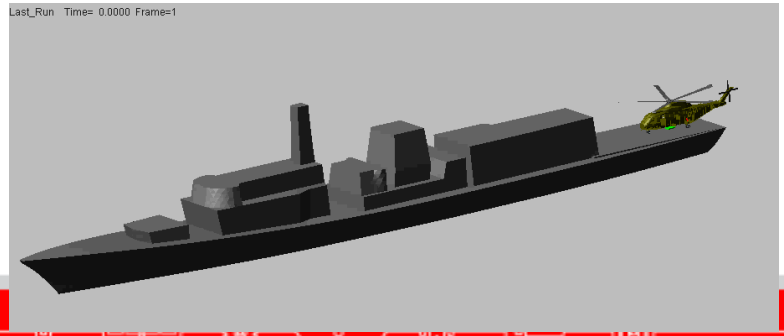


•Rotor Control Chain
•Blade Flap Stops
•Helicopter

Rotor Transient



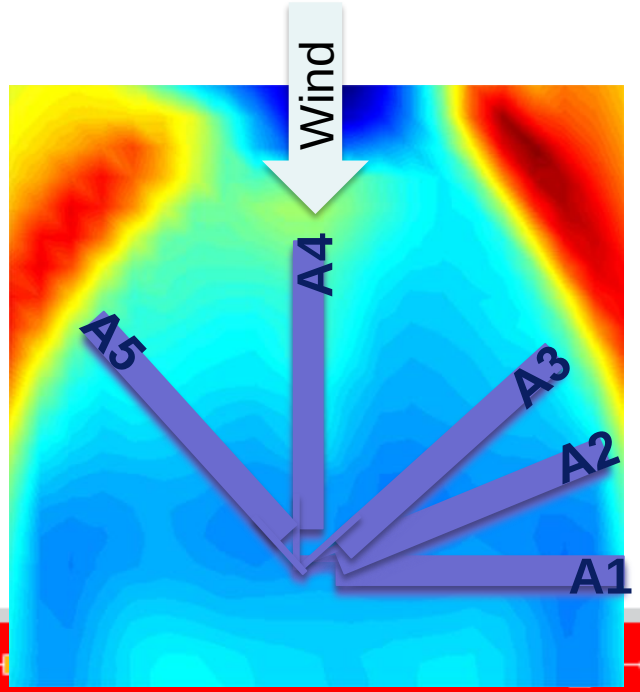
Ship:
• Motions
• Helicopter Spot

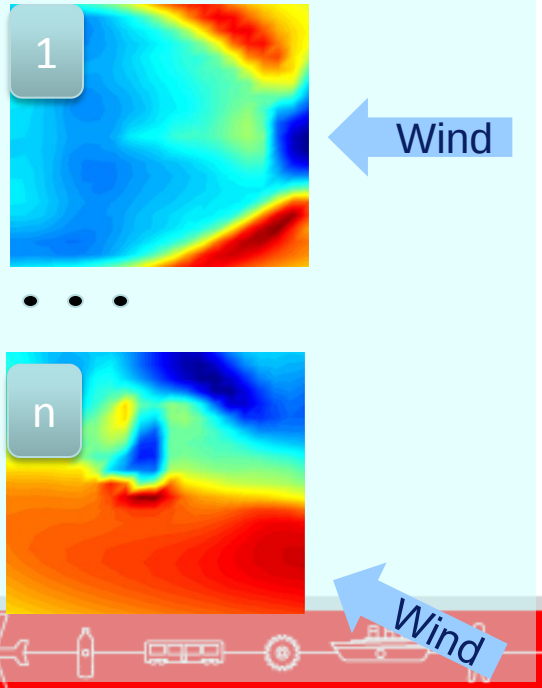


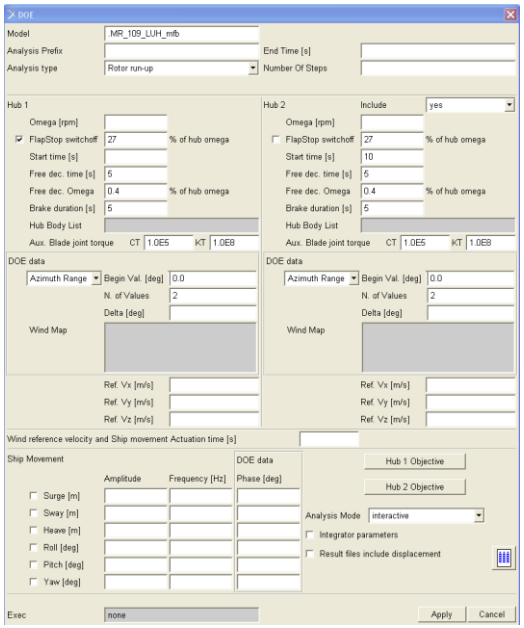
Doe Analysis

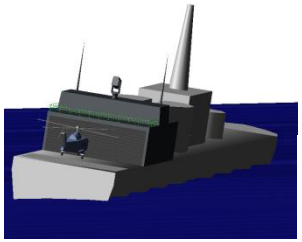
Customized Advanced Design of Experiment:

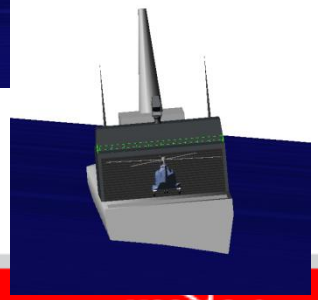
- Single Blade Analysis
- Blade Starting Azimuth
- Wind Maps (CFD)
- Ship Motion Phases







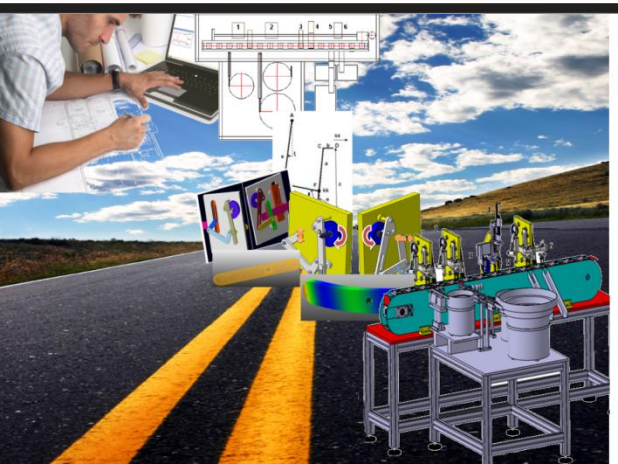




CAE & Ricerca

Application a Sistemi Meccanici

Presented By: Dr. Ferdinando Cannella, IIT Genova



LA FRONTIERA DELLA SIMULAZIONE NEL SETTORE MACHINERY:
dalla progettazione alla messa a punto di macchine e meccanismi

POLITECNICO DI MILANO
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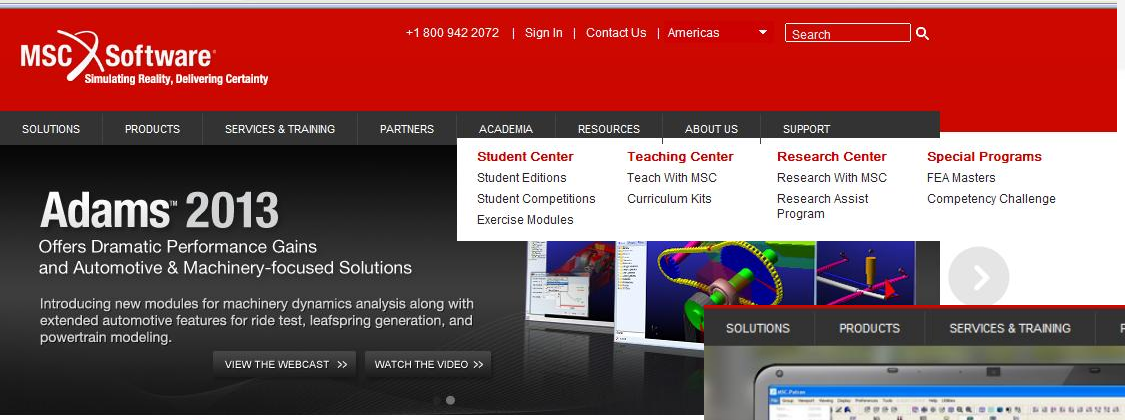

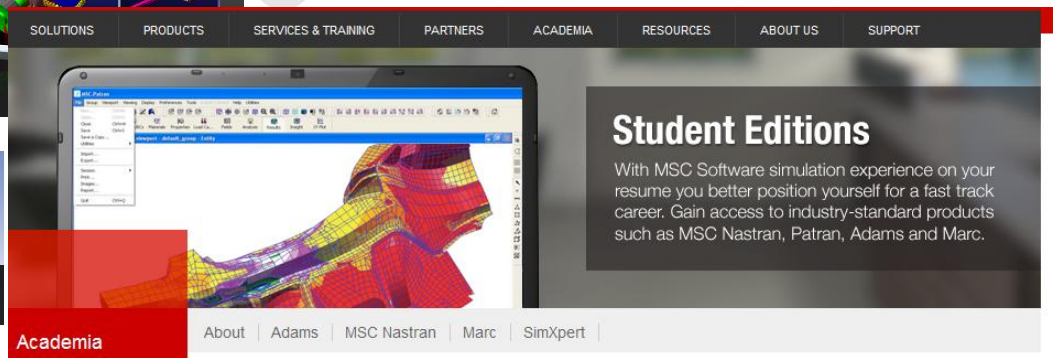

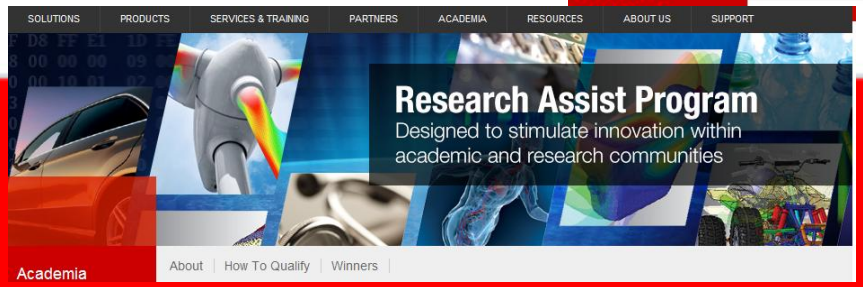

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Contatti:

- www.mscsoftware.com
- daniele.catelani@mscsoftware.com

Grazie