Metodi e strumenti di calcolo per la prototipazione virtuale: l'analisi multibody e multidisciplinare
Adams: Automatic Dynamic Analysis of Mechanical Systems

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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
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)
Basic Concepts

- **Rigid Bodies:**
  - Use 6 coordinates to represent rigid body location
  - Represent inertia forces in terms 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 ($\lambda$)

- **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, $\Phi$, has $f = (n-m)$ dof
  - $n$ coordinates $q$, and $m$ variables $\lambda = (n+m)$ 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

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

$\sum A_{ij}(q) \dot{q}_i + A_{it} = 0$
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
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 integrated 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
    - \( M\ddot{u} + Cu + Kq = 0 \)
    - \( u - \dot{q} = 0 \)
  - \( M, C, K \) 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
Basic Concepts

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

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

with:
- \( L \) = T-V = kinetic energy of the system - potential energy
- \( q \) = generalized coordinates of the system
- \( \Phi \) = constraint function
- \( \lambda \) = Lagrange-multiplicators
- \( Q \) = generalized external loads
- \( m \) = number of constraint equations
- \( l \) = 1,2,...,5,6 (translational and rotational components)
Equation Formulation: Dynamics

\[ \dot{p} - \frac{\partial L}{\partial q} + \phi_q^T \lambda - H^T F = 0 \rightarrow \text{Differential Equation} \]

\[ p - \frac{\partial L}{\partial \dot{q}} = 0 \rightarrow \text{Momentum Definition} \]

\[ u - \dot{q} = 0 \rightarrow \text{Differential Equation} \]

\[ \phi(q,t) = 0 \rightarrow \text{Constraint Equation} \]

\[ F - f(q,u,t) = 0 \rightarrow \text{Force Definition} \]
Solution of DAE

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

**Phase 1:** Predict an initial guess
\[
y_{n+1}^p = \sum_{i=0}^{k} \frac{h^i y_n^{(i)}}{i!}, \quad k=\text{integration order}
\]

**Phase 2:** Correct the guess
\[
\begin{align*}
\left[ \frac{\partial G}{\partial y} + \frac{1}{h\beta_0} \frac{\partial G}{\partial \dot{y}} \right] \Delta y &= -G \\
y^{(\text{new})} &= y^{(\text{old})} + \Delta y
\end{align*}
\]

**Phase 3:** Evaluate quality of solution (accept solution)
\[
\|\Delta y\| \leq \text{corrector error tolerance}
\]

**Phase 4:** Prepare for next step
Basic Concepts

- Displacement, velocities, accelerations, reaction forces: Jacobian matrix evaluation
  \[
  \Phi(q,t) = 0
  \]
  \[
  \Phi(q,\dot{q},t) = \left[ \frac{\partial \Phi}{\partial q} \right] \dot{q} + \frac{\partial \Phi}{\partial t} = 0
  \]
  \[
  \left[ \frac{\partial \Phi}{\partial q} \right] \dot{q} = -\frac{\partial \Phi}{\partial t} \quad \text{or} \quad \dot{q} = -\left[ \frac{\partial \Phi}{\partial q} \right]^{-1} \frac{\partial \Phi}{\partial t}
  \]

- 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

\[ f(x) = 0 \]

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

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

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

\[ \ldots \]
Basic Concepts

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

\[
x^{(1)} = x^{(0)} - \frac{f(x^{(0)})}{f'(x^{(0)})}
\]
\[
\vdots
\]
\[
x^{(4)} = x^{(3)} - \frac{f(x^{(3)})}{f'(x^{(0)})}
\]
\[
x^{(5)} = x^{(4)} - \frac{f(x^{(4)})}{f'(x^{(4)})}
\]
\[
\vdots
\]
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)
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, Cylindrical, 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*
Il codice di calcolo multi-body

**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
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 sensibilità
- Ottimizzazione

- Confronto con risultati sperimentali
  - Verifica e iterazione
- Certificazione e produzione
Product Development

(The Old Way)

Physical Test and Redesign

Hardware Based

Manual Drafting

Physical Prototype

Product Development
Product Development
(The New Way)

Functional Virtual Prototyping

Virtual Product Development

3D CAD

Digital Mock-up
Integration Platform

- **3D CAD**: Import models and data from CAD, In-house models, and other MSC products.
- **MSC.EASY5**: Import models and data from CAD, In-house models, and other MSC products.
- **MSC.Nastran**: Import models and data from CAD, In-house models, and other MSC products.
- **In House Tire Models**: Import models and data from CAD, In-house models, and other MSC products.
- **CFD Models**: Import models and data from CAD, In-house models, and other MSC products.

- **Detailed Loading Conditions for MSC.Nastran**: Export data for detailed stress simulation and durability analysis.
- **Stress time Histories for MSC.Fatigue**: Export data for detailed stress simulation and durability analysis.
- **Durability**: Export data for detailed stress simulation and durability analysis.
Supported CAD Integration

Suppliers and Customers use different CAD systems.

MSC.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.
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

ADAMS/Durability
Esempi
Low Voltage Circuit Breaker

- Simple geometry
- Structural Springs including Mass
- Very rapid dynamics
- Rigid vs Flexible Results
Low Voltage Circuit Breaker

Graphs showing reaction forces for different spring types. The graphs display the forces in the x and y directions as functions of time.

- **Reaction FlexStruct/Ground -Fx**
- **Reaction FlexStruct/Ground Fy**

Spring Forces depending on spring type:

1. **Flexible**
2. **Rigid**

Graphs also show data from ANSYS structural spring and ADAMS spring.
Pothole passing with a Truck - 1

- Pothole-passing manoeuvre 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
Pothole passing with a Truck - 2

- 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

Improve collaboration between your controls engineers and your systems engineers.

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

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

Simultaneously understand the operation of your mechanical and control systems.

Share the Same Models

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
Motorsport
Motorcycle
Engine & Driveline
Rail
Aircraft
Wind Energy
Machinery, Packaging & Robot
Design Process
“IDEAL” DESIGN PROCESS

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

Technical Specifications

CAD MODEL

CATIA V5

FE MODEL

MSC.Nastran

CAD

MULTIBODY MODEL

MSC.Adams

Adams/flex

Adams/Durability

FATIGUE MODEL

MSC.Fatigue

Certification & Product

MSC.Patran

MSC.Adams

MSC.Patran

MSC.Nastran

MSC.Fatigue

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

Technical Specifications

SKETCHED MODEL

K (stiffness) & M (mass) data

Approximations
Hypothesis
Fantasy
Previous Data
Experimental Data

MULTIBODY MODEL

Preliminary Design

MSC.Adams

MSC.Nastran

MSC.Patran

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

Technical Specifications

DETAILED MODEL

FE MODEL

Preliminary design

Concurrent Engineering

Logic Process Flow

All data available

Project history (pedigree)

ALL DEPts work together

MSC.Patran

MSC.Nastran

CATIA V5

CFD

Tires

S/A

Brakes

CFD

Aeroelastic Analysis

ALL DEPts work together

Concurrent Engineering

Logic Process Flow

All data available

Project history (pedigree)
“REAL” DESIGN PROCESS: from Detailed design to Certification and Product
L’analisi multidisciplinare
Multidiscipline Parts & Systems
Controls-MBD-FE Integration

MBS + Fatigue

MBS + CFD + Fatigue + EE + Controls
Tetra Pak A3 Flex
Multibody and Hydraulic Co-Simulation

Courtesy by TetraPak
The Package Forming Process

- The packaging material is sterilized.
- The packaging material is formed into a tube.
- The tube is filled with the product.
- The tube is shaped and cut into individual packages.

Competition requirements:
- high production speed
- high precision
- minimum number of rejections
- lower cost
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
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.

A bad synchronism or oscillations could cause damage to the products.
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.
Parameters to optimize:
- Section area
- Elastic module of flexible pipes
- Volumes
- Axisimmetry of hydraulic circuit
- Pressure oscillation of cutting jaw

Tetra Pak A3 Flex: Multibody + Hydraulic CoSimulation

Double effect actuators:
- Pressure Jaw
  
  Function: Closing/opening hooks
  
  Design variables:
  - Pressure = 100 bar
  - Stroke = 7.2 mm

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)

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.
CFD-FEM-Multibody Integrated Simulation for System-Level Dynamic Performance Including Aerodynamic Profiles
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
- Calculate and Reduce flexibility
- Integrate within MBS model

Craig-Bampton Component Mode Synthesis method
- Static Correction Modes
- Normal Modes

Modal Neutral File
**Multibody – Aerodynamic Effect**

- **MSC.Patran modeling**
- **CFD solver**
- **Pressure mapping**
- **Modal Neutral File (MNF) generation**
- **Integration into full-vehicle MB model**

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

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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)
Coupling CFD/FEM/MB

Aero Map Scaling factors

FUNCTION OF:

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

Scaling factor expression:

\[ F(\text{time, states}) \]

\[ \frac{D}{\text{DT}} \] and \[ \frac{D^2}{\text{DT}^2} \]

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)
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

INTEGRATED ANALYSIS ENVIRONMENT

FEM

CFD

MULTIBODY

DOE

Blade Structure

Aerodynamic Environment

Controls Description

Transient Manoeuvres

Ship Motions

Conditions Simulations
Blade Structure: FEM / ADAMS Flex

MSC.Nastran Beams Model

Component Mode Synthesis

Inertia
Structural Stiffness

Centrifugal Stiffness
Center Mass
Elastic Deflection

= +
Aerodynamic Environment

Blade Aerodynamic Forces

- Panel method
- Steady/unsteady flow
- Inflow effect
- Axial/hovering/forward flight

Rotor Aerodynamic Field

- CFD Based
- 3D Interpolation

Wind Non Uniform Field
CFD Based Aerodynamic

- CFD Analysis
- Wind Components on Grid Points
- 3D Interpolation
- Non Uniform Wind Velocity Field
- Wind Additional Components
- Aerodynamic Forces

Ship Motion
Rotor Motions
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
LA FRONTEIRA DELLA SIMULAZIONE
NEL SETTORE MACHINERY:
dalla progettazione alla messa a
punto di macchine e meccanismi

POLITECNICO DI MILANO
8 GIUGNO 2012
Il metodo multibody: casi industriali ed esperienze didattiche

Ing. Hermes Giberti
Multibody, DOE & Fatigue Simulation for new Track Suspension Design

Courtesy By Iveco
“Predict Your Future” with MSC Student Editions
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Grazie