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CALIFORNIA INSTITUTE OF TECHNOLOGY
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Mechanical Simulation Engine : User's Manual
Giancalro Cella Univ. of Pisa

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California Institute of Technology
LIGO Project - MS 51-33
Pasadena CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project - MS 20B-145
Cambridge, MA 01239
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

WWW: <http://www.ligo.caltech.edu/>

MSE

— Version 0.1 November 6, 1999 —

A library for the simulation of mechanical systems.

Giancarlo Cella

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Mechanical Simulation Engine documentation

The mechanical simulation engine is a library of C++ classes which can be used to simulate a mechanical system in the time domain. It provides also additional capabilities of extracting, with some restrictions, frequency domain informations (transfer functions).

The mechanical system is defined by making an instance of the MSystem class. Next different mechanical objects can be added to the system and connected together. Each mechanical object is a derivate class of the MObject, see the relative documentation for the common methods. The more important point is that the configuration of a mechanical object is completely specified by a finite number of Frames. For details on the definition of a frame see the documentation of the Frame class.

The connection of different mechanical object is specified by a rigid constraint between two frames, using the Connect method of the MSystem class. When all the connections are done, the system can be decomposed in clusters of unconnected frames. Each cluster is in a one-to-one correspondence with six degrees of freedom of the system, three for the translations and three for the rotations.

On each frame a force and a torque is defined. For cluster of connected frames we can choose a representative frame (which we call master frame) which parametrize the dynamics. In order to write the motion equations we must evaluate the total force and torque applied to the master frame. This can be done using the relations

$$\begin{aligned}\vec{f}_i &= \vec{f}_j \\ \vec{\tau}_i &= \vec{\tau}_j + \vec{r}_{ij} \wedge \vec{f}_j\end{aligned}$$

which connect the force and the torque between two different geometrical points ($\vec{r}_{ij} = \vec{r}_i - \vec{r}_j$ is the separation between the two points).

The linearized dynamics can be written in the form

$$M \frac{d^2 x}{dt^2} + \Lambda \frac{dx}{dt} + Kx = f \quad (1)$$

where M is a mass matrix, Λ a damping matrix and K a stiffness matrix. The symbol x stands for a vector of six components, which are the three small linear variations and the three small angular variations, and f is a vector with three forces and three torques

$$x \equiv (\delta x, \delta y, \delta z, \delta \theta_x, \delta \theta_y, \delta \theta_z) \quad (2)$$

$$f \equiv (f_x, f_y, f_z, \tau_x, \tau_y, \tau_z) \quad (3)$$

Each mechanical object provide on each of its frames the quantities f, M, Λ and K , which must be added together after a transformation to the reference of the master frame. This can be done in the following way. When we write the motion equation in the reference of the master frame we get

$$MQ_X \frac{d^2 x_{MF}}{dt^2} + \Lambda Q_X \frac{dx_{MF}}{dt} + K Q_X x_{MF} = Q_F f_{MF} \quad (4)$$

or

$$Q_F^{-1} M Q_X \frac{d^2 x_{MF}}{dt^2} + Q_F^{-1} \Lambda Q_X \frac{dx_{MF}}{dt} + Q_F^{-1} K Q_X x_{MF} = f_{MF} \quad (5)$$

and this means that the mass, damping and stiffness array transform as

$$A_{MF} = Q_F^{-1} A Q_X \quad (6)$$

More explicitly this means

$$\begin{pmatrix} A_{11, MF} & A_{12, MF} \\ A_{11, MF}^T & A_{22, MF} \end{pmatrix} = \begin{pmatrix} I & 0 \\ \vec{r} \wedge & I \end{pmatrix} \begin{pmatrix} A_{11} & A_{12} \\ A_{11}^T & A_{22} \end{pmatrix} \begin{pmatrix} I & -\vec{r} \wedge \\ 0 & I \end{pmatrix}. \quad (7)$$

Note that the transformed array preserve its simmetry. Explicitly

1

MSE tutorial.

Some simple examples of system construction.

Names

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1.1

Simple pendulum.

We want to construct a very simple mechanical system, namely a pendulum. In the mse framework this can be done by connecting a simple spring to a rigid body.

First of all we need to include some header files which contains the definition of the classes we will use. In this case:

```
#include <mse/MSystem.H>
#include <mse/Spring.H>
#include <mse/RigidBody.H>
#include <mse/PositionActuator.H>
#include <mse/PositionSensor.H>
```

Now we start the main program, and we declare an instance of the MSystem class, which will represent the pendulum.

```
int main()
{
    MSystem pendulum;
    pendulum.SetParameter("Name","Simple pendulum");
```

There are several parameters of the MSystem class which can be altered. We have changed the **Name** parameter, for documentation purposes. Next we declare a spring of given rest length,

```
double wire_length = 1.0;
Spring wire = Spring();
wire.SetParameter("Name","Pendulum wire");
wire.SetParameter("Separation",&wire_length);
```

and a spherical rigid body of given mass

```

double body_mass = 1.0;
double body_inertia = 1.0;
RigidBody mass = RigidBody(Frame::d3(-1.0));
mass.SetParameter("Name","Pendulum mass");
mass.SetParameter("Mass",&body_mass);
mass.SetParameter("Ixx",&body_inertia);
mass.SetParameter("Iyy",&body_inertia);
mass.SetParameter("Izz",&body_inertia);

```

Note the argument of the constructor, which is optional. It provides informations about the initial positioning of the mass, and can be used to speed-up the search for the working point of the system.

In order to apply a force to our system we need an actuator, so we declare

```

PositionActuator piezo = PositionActuator();
piezo.SetParameter("Name","Piezo");

```

and we need also a sensor to get informations about the evolution of the system

```

PositionSensor pos = PositionSensor();
pos.SetParameter("Name","Sensor");

```

Now we have to construct the system, connecting together all the pieces. We want to move the top of the pendulum wire, and to look at the movement of the mass. So we first attach to the system the position actuator

```

pendulum.Connect(piezo.frame(1), pendulum.frame(0), Frame::Coincident);

```

This instruction generate a rigid connection between the frame 1 of the position actuator and the frame 0 (the unique one) of the mechanical system. The third argument describe the nature of this connection. In this case we want the two frames completely overlapped.

The frame 0 of the position actuator must be attached to the top of the wire. As we can set the relative position of the two frames in the position actuator, we will be able to move the top of the wire with respect to the mechanical system fixed reference frame.

```

pendulum.Connect(piezo.frame(0), wire.frame(1), Frame::Coincident);

```

Now we attach the mass at the bottom of the wire

```

pendulum.Connect(mass.frame(0), wire.frame(0), Frame::Coincident);

```

There is a single frame defined in the `RigidBody` class, which is positioned in the center of mass of the object. As the third argument of the `MSystem::Connect` class is `Frame::Coincident` we attached the wire to the center of mass of the body.

The last step of the construction phase is to attach a position sensor. We want to get the position of the center of mass of the body relative to the reference frame, so we write

```

pendulum.Connect(mass.frame(0), pos.frame(0), Frame::Coincident);
pendulum.Connect(pendulum.frame(0), pos.frame(1), Frame::Coincident);

```

In order to use the mechanical system we constructed we must find its equilibrium position. This can be done with the following sequence of instructions

```

pendulum.FindWorkingPointInit();

do {

} while(pendulum.FindWorkingPoint());

pendulum.FindWorkingPointEnd();

```

Inside the `do { }` loop we can put some code which can be used to monitor the iterative search of the working point. This loop ends when some accuracy requirement, which depends on the search algorithm, is reached. Both the algorithm and the required accuracy can be entered as parameter of the `MSystem` class.

Now it is possible to start the evolution of the system. This can be done with the loop

```

pendulum.TimeDynamicsInit();
do {
    piezo.set_x(sin(pendulum.CurrentTime()));
    cout << pendulum.CurrentTime() << " " << pos.get_x() << "\n";
} while(pendulum.TimeDynamics());
TimeDynamicsEnd();
}

```

Inside the loops we put an example of an instruction that set the values of the actuator displacement with some externally provided function (a sinusoidal function), and another that read the values of the current positions. In the current example we print the current x displacement of the pendulum's bottom.

We can also get informations about transfer function. In the following example we print a table with the real and the imaginary part of the horizontal transfer function between the top and the bottom of the pendulum, between 10^{-1} and 10^3 Hz.

```

double logstep = pow(10.0,0.1);
pendulum.FrequencyDynamicsInit();
piezo.set_x(1.0,Real);
piezo.set_x(0.0,Imaginary);
for(double f=0.1;f<=1.0e3;f*=logstep) {
    pendulum.FrequencyDynamics(f);
    cout << f << " " << pos.get_x(Real) << " " << pos.get_x(Imaginary) << "\n";
}
pendulum.FrequencyDynamicsEnd();

```

Note that the initialization of the system in the frequency domain set all actuators to the “no actuation” condition, so it is redundant to set the imaginary part of the piezo amplitude to zero. If many actuators are included in the system the amplitudes and the phases of each of them can be initialized in an arbitrary way.

1.2

A composite suspended system.

The system consist in a rigid body suspended to four wires.

1.3**A simple attenuation chain.**

This is a toy model for a complete attenuation chain which provides attenuation both for horizontal and vertical sollecitations. In is made of a triple inverted pendulum, with a double stage pendulum on the top. Each stage of the double pendulum provide vertical attenuation capabilities, obtained with three cantilevered blades mounted horizontally.

High level library classes

The reference documentation for the C++ API

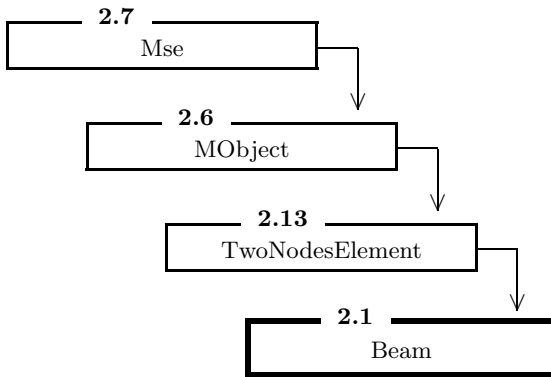
Names

2.1	class	Beam : public TwoNodesElement <i>Complete model for a beam.</i>	8
2.2	class	Clamp : public Mse <i>A constraint between two frames.</i>	10
2.3	class	ForceActuator : public TwoNodesElement <i>A generator of force.</i>	13
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2.5	class	Frame : public Mse <i>A frame owned by a mechanical object.</i>	20
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2.7	class	Mse <i>This is the base class for all the mechanical classes.</i>	40
2.8	class	MSystem : public MObject <i>A mechanical subsystem.</i>	48
2.9	class	PositionActuator : public TwoNodesElement <i>A position actuator.</i>	53
2.10	class	PositionSensor : public TwoNodesElement <i>A position sensor.</i>	60
2.11	class	RigidBody : public MObject <i>A rigid body without internal structure.</i>	64
2.12	class	Spring : public TwoNodesElement <i>This is the model for a simple spring.</i>	67
2.13	class	TwoNodesElement : public MObject <i>Base class for all the mechanical object with two frames.</i>	69
2.14	class	Wire : public TwoNodesElement <i>This is the model for a simple wire with torsional stiffness.</i>	71

```
class Beam : public TwoNodesElement
```

Complete model for a beam.

Inheritance



Public Members

2.1.1	Beam ()	<i>Default constructor.</i>	10
2.1.2	Beam (double length, double width0, double height0, double width1, double height1, double young, double poisson, double rho, int elements)	<i>Constructor with parameters.</i>	10
2.1.3	~Beam ()	<i>Destructor</i>	10
2.1.4	virtual char* name ()	<i>Identificative string.</i>	10

Protected Members

virtual void	UpdateForces (bool EvalJacobian=true)
virtual void	psdraw (int i, int j, int lbl)

Complete model for a beam.

Parameters:

Parameter name	Parameter type	Description	Default value
Name	TYPE_STRING64	The name of the instance of the class	""
Separation	TYPE_DOUBLE	Length of the wire at rest	...
Young Modulus	TYPE_DOUBLE	Young's modulus of the material	...
Poisson Ratio	TYPE_DOUBLE	Poisson's ratio of the material	...
Initial Width	TYPE_DOUBLE	Initial width of the beam	...
Initial Height	TYPE_DOUBLE	Initial height of the beam	...
Final Width	TYPE_DOUBLE	Final width of the beam	...
Final Height	TYPE_DOUBLE	Final height of the beam	...
Density	TYPE_DOUBLE	Density of the material	...
Elements	TYPE_INT	Number of internal elements in the model	...

2.1.1

Beam ()

Default constructor.

Default constructor.

2.1.2

```
Beam (double length, double width0, double height0, double width1, double height1,
      double young, double poisson, double rho, int elements)
```

Constructor with parameters.

Constructor with parameters.

2.1.3

```
~Beam ()
```

Destructor

Destructor

2.1.4

```
virtual char* name ()
```

Identificative string.

Identificative string.

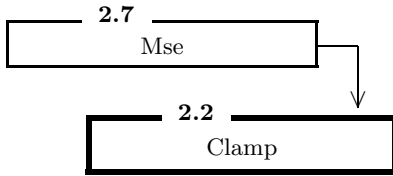
Return Value: the name of the class

2.2

```
class Clamp : public Mse
```

A constraint between two frames.

Inheritance



Public Members

2.2.1		Clamp (Frame *f1, Frame *f2, const mech_frame& t2_1)		
			<i>Constructor.</i>	11
2.2.2	Frame*	C1 ()	<i>Actual first frame value.</i>	12
2.2.3	Frame*	C2 ()	<i>Actual second frame value.</i>	12
2.2.4	mech_frame	F2_1 ()	<i>Connection between the frames.</i>	12
2.2.5	mech_frame	F1_2 ()	<i>Connection between the frames.</i>	12
2.2.6	virtual void	PutOnStream (ostream& os)	<i>Write on stream.</i>	13
2.2.7	int&	dof ()	<i>Degree of freedom.</i>	13
2.2.8	virtual char*	name ()	<i>Identificative string.</i>	13

A constraint between two frames.

Parameters:

Parameter name & Parameter type & Description & Default value

Name & TYPE_STRING64 & The name of the instance of the class & ""

2.2.1

Clamp (Frame *f1, Frame *f2, const mech_frame& t2_1)

Constructor.

Constructor.

Parameters:

f1	a pointer to the first frame
f2	a pointer to the second frame

2.2.2

Frame* **C1** ()

Actual first frame value.

Actual first frame value.

Return Value: a pointer to the first frame

2.2.3

Frame* **C2** ()

Actual second frame value.

Actual second frame value.

Return Value: a pointer to the second frame.

2.2.4

mech_frame **F2_1** ()

Connection between the frames.

Connection between the frames.

Return Value: the transformation that map the first frame on the second one.

2.2.5

mech_frame **F1_2** ()

Connection between the frames.

Connection between the frames.

Return Value: the transformation that map the second frame on the first one.

2.2.6

```
virtual void PutOnStream (ostream& os)
```

Write on stream.

Write on stream. This method can be used to write a description of the class instance on a stream.

Parameters: `os` the output stream to use

2.2.7

```
int& dof ()
```

Degree of freedom.

Degree of freedom.

Return Value: the id of the degree of freedom this clamp belong

2.2.8

```
virtual char* name ()
```

Identificative string.

Identificative string.

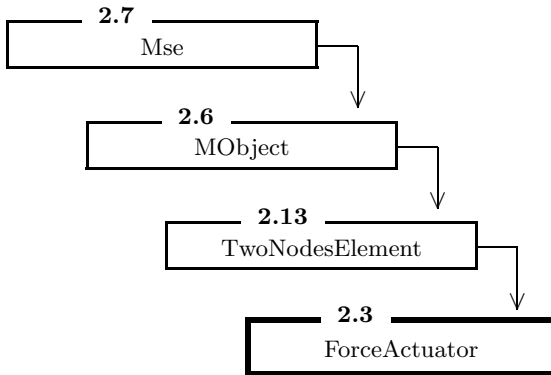
Return Value: the name of the class

2.3

```
class ForceActuator : public TwoNodesElement
```

A generator of force.

Inheritance



Public Members

2.3.1		ForceActuator ()	<i>Default constructor.</i>	15
2.3.2	virtual char*	name ()	<i>Identificative string.</i>	15
2.3.3	virtual void	set_force (mech_dvec *frc, ComplexType sel=Real)	<i>Set an internal generalized force to a given value.</i>	15
	virtual void	set_fx (double f, ComplexType sel=Real)		
	virtual void	set_fy (double f, ComplexType sel=Real)		
	virtual void	set_fz (double f, ComplexType sel=Real)		
	virtual void	set_tx (double t, ComplexType sel=Real)		
	virtual void	set_ty (double t, ComplexType sel=Real)		
	virtual void	set_tz (double t, ComplexType sel=Real)		

Protected Members

virtual void	psdraw (int i, int j, int lbl)
int	InputMappingArray (double *m=0)

A generator of force. This object has two frames, which are completely independent during the search for the working point (no forces and torques between them). During the linear evolution the force and the torque that the frame 0 apply on the frame 1 can be specified, giving a way to apply forces on the system.

Parameters:

Parameter name & Parameter type & Description & Default value
Name & TYPE_STRING64 & The name of the instance of the class & ""

2.3.1

ForceActuator ()

Default constructor.

Default constructor.

2.3.2

```
virtual char* name ()
```

Identificative string.

Identificative string.

Return Value: the name of the class

2.3.3

```
virtual void set_force (mech_dvec *frc, ComplexType sel=Real)
```

Set an internal generalized force to a given value.

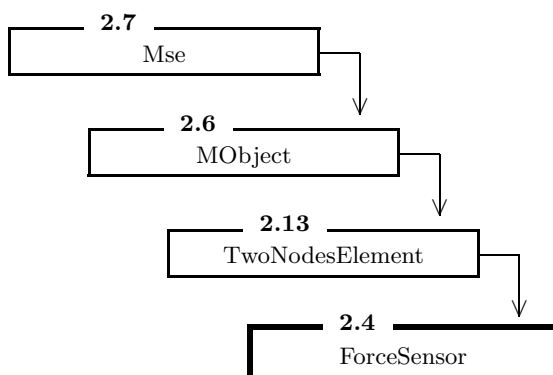
Set an internal generalized force to a given value.

2.4

```
class ForceSensor : public TwoNodesElement
```

A force sensor.

Inheritance



Public Members

2.4.1		ForceSensor ()	<i>Default constructor</i>	17
	virtual int	LinearDim ()		
2.4.2	virtual void	get_force (mech_dvec *frc, ComplexType sel=Real)	<i>Get the forces relative to the working point.</i> ...	17
2.4.3	virtual double	get_fx (ComplexType sel=Real)	<i>Get the force in the x direction relative to the working point.</i>	17
2.4.4	virtual double	get_fy (ComplexType sel=Real)	<i>Get the force in the y direction relative to the working point.</i>	18
2.4.5	virtual double	get_fz (ComplexType sel=Real)	<i>Get the force in the z direction relative to the working point.</i>	18
2.4.6	virtual double	get_tx (ComplexType sel=Real)	<i>Get the torque in the x direction relative to the working point.</i>	18
2.4.7	virtual double	get_ty (ComplexType sel=Real)	<i>Get the torque in the y direction relative to the working point.</i>	19
2.4.8	virtual double	get_tz (ComplexType sel=Real)	<i>Get the torque in the z direction relative to the working point.</i>	19
2.4.9	virtual bool	PositionConstrained (int f1, int f2)	<i>Redefinition of PositionConstrained.</i>	19
2.4.10	virtual char*	name ()	<i>Identificative string.</i>	20

Protected Members

	void	psdraw (int i, int j, int lbl)		
2.4.11	virtual int	StiffMatrix (double *m)	<i>This is a redefinion of the Stiff matrix for this system.</i>	20
	virtual int	OutputMappingArray (double *m=0)		

A force sensor. This object has two coincident frames. It is not possible to change the relative position and orientation of them, but the force and the torque that is applied on the frame 1 from the frame 0 can be obtained.

Parameters:

Parameter name & Parameter type & Description & Default value

Name & TYPE_STRING64 & The name of the instance of the class & ""

2.4.1**ForceSensor** ()*Default constructor*

Default constructor

2.4.2

```
virtual void get_force (mech_dvec *frc, ComplexType sel=Real)
```

Get the forces relative to the working point.

Get the forces relative to the working point. The values returned by this method depend on the current state of the mechanical system. If we are working in the time domain the current linear variations from the working point forces are returned. These are real numbers, so the case `sel=Imaginary` is not applicable. If we are working in the frequency domain the response at the current frequency is returned, the real part if `sel=Real` and the imaginary part if `sel=Imaginary`.

Parameters:

- `pos` a pointer to the structure which the current displacements are copied to.
- `sel` select in the frequency domain if the real (`sel=Real`) or the imaginary (`sel=Imaginary`) part is returned.

2.4.3

```
virtual double get_fx (ComplexType sel=Real)
```

Get the force in the x direction relative to the working point.

Get the force in the x direction relative to the working point. The value returned by this method depends on the current state of the mechanical system. If we are working in the time domain the current x force increment relative to the working point condition is returned. This is a real number, so the case `sel=Imaginary` is not applicable. If we are working in the frequency domain the x response in force at the current frequency is returned, the real part if `sel=Real` and the imaginary part if `sel=Imaginary`.

Return Value: the current x force relative to the working point condition

Parameters:

- `sel` select in the frequency domain if the real (`sel=Real`) or the imaginary (`sel=Imaginary`) part is returned.

2.4.4

```
virtual double get_fy (ComplexType sel=Real)
```

Get the force in the y direction relative to the working point.

Get the force in the y direction relative to the working point. The value returned by this method depends on the current state of the mechanical system. If we are working in the time domain the current y force increment relative to the working point condition is returned. This is a real number, so the case `sel=Imaginary` is not applicable. If we are working in the frequency domain the y response in force at the current frequency is returned, the real part if `sel=Real` and the imaginary part if `sel=Imaginary`.

Return Value: the current y force relative to the working point condition
Parameters: `sel` select in the frequency domain if the real (`sel=Real`) or the imaginary (`sel=Imaginary`) part is returned.

2.4.5

```
virtual double get_fz (ComplexType sel=Real)
```

Get the force in the z direction relative to the working point.

Get the force in the z direction relative to the working point. The value returned by this method depends on the current state of the mechanical system. If we are working in the time domain the current z force increment relative to the working point condition is returned. This is a real number, so the case `sel=Imaginary` is not applicable. If we are working in the frequency domain the z response in force at the current frequency is returned, the real part if `sel=Real` and the imaginary part if `sel=Imaginary`.

Return Value: the current z force relative to the working point condition
Parameters: `sel` select in the frequency domain if the real (`sel=Real`) or the imaginary (`sel=Imaginary`) part is returned.

2.4.6

```
virtual double get_tx (ComplexType sel=Real)
```

Get the torque in the x direction relative to the working point.

Get the torque in the x direction relative to the working point. The value returned by this method depends on the current state of the mechanical system. If we are working in the time domain the current x torque increment relative to the working point condition is returned. This is a real number, so the case `sel=Imaginary` is not applicable. If we are working in the frequency domain the x response in torque at the current frequency is returned, the real part if `sel=Real` and the imaginary part if `sel=Imaginary`.

Return Value: the current x torque relative to the working point condition
Parameters: `sel` select in the frequency domain if the real (`sel=Real`) or the imaginary (`sel=Imaginary`) part is returned.

2.4.7

```
virtual double get_ty (ComplexType sel=Real)
```

Get the torque in the y direction relative to the working point.

Get the torque in the y direction relative to the working point. The value returned by this method depends on the current state of the mechanical system. If we are working in the time domain the current y torque increment relative to the working point condition is returned. This is a real number, so the case `sel=Imaginary` is not applicable. If we are working in the frequency domain the y response in torque at the current frequency is returned, the real part if `sel=Real` and the imaginary part if `sel=Imaginary`.

Return Value: the current y torque relative to the working point condition
Parameters: `sel` select in the frequency domain if the real (`sel=Real`) or the imaginary (`sel=Imaginary`) part is returned.

2.4.8

```
virtual double get_tz (ComplexType sel=Real)
```

Get the torque in the z direction relative to the working point.

Get the torque in the z direction relative to the working point. The value returned by this method depends on the current state of the mechanical system. If we are working in the time domain the current z torque increment relative to the working point condition is returned. This is a real number, so the case `sel=Imaginary` is not applicable. If we are working in the frequency domain the z response in torque at the current frequency is returned, the real part if `sel=Real` and the imaginary part if `sel=Imaginary`.

Return Value: the current z torque relative to the working point condition
Parameters: `sel` select in the frequency domain if the real (`sel=Real`) or the imaginary (`sel=Imaginary`) part is returned.

2.4.9

```
virtual bool PositionConstrained (int f1, int f2)
```

Redefinition of PositionConstrained.

Redefinition of PositionConstrained. For a force sensor this function must return true.

Return Value: true if the relative position of frames f1,f2 is constrained, 0 otherwise.
Parameters: `f1` the first frame
`f2` the second frame

2.4.10

```
virtual char* name ()
```

Identificative string.

Identificative string.

Return Value: the name of the class

2.4.11

```
virtual int StiffMatrix (double *m)
```

This is a redefinition of the Stiff matrix for this system.

This is a redefinition of the Stiff matrix for this system. There are 18 variables ($\vec{\lambda}, \vec{x}_1, \vec{x}_2$), where \vec{x}_i correspond to the two clamps and $\vec{\lambda}$ are six internal variables. In block form the stiffness array is

$$K = \begin{pmatrix} 0 & I & -I \\ I & 0 & 0 \\ -I & 0 & 0 \end{pmatrix} \quad (8)$$

where each block is a 6×6 array.

Return Value: the total storage required for the stiffness array (18×18)

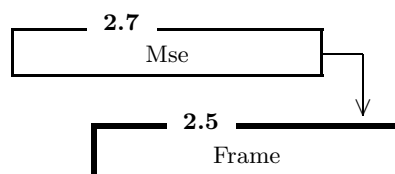
Parameters: m a pointer to the start of the memory location where the stiffness array must be copied. If m is a null pointer no operation is performed, only the total storage required for the stiffness array is returned.

2.5

```
class Frame : public Mse
```

A frame owned by a mechanical object.

Inheritance



Public Members

2.5.1	class MSystem	Frame (MObject *o)	<i>The constructor.</i>	22
2.5.2		~Frame ()	<i>The destructor.</i>	22
2.5.3	virtual void	PutOnStream (ostream& os)	<i>Write on stream.</i>	23
2.5.4	virtual char*	name ()	<i>Identificative string.</i>	23
2.5.5	mech_frame*	frame ()	<i>Raw access to frame.</i>	23
2.5.6	mech_mat*	ee ()	<i>Raw access to orientation.</i>	23
2.5.7	double&	ee (int i, int j)	<i>Axes orientation.</i>	24
2.5.8	double&	o (int k)	<i>Origin's coordinate.</i>	24
2.5.9	double&	f (int k)	<i>Equilibrium position force.</i>	24
2.5.10	MObject*&	owner ()	<i>The owner of the frame.</i>	25
2.5.11	static mech_frame	Coincident	<i>A frame coincident with the reference one.</i> ...	25
2.5.12	static mech_frame	dx (double d)	<i>A frame aligned with the reference one, but translated in the x direction.</i>	25
2.5.13	static mech_frame	dy (double d)	<i>A frame aligned with the reference one, but translated in the y direction.</i>	25
2.5.14	static mech_frame	dz (double d)	<i>A frame aligned with the reference one, but translated in the z direction.</i>	26
2.5.15	static mech_frame	rx (double a)	<i>A frame with the same origin of the reference one, but rotated around the x axis of a radians.</i>	26
2.5.16	static mech_frame	ry (double a)	<i>A frame with the same origin of the reference one, but rotated around the y axis of a radians.</i>	26
2.5.17	static mech_frame	rz (double a)	<i>A frame with the same origin of the reference one, but rotated around the z axis of a radians.</i>	27
2.5.18	static mech_frame	dxdydz (double x, double y, double z)	<i>A frame aligned with the reference one, but with a general translation.</i>	27
2.5.19	bool	positioned ()	<i>Positioned flag.</i>	27
2.5.20	void	positioned (bool flag)	<i>Set the positioned flag to a desired value.</i>	28

A frame owned by a mechanical object. A frame is defined by a vector which defines its origin *o* and by a reference

frame U , which is a set of three orthonormal vectors

$$U \equiv (e_1, e_2, e_3), \quad e_i \cdot e_j = \delta_{ij} \quad (9)$$

It is convenient also to see U as an orthogonal array, where e_i is the i -th array's column. The rigid connection between two frames can be expressed in the following way:

$$U' = UT \quad (10)$$

$$o' = o + Ud \quad (11)$$

where the orthogonal transformation T and the vector d do not depend on the external reference frame used to specify U, U', o, o' . The couple (T, d) can be interpreted as the frame (U', o') as seen from the reference frame (U, o) . We can write

$$T = U^T U' \quad (12)$$

$$d = U^T (o' - o) \quad (13)$$

Parameters:

Parameter name & Parameter type & Description & Default value

Name & TYPE_STRING64 & The name of the instance of the class & ""

2.5.1

```
class MSystem Frame (MObject *o)
```

The constructor.

The constructor. The orientation and the position of the constructed frame is the default Reference.

Parameters: o is the owner of the frame

2.5.2

```
~Frame ()
```

The destructor.

The destructor.

2.5.3

```
virtual void PutOnStream (ostream& os)
```

Write on stream.

Write on stream. This method can be used to write a description of the class instance on a stream.

Parameters: os the output stream to use

2.5.4

```
virtual char* name ()
```

Identificative string.

Identificative string.

Return Value: the name of the class

2.5.5

```
mech_frame* frame ()
```

Raw access to frame.

Raw access to frame.

Return Value: a pointer

2.5.6

```
mech_mat* ee ()
```

Raw access to orientation.

Raw access to orientation.

Return Value: a pointer

2.5.7

```
double& ee (int i, int j)
```

Axes orientation.

Axes orientation. The orientation is described by a orthogonal 3x3 array which transform the fundamental base vectors in the rotated ones. This array can be written in the form

$$R = \left(\begin{array}{c|c|c} \vec{e}_1 & \vec{e}_2 & \vec{e}_3 \end{array} \right) \quad (14)$$

where \vec{e}_i are the rotated base vectors

Return Value: the value of the (i,j) element of the orthogonal array
Parameters: i the row index of the rotation array
 j the column index of the rotation array

2.5.8

```
double& o (int k)
```

Origin's coordinate.

Origin's coordinate.

Return Value: the value of the k-th coordinate of the origin.
Parameters: k the coordinate index

2.5.9

```
double& f (int k)
```

Equilibrium position force.

Equilibrium position force. This is the generalized force which acts on the frame in the equilibrium position.

Return Value: the k-th component of the generalized force
Parameters: k is the index of the component of the generalized force.

2.5.10

```
MObject*& owner ()
```

The owner of the frame.

The owner of the frame.

Return Value: a pointer to the MObject which is the owner of the frame

2.5.11

```
static mech_frame Coincident
```

A frame coincident with the reference one.

A frame coincident with the reference one. All the components of the o vector are zero, and the U array is the identity.

2.5.12

```
static mech_frame dx (double d)
```

A frame aligned with the reference one, but translated in the x direction.

A frame aligned with the reference one, but translated in the x direction. The U array is the identity, and $o = (d, 0, 0)$.

Return Value: the frame (U, o) .

Parameters: d the displacement

2.5.13

```
static mech_frame dy (double d)
```

A frame aligned with the reference one, but translated in the y direction.

A frame aligned with the reference one, but translated in the y direction. The U array is the identity, and $o = (0, d, 0)$.

Return Value: the frame (U, o) .

Parameters: d the displacement

2.5.14

```
static mech_frame dz (double d)
```

A frame aligned with the reference one, but translated in the z direction.

A frame aligned with the reference one, but translated in the z direction. The U array is the identity, and $o = (0, 0, d)$.

Return Value: the frame (U, o) .

Parameters: d the displacement

2.5.15

```
static mech_frame rx (double a)
```

A frame with the same origin of the reference one, but rotated around the x axis of a radians.

A frame with the same origin of the reference one, but rotated around the x axis of a radians. The components of the o vector are zero, and the array U is

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos a & \sin a \\ 0 & -\sin a & \cos a \end{pmatrix} \quad (15)$$

Return Value: the frame (U, o) .

Parameters: a the rotation angle in radians

2.5.16

```
static mech_frame ry (double a)
```

A frame with the same origin of the reference one, but rotated around the y axis of a radians.

A frame with the same origin of the reference one, but rotated around the y axis of a radians. The components of the o vector are zero, and the array U is

$$U = \begin{pmatrix} \cos a & 0 & \sin a \\ 0 & 1 & 0 \\ -\sin a & 0 & \cos a \end{pmatrix} \quad (16)$$

Return Value: the frame (U, o) .

Parameters: a the rotation angle in radians

2.5.17

```
static mech_frame rz (double a)
```

A frame with the same origin of the reference one, but rotated around the z axis of a radians.

A frame with the same origin of the reference one, but rotated around the z axis of a radians. The components of the o vector are zero, and the array U is

$$U = \begin{pmatrix} \cos a & \sin a & 0 \\ -\sin a & \cos a & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (17)$$

Return Value: the frame (U, o) .
Parameters: a the rotation angle in radians

2.5.18

```
static mech_frame dxdydz (double x, double y, double z)
```

A frame aligned with the reference one, but with a general translation.

A frame aligned with the reference one, but with a general translation. The U array is the identity, and the o vector is $o = (dx, dy, dz)$.

Return Value: the frame (U, o) .
Parameters: dx the x component of the translation
 dy the y component of the translation
 dz the z component of the translation

2.5.19

```
bool positioned ()
```

Positioned flag.

Positioned flag. It is used to indicate that the frame was positioned explicitly.

Return Value: true if the frame was explicitly positioned, false otherwise
See Also: positioned(bool)

2.5.20

```
void positioned (bool flag)
```

Set the positioned flag to a desired value.

Set the positioned flag to a desired value. The flag is used to indicate that the frame was explicitly positioned.

Parameters: `flag` the desired value of the flag

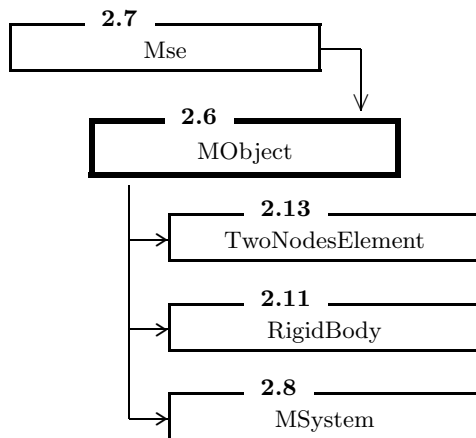
See Also: `positioned()`

2.6

```
class MObject : public Mse
```

This is the base class for all object that can be composed into a mechanical system.

Inheritance



Public Members

2.6.1	class MSystem	MObject (int NumberOfFrames)	<i>Default constructor.</i>	32
2.6.2		~MObject ()	<i>Destructor.</i>	32
2.6.3	Frame*	frame (int k)	<i>Access to a predefined frame.</i>	32
2.6.4	int	frames ()	<i>This method return the number of predefined frames of the object.</i>	33
2.6.5	virtual bool	ValidFrame (int f)	<i>This method can be used to verify the presence of a given frame.</i>	33
2.6.6	virtual bool	LinearForceConstrained (int frame)		

			<i>This method can be used to verify if the linearized generalized force applied to the given frame is constrained or not.</i>	33
2.6.7	virtual bool	LinearPositionConstrained (int frame1, int frame2)	<i>This method can be used to verify if the linearized relative displacement between two frames is constrained or not.</i>	34
2.6.8	virtual bool	ForceConstrained (int frame)	<i>This method can be used to verify if the generalized force applied to the given frame is constrained or not.</i>	34
2.6.9	virtual bool	PositionConstrained (int frame1, int frame2)	<i>This method can be used to verify if the relative displacement between two frames is constrained or not.</i>	34
2.6.10	virtual char*	name ()	<i>Identificative string.</i>	34
	double	random_force ()		
	int	n_input		
	int	n_output		
	double**	inputs		
	double**	outputs		
Protected Members				
2.6.11	int	Inputs ()	<i>This method return the number of input variables that can be adjusted in the linear regime.</i>	35
2.6.12	int	Outputs ()	<i>This method return the number of output variables that can be read in the linear regime.</i>	35
	void	LinkOutput (int n, int offset, double *base)		
	void	LinkInput (int n, int offset, double *base)		
	void	SetFlag (unsigned int fl)		
	void	ResetFlag (unsigned int fl)		
	bool	TestFlag (unsigned int fl)		
2.6.13	virtual void	UpdateForces (bool EvalJacobian=true)	<i>This method evaluate the forces applied by the mechanical element on its nodes in the configuration specified by the current frame coordinates.</i>	
2.6.14	virtual int	LinearDim ()	<i>This method return the dimension of the mass, damping and stiffness array which describe the system in the linearized dynamic regime.</i>	36
2.6.15	int	InternalDim ()	<i>This method return the number of internal variables added to the description of this mechanical element.</i>	36

2.6.16	virtual int	BlockBase (int f1, int f2)	<i>This method return the base offset of the block in themass, damping or stiffness array which connect two given frames, or a given frame to the internal variables space.</i>	37
2.6.17	virtual int	BlockRows (int f1, int f2)	<i>This method return the number of rows in the block in themass, damping or stiffness array which connect two given frames, or a given frame to the internal variables space.</i>	37
2.6.18	virtual int	BlockCols (int f1, int f2)	<i>This method return the number of column in the block in themass, damping or stiffness array which connect two given frames, or a given frame to the internal variables space.</i>	38
2.6.19	virtual int	BlockLeadingDimension (int f1, int f2)	<i>This method return the leading dimension of the block in themass, damping or stiffness array which connect two given frames, or a given frame to the internal variables space.</i>	38
	virtual int	InputMapLeadingDimension ()		
	virtual int	InputMapBlockBase (int f)		
	virtual int	OutputMapLeadingDimension ()		
	virtual int	OutputMapBlockBase (int f)		
2.6.20	virtual int	MassMatrix (double *m=0)	<i>This method evaluate the current mass matrix for the system.</i>	38
2.6.21	virtual int	DampMatrix (double *m=0)	<i>This method evaluate the current damping matrix for the system.</i>	39
2.6.22	virtual int	StiffMatrix (double *m=0)	<i>This method evaluate the current stiffness matrix for the system.</i>	39
	virtual int	InputMappingArray (double *m=0)		
	virtual int	OutputMappingArray (double *m=0)		
2.6.23	virtual void	ApplyGravity (double ax, double ay, double az)	<i>This method apply on the element an external gravitationalconstant acceleration field.</i>	40
	double&	hess (int frame1, int frame2, int i, int j)		
	mech_hess*	hess_link (mech_hess *nh, int f1, int f2)		
	virtual void	psdraw (int i, int j, int lbl)		
	int	nof		
	Frame**	_frames		
2.6.24	mech_hess**	_hessians	<i>Local stiffness array.</i>	40
	int*	allocated_h		
	static double	strength		

static double **rnd**
 static int **Internal**

This is the base class for all object that can be composed into a mechanical system. A mechanical object can be seen as a set of N_F frames. Each of them carries six degrees of freedom, which can be parametrized by the three coordinates of the origin and by the three Euler's angles which describe the orientation of the reference frame. A mechanical element must provide:

1. A complete statical description of the system, that is a potential energy W which is function of all the frames.
2. A linearized dynamical description, in term a set of mass, damping and stiffness array in the coordinate space. $6 \times N_F$ coordinates are the linearized version of the general coordinates of the N_F frames. Additional coordinates can be present, in order to carry informations about internal modes.

A generalized (statical) force is defined as minus the derivative of the potential energy with respect to a coordinate, so on each frame six generalized forces are defined. For the three coordinates of the origin of the frame, the generalized force is the traditional forces f_i . For the variation of the angular coordinates we set a convention. A general rotation array can be written as

$$\Delta(\alpha_x, \alpha_y, \alpha_z) = R_z(\alpha_z)R_y(\alpha_y)R_x(\alpha_x) \quad (18)$$

where $R_i(\alpha)$ is a rotation of angle α around the i -th axis. The potential energy can be written as

$$w(\dots, \alpha_i^{(k)}, x_i^{(k)}, \dots) = W(\dots, \Delta^{(k)}U^{(k)}, o^{(k)} + \delta^{(k)}, \dots) \quad (19)$$

which we can expand to the first order around the frame (U, o) . We obtain

$$f_i^{(k)} = -\frac{\partial w}{\partial \delta_i^{(k)}} = -\frac{\partial W}{\partial o_i^{(k)}} \quad (20)$$

and

$$\tau_i^{(k)} = -\frac{\partial w}{\partial \alpha_i^{(k)}} = -\frac{\partial W}{\partial U_{ab}^{(k)}} \left(\frac{\partial \Delta^{(k)}}{\partial \alpha_i^{(k)}} U^{(k)} \right)_{ab} \quad (21)$$

evaluated for $\alpha_i = \delta_i = 0$.

We are interested also in the second order variation of the energy with respect to the coordinates. This can be used in some algorithm in order to find the equilibrium position, and in the most common case it is simply related to the stiffness array of the system. We get

$$-\frac{\partial^2 w}{\partial \delta_i^{(k)} \partial \delta_j^{(l)}} = -\frac{\partial^2 W}{\partial o_i^{(k)} \partial o_j^{(l)}} = \frac{\partial f_i^{(k)}}{\partial x_j^{(l)}} = \frac{\partial f_j^{(l)}}{\partial x_i^{(k)}} \quad (22)$$

$$-\frac{\partial^2 w}{\partial \delta_i^{(k)} \partial \alpha_j^{(l)}} = -\frac{\partial^2 W}{\partial o_i^{(k)} \partial U_{ab}^{(l)}} \left(\frac{\partial \Delta^{(l)}}{\partial \alpha_j^{(l)}} U^{(l)} \right)_{ab} = \frac{\partial f_i^{(k)}}{\partial \alpha_j^{(l)}} \quad (23)$$

$$-\frac{\partial^2 w}{\partial \alpha_i^{(k)} \partial \delta_j^{(l)}} = -\frac{\partial^2 W}{\partial U_{ab}^{(k)} \partial \delta_j^{(l)}} \left(\frac{\partial \Delta^{(k)}}{\partial \alpha_i^{(k)}} U^{(k)} \right)_{ab} = \frac{\partial \tau_i^{(k)}}{\partial x_j^{(l)}} \quad (24)$$

$$-\frac{\partial^2 w}{\partial \alpha_i^{(k)} \partial \alpha_j^{(l)}} = -\frac{\partial^2 W}{\partial U_{ab}^{(k)} \partial U_{cd}^{(l)}} \left(\frac{\partial \Delta^{(k)}}{\partial \alpha_i^{(k)}} U^{(k)} \right)_{ab} \left(\frac{\partial \Delta^{(l)}}{\partial \alpha_j^{(l)}} U^{(l)} \right)_{cd} - \delta^{kl} \frac{\partial W}{\partial U_{ab}^{(k)}} \left(\frac{\partial^2 \Delta^{(k)}}{\partial \alpha_i^{(k)} \partial \alpha_j^{(k)}} U^{(k)} \right)_{ab} = \frac{\partial \tau_i^{(k)}}{\partial \alpha_j^{(l)}} = \frac{\partial \tau_j^{(l)}}{\partial \alpha_i^{(k)}} \quad (25)$$

The `UpdateForces()` method evaluate these quantities.

The linearized description is of the following form:

$$M \frac{d^2}{dt^2} Y + \Lambda \frac{d}{dt} Y + KY = F \quad (26)$$

and is parametrized by the constant arrays M , Λ , K . The forcing variables F is mapped on the input variables X_{in} by the array A , and the output variables X_{out} are mapped on the internal variables by the array B :

$$F = AX_{in}, \quad X_{out} = BY \quad (27)$$

It is responsibility of the mechanical object to construct the arrays M, Λ, K, A and B .

Parameters:

Parameter name & Parameter type & Description & Default value

Name & TYPE_STRING64 & The name of the instance of the class & ""

2.6.1

```
class MSystem MObject (int NumberOfFrames)
```

Default constructor.

Default constructor. There are no user-defined parameters for this class.

Parameters: `NumberOfFrames` is the number of independent frames

2.6.2

```
~MObject ()
```

Destructor.

Destructor.

2.6.3

```
Frame* frame (int k)
```

Access to a predefined frame.

Access to a predefined frame. On each mechanical object there is a set of predefined frames, which correspond to independent generalized degrees of freedom. This method can be used to access them.

Return Value: a pointer to the k-th frame

Parameters: `k` the number of the frame, between 0 and frames()-1 (inclusive)

2.6.4

```
int frames ()
```

This method return the number of predefined frames of the object.

This method return the number of predefined frames of the object. The frames can be accessed using the `frame(int)` method.

Return Value: the max number of frames

2.6.5

```
virtual bool ValidFrame (int f)
```

This method can be used to verify the presence of a given frame.

This method can be used to verify the presence of a given frame.

Return Value: true if the given frame or internal space exists, false otherwise

Parameters: `f` is the frame number. If `f==MObject::Internal` the existence of internal degree of freedom is checked.

2.6.6

```
virtual bool LinearForceConstrained (int frame)
```

This method can be used to verify if the linearized generalized force applied to the given frame is constrained or not.

This method can be used to verify if the linearized generalized force applied to the given frame is constrained or not. This is the case, for example, for a force actuator.

Return Value: true if the force applied to the frame is constrained, false otherwise.

Parameters: `frame` the frame which must be tested

2.6.7

```
virtual bool LinearPositionConstrained (int frame1, int frame2)
```

This method can be used to verify if the linearized relative displacement between two frames is constrained or not.

This method can be used to verify if the linearized relative displacement between two frames is constrained or not. This is the case, for example, for a position actuator.

Parameters:

frame1	the first frame which must be tested
frame2	the second frame which must be tested

2.6.8

```
virtual bool ForceConstrained (int frame)
```

This method can be used to verify if the generalized force applied to the given frame is constrained or not.

This method can be used to verify if the generalized force applied to the given frame is constrained or not.

Return Value: true if the force applied to the frame is constrained, false otherwise.
Parameters: **frame** the frame which must be tested

2.6.9

```
virtual bool PositionConstrained (int frame1, int frame2)
```

This method can be used to verify if the relative displacement between two frames is constrained or not.

This method can be used to verify if the relative displacement between two frames is constrained or not.

Parameters:

frame1	the first frame which must be tested
frame2	the second frame which must be tested

2.6.10

```
virtual char* name ()
```

Identificative string.

Identificative string.

Return Value: the name of the class

2.6.11

```
int Inputs ()
```

This method return the number of input variables that can be adjusted in the linear regime.

This method return the number of input variables that can be adjusted in the linear regime.

Return Value: The number of double precision (time domain) or complex (frequency domain) variables that can be adjusted.

2.6.12

```
int Outputs ()
```

This method return the number of output variables that can be readin the linear regime.

This method return the number of output variables that can be readin the linear regime.

Return Value: The number of double precision (time domain) or complex (frequency domain) variables that can be read.

2.6.13

```
virtual void UpdateForces (bool EvalJacobian=true)
```

This method evaluate the forces applied by the mechanicalelement on its nodes in the configuration specified by thecurrent frame coordinates.

This method evaluate the forces applied by the mechanicalelement on its nodes in the configuration specified by thecurrent frame coordinates. It must evaluate also, in the same configuration, the first order variation of forces around the current position. This is an array of the following form

$$H = \begin{pmatrix} H_{1,1} & \cdots & H_{1,j} & \cdots & H_{1,N_F} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ H_{i,1} & \cdots & H_{i,j} & \cdots & H_{i,N_F} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ H_{N_F,1} & \cdots & H_{N_F,j} & \cdots & H_{N_F,N_F} \end{pmatrix} \quad (28)$$

where $H_{i,j}$ is a 6×6 block of the following form ($N_F = \text{frames}()$).

$$H_{i,j} = \begin{pmatrix} \partial f_x^{(i)} / \partial x^{(j)} & \partial f_x^{(i)} / \partial y^{(j)} & \partial f_x^{(i)} / \partial z^{(j)} & \partial f_x^{(i)} / \partial \alpha_x^{(j)} & \partial f_x^{(i)} / \partial \alpha_y^{(j)} & \partial f_x^{(i)} / \partial \alpha_z^{(j)} \\ \partial f_y^{(i)} / \partial x^{(j)} & \partial f_y^{(i)} / \partial y^{(j)} & \partial f_y^{(i)} / \partial z^{(j)} & \partial f_y^{(i)} / \partial \alpha_x^{(j)} & \partial f_y^{(i)} / \partial \alpha_y^{(j)} & \partial f_y^{(i)} / \partial \alpha_z^{(j)} \\ \partial f_z^{(i)} / \partial x^{(j)} & \partial f_z^{(i)} / \partial y^{(j)} & \partial f_z^{(i)} / \partial z^{(j)} & \partial f_z^{(i)} / \partial \alpha_x^{(j)} & \partial f_z^{(i)} / \partial \alpha_y^{(j)} & \partial f_z^{(i)} / \partial \alpha_z^{(j)} \\ \partial \tau_x^{(i)} / \partial x^{(j)} & \partial \tau_x^{(i)} / \partial y^{(j)} & \partial \tau_x^{(i)} / \partial z^{(j)} & \partial \tau_x^{(i)} / \partial \alpha_x^{(j)} & \partial \tau_x^{(i)} / \partial \alpha_y^{(j)} & \partial \tau_x^{(i)} / \partial \alpha_z^{(j)} \\ \partial \tau_y^{(i)} / \partial x^{(j)} & \partial \tau_y^{(i)} / \partial y^{(j)} & \partial \tau_y^{(i)} / \partial z^{(j)} & \partial \tau_y^{(i)} / \partial \alpha_x^{(j)} & \partial \tau_y^{(i)} / \partial \alpha_y^{(j)} & \partial \tau_y^{(i)} / \partial \alpha_z^{(j)} \\ \partial \tau_z^{(i)} / \partial x^{(j)} & \partial \tau_z^{(i)} / \partial y^{(j)} & \partial \tau_z^{(i)} / \partial z^{(j)} & \partial \tau_z^{(i)} / \partial \alpha_x^{(j)} & \partial \tau_z^{(i)} / \partial \alpha_y^{(j)} & \partial \tau_z^{(i)} / \partial \alpha_z^{(j)} \end{pmatrix} \quad (29)$$

where $f_k^{(i)}$ $\tau_k^{(i)}$ are the components of the force and torque applied on the i -th frame while $x^{(j)}$, $y^{(j)}$, $z^{(j)}$ and $\alpha_k^{(j)}$ are the components of the position of the j -th frame. This is a default that set the forces and the Hessian components to zero. If special actions must be done this method has to be redefined in the derived class. The responsibility of evaluating the forces and the Hessian is completely demanded to the MObject. In this way this information can be obtained using analytical expressions, if they are available, or approximate numerical techniques.

Parameters: **EvalJacobian** If true both forces and Jacobian are evaluated (default).
If false only forces are evaluated.

2.6.14

```
virtual int LinearDim ()
```

This method return the dimension of the mass, damping and stiffnessarray which describe the system in the linearized dynamic regime.

This method return the dimension of the mass, damping and stiffnessarray which describe the system in the linearized dynamic regime. This can be greater than $6*\text{frames}()$, because the array can contain informations about internal degree of freedom

Return Value: the dimension of mass, damping and stiffness array

2.6.15

```
int InternalDim ()
```

This method return the number of internal variables added tothe description of this mechanical element.

This method return the number of internal variables added tothe description of this mechanical element. This is equal to $\text{LinearDim}()-6*\text{frames}()$

Return Value: $\text{LinearDim}-6*\text{frames}()$

2.6.16

```
virtual int BlockBase (int f1, int f2)
```

This method return the base offset of the block in themass, damping or stiffness array which connect two given frames, or a given frame to the internal variables space.

This method return the base offset of the block in themass, damping or stiffness array which connect two given frames,or a given frame to the internal variables space.

Return Value: an integer offset which is the start of the required block in the mass, damping or stiffness array, or -1 if the f1,f2 values are incorrect

Parameters: f1 is the first frame, or the internal variables if f1=MObject::Internal
f2 is the second frame, or the internal variables if f2=MObject::Internal

See Also: BlockRows
BlockCols
BlockLeadingDimension
MassMatrix
DampMatrix
StiffMatrix

2.6.17

```
virtual int BlockRows (int f1, int f2)
```

This method return the number of rows in the block in themass, damping or stiffness array which connect two given frames,or a given frame to the internal variables space.

This method return the number of rows in the block in themass, damping or stiffness array which connect two given frames,or a given frame to the internal variables space.

Return Value: an integer offset which is the number of rows in the required block in the mass, damping or stiffness array, or -1 if the f1,f2 values are incorrect

Parameters: f1 is the first frame, or the internal variables if f1=MObject::Internal
f2 is the second frame, or the internal variables if f2=MObject::Internal

See Also: BlockBase
BlockCols
BlockLeadingDimension
MassMatrix
DampMatrix
StiffMatrix

2.6.18

```
virtual int BlockCols (int f1, int f2)
```

This method return the number of column in the block in themass, damping or stiffness array which connect two given frames,or a given frame to the internal variables space.

This method return the number of column in the block in themass, damping or stiffness array which connect two given frames,or a given frame to the internal variables space.

Return Value: an integer offset which is the number of columns in the required block in the mass, damping or stiffness array

Parameters: **f1** is the first frame, or the internal variables if **f1=MObject::Internal**
f2 is the second frame, or the internal variables if **f2=MObject::Internal**

See Also: BlockBase
BlockRows
BlockLeadingDimension
MassMatrix
DampMatrix
StiffMatrix

2.6.19

```
virtual int BlockLeadingDimension (int f1, int f2)
```

This method return the leading dimension of the block in themass, damping or stiffness array which connect two given frames,or a given frame to the internal variables space.

This method return the leading dimension of the block in themass, damping or stiffness array which connect two given frames,or a given frame to the internal variables space.

Return Value: an integer offset which is the leading dimension of the required block in the mass, damping or stiffness array

Parameters: **f1** is the first frame, or the internal variables if **f1=MObject::Internal**
f2 is the second frame, or the internal variables if **f2=MObject::Internal**

See Also: BlockBase
BlockRows
BlockCols
MassMatrix
DampMatrix
StiffMatrix

2.6.20

```
virtual int MassMatrix (double *m=0)
```

This method evaluate the current mass matrix for the system.

This method evaluate the current mass matrix for the system. The space for the data must be allocated by the

calling procedure and the used space is returned. The array has `LinearDim()` rows and `LinearDim()` columns. This base definition simply return a matrix filled with zeros. The routine must be redefined for a derivate class.

Return Value: the total storage used in the workspace `m`
Parameters: `m` a pointer to the workspace where the mass matrix must be copied. If `m=0` (default) only the total storage is evaluated and returned.
See Also: `BlockBase`
`BlockRows`
`BlockCols`
`BlockLeadingDimension`
`DampMatrix`
`StiffMatrix`

2.6.21

```
virtual int DampMatrix (double *m=0)
```

This method evaluate the current damping matrix for the system.

This method evaluate the current damping matrix for the system. The space for the data must be allocated by the calling procedure and the used space is returned. The array has `LinearDim()` rows and `LinearDim()` columns. This base definition simply return a matrix filled with zeros. The routine must be redefined for a derivate class.

Return Value: the total storage used in the workspace `m`
Parameters: `m` a pointer to the workspace where the mass matrix must be copied. If `m=0` (default) only the total storage is evaluated and returned.
See Also: `BlockBase`
`BlockRows`
`BlockCols`
`BlockLeadingDimension`
`MassMatrix`
`StiffMatrix`

2.6.22

```
virtual int StiffMatrix (double *m=0)
```

This method evaluate the current stiffness matrix for the system.

This method evaluate the current stiffness matrix for the system. The space for the data must be allocated by the calling procedure and the used space is returned. The array has `LinearDim()` rows and `LinearDim()` columns, and must be destroyed by the calling procedure. This base definition simply return a matrix filled with the current hessian. The routine must be redefined for a derivate class.

Return Value: the total storage used in the workspace `m`

Parameters: `m` a pointer to the workspace where the mass matrix must be copied. If `m=0` (default) only the total storage is evaluated and returned.

See Also: BlockBase
BlockRows
BlockCols
BlockLeadingDimension
MassMatrix
DampMatrix

2.6.23

```
virtual void ApplyGravity (double ax, double ay, double az)
```

This method apply on the element an external gravitationalconstant acceleration field.

This method apply on the element an external gravitationalconstant acceleration field. This is a default for a generic mechanical element which does nothing. If special actions must be done this method has to be redefined in the derived class.

Parameters: `ax` the x component of the gravitational acceleration
`ay` the x component of the gravitational acceleration
`az` the x component of the gravitational acceleration

2.6.24

```
mech_hess** _hessians
```

Local stiffness array.

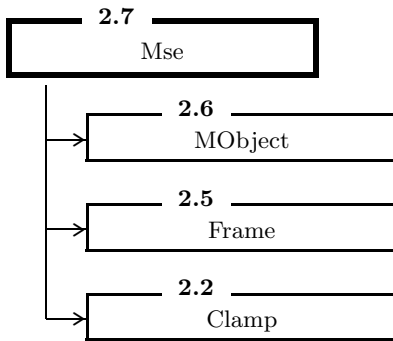
Local stiffness array.

2.7

```
class Mse
```

This is the base class for all the mechanical classes.

Inheritance



Public Members

2.7.1		Mse ()	<i>Default constructor.</i>	42
2.7.2	virtual	~Mse ()	<i>Destructor.</i>	42
2.7.3	virtual char*	name ()	<i>Identificative string.</i>	43
2.7.4	int&	id ()	<i>Unique id.</i>	43
2.7.5	virtual void	PutOnStream (ostream& os)	<i>Write on stream.</i>	43
2.7.6	const char*	uname ()	<i>Get the user defined name.</i>	43
2.7.7	void	uname (const char *un)	<i>Set the user defined name.</i>	44
2.7.8	int	Parameters ()	<i>Each mechanical element has some parameters that can be changed.</i>	44
2.7.9	char*	ParametersName (int k)	<i>Each settable parameter is indexed with an integer which is between 0 and Parameters()-1 inclusive.</i>	44
2.7.10	int	ParameterByName (char *name)	<i>This method can be used to retrieve the index of a parameter, given its name.</i>	45
2.7.11	int	ParametersType (int k)	<i>This call return the type of the parameter indexed by k.</i>	45
2.7.12	int	GetParameter (int k, void *val)	<i>This method can be used to access the value of a given parameter.</i>	45
2.7.13	int	GetParameter (char *name, void *val)	<i>This method can be used to access the value of a given parameter.</i>	46
2.7.14	int	SetParameter (int k, void *val)	<i>This method can be used to set the value of a given parameter.</i>	46
2.7.15	void	SetParameter (char *name, void *val)		

			<i>This method can be used to set the value of a given parameter.</i>	46
2.7.16	void	operator= (Mse& el)	<i>This method set the value of the parameters of this instance of the class to the same value of those in the el instance.</i>	47
2.7.17	static ofstream*	logfile	<i>Log file stream.</i>	47
2.7.18	static ofstream*	dumpfile	<i>Dump file stream.</i>	47

Protected Members

2.7.19	int	AddParameter (char *name, parameter_type type, void *val)	<i>This method can be used to add a parameter to the list of settableparameter for the class.</i>	47
--------	-----	--	--	----

This is the base class for all the mechanical classes.

Parameters:

Parameter name & Parameter type & Description & Default value

Name & TYPE_STRING64 & The name of the instance of the class & ""

2.7.1

Mse ()

Default constructor.

Default constructor.

2.7.2

virtual **~Mse** ()

Destructor.

Destructor.

2.7.3

```
virtual char* name ()
```

Identificative string.

Identificative string.

Return Value: the name of the class

2.7.4

```
int& id ()
```

Unique id.

Unique id.

Return Value: an unique integer associated to the class instance

2.7.5

```
virtual void PutOnStream (ostream& os)
```

Write on stream.

Write on stream. This method can be used to write a description of the class instance on a stream.

Parameters: `os` the output stream to use

2.7.6

```
const char* uname ()
```

Get the user defined name.

Get the user defined name. This method return a null-terminated string which represent the name a mnemonic identifier for the instance of the object. The identifier can be changed by the user using the `uname(char*)` method.

Return Value: a pointer to a null-terminated string

2.7.7

```
void uname (const char *un)
```

Set the user defined name.

Set the user defined name. This method can be used to set the string which identify the instance of the class. The max length of the identification string is 63.

Parameters: **un** the new identification string. If its length is greather than 63 the string is truncated.

2.7.8

```
int Parameters ()
```

Each mechanical element has some parameters thatcan be changed.

Each mechanical element has some parameters thatcan be changed. This method returns the number of parameters defined for this class.

Return Value: the number of parameters.

2.7.9

```
char* ParametersName (int k)
```

Each settable parameter is indexed with an integerwhich is between 0 and Parameters()-1 inclusive.

Each settable parameter is indexed with an integerwhich is between 0 and Parameters()-1 inclusive. Each parameter has also a name, which is returned by this method.

Return Value: the name of the parameter or NULL if the parameter is not defined

Parameters: **k** is a parameter index

2.7.10

```
int ParameterByName (char *name)
```

This method can be used to retrieve the index of a parameter, given itsname.

This method can be used to retrieve the index of a parameter, given itsname.

Return Value: the index of the parameter
Parameters: name the name of the parameter

2.7.11

```
int ParametersType (int k)
```

This call return the type of the parameter indexed by k.

This call return the type of the parameter indexed by k. The available types are:

- TYPE_UNDEF. An undefined parameter.
- TYPE_DOUBLE. A double precision number.
- TYPE_INT. An integer number.
- TYPE_STRING64. An null-terminated string with a maximul length of 63 characters.

Return Value: the type of the parameter
Parameters: k is the index of the parameter

2.7.12

```
int GetParameter (int k, void *val)
```

This method can be used to access the value of a given parameter.

This method can be used to access the value of a given parameter. The value of the parameter is copied in a position specified by a void pointer.

Parameters: k the index of the parameter
 val a pointer to a location where the parameter value must be copied. It is responsibility of the caller that the type of the variable pointed by val is of the correct type.

2.7.13

```
int GetParameter (char *name, void *val)
```

This method can be used to access the value of a given parameter.

This method can be used to access the value of a given parameter. The value of the parameter is copied in a position specified by a void pointer.

Parameters:

name	the name of the parameter.
val	a pointer to a location where the parameter value must be copied. It is responsibility of the caller that the type of the variable pointed by val is of the correct type.

2.7.14

```
int SetParameter (int k, void *val)
```

This method can be used to set the value of a given parameter.

This method can be used to set the value of a given parameter. The value of the parameter is copied from the position specified by a void pointer.

Parameters:

k	the parameter index
val	a pointer to the location the parameter value must be copied from. It is responsibility of the caller that the type of the variable pointed by val is of the correct type.

2.7.15

```
void SetParameter (char *name, void *val)
```

This method can be used to set the value of a given parameter.

This method can be used to set the value of a given parameter. The value of the parameter is copied from the position specified by a void pointer.

Parameters:

name	the name of the parameter
val	a pointer to the location the parameter value must be copied from. It is responsibility of the caller that the type of the variable pointed by val is of the correct type.

2.7.16

```
void operator= (Mse& el)
```

This method set the value of the parameters of this instance of the class to the same value of those in the el instance.

This method set the value of the parameters of this instance of the class to the same value of those in the el instance. If a parameter of this instance is not present in the el instance its value is unchanged. Parameters in the el instance which are not in this instance are ignored.

Parameters: **el** an instance of the class

2.7.17

```
static    ofstream* logfile
```

Log file stream.

Log file stream.

2.7.18

```
static    ofstream* dumpfile
```

Dump file stream.

Dump file stream.

2.7.19

```
int AddParameter (char *name, parameter_type type, void *val)
```

This method can be used to add a parameter to the list of settableparameter for the class.

This method can be used to add a parameter to the list of settableparameter for the class. Note that the parameter is added only to the particular instance of the class.

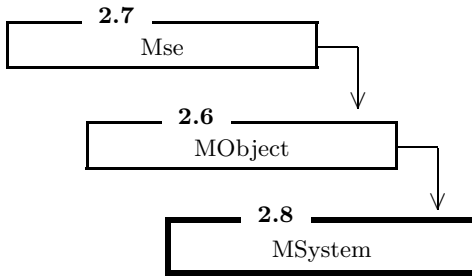
Parameters: **name** the name of the new parameter
 type the type of the new parameter
 val a pointer to an (optional) initial value for the parameter

2.8

```
class MSystem : public MObject
```

A mechanical subsystem.

Inheritance



Public Members

2.8.1		MSystem ()	<i>Default constructor.</i>	49
2.8.2		~MSystem ()	<i>Destructor.</i>	49
2.8.3	void	Connect (Frame *f1, Frame *f2, const mech_frame& t12)	<i>Element connection.</i>	49
2.8.4	void	FindWorkingPointInit ()	<i>Initialize the search for the working point.</i>	50
2.8.5	int	FindWorkingPoint ()	<i>Find working point of the system.</i>	50
2.8.6	void	FindWorkingPointEnd ()	<i>Termination of the search for the working point.</i>	51
2.8.7	void	TimeDynamicsInit ()	<i>Initialize the linear dynamics.</i>	51
2.8.8	int	TimeDynamics ()	<i>Linear dynamics evolution.</i>	51
2.8.9	void	TimeDynamicsEnd ()	<i>Termination of the linear dynamics evolution.</i>	51
2.8.10	void	BuildStateSpace ()	<i>Construction of the system description in the s-tate space.</i>	52
2.8.11	double	CurrentTime ()	<i>Return the current value of elapsed time in the linear evolution.</i>	52
2.8.12	void	FrequencyDynamicsInit ()	<i>Initialization of the evaluation of system response in the frequency domain.</i>	52
2.8.13	void	FrequencyDynamics (double f)	<i>Evaluate the response of the system in the frequency domain.</i>	53
2.8.14	void	FrequencyDynamicsEnd ()	<i>Termination of the evaluation of system response in the frequency domain.</i>	53
2.8.15	virtual char*	name ()	<i>Identificative string.</i>	53

A mechanical subsystem. This class provides a single clamp, which is used specify an inertial reference frame. In this sense it is a MObject, a sort of RigidBody with infinite mass. The main role of this class is to provide a representation for all the system in its different aspects: geometric, static and dynamic. A mechanical system is

Parameters:

Parameter name	Parameter type	Description	Default value
<code>Name</code>	<code>TYPE_STRING64</code>	The name of the instance of the class	""
<code>Initial strength</code>	<code>TYPE_DOUBLE</code>	Reduction factor for forces (initial value)	1.0
<code>Time step</code>	<code>TYPE_DOUBLE</code>	Time step for linear evolution	0.001
<code>gx</code>	<code>TYPE_DOUBLE</code>	The x component of gravitational force	0.0
<code>gy</code>	<code>TYPE_DOUBLE</code>	The y component of gravitational force	0.0
<code>gz</code>	<code>TYPE_DOUBLE</code>	The z component of gravitational force	-9.8

a set of interconnected mechanical objects.

2.8.1

MSystem ()

Default constructor.

Default constructor.

2.8.2

~MSystem ()

Destructor.

Destructor.

2.8.3

void Connect (Frame *f1, Frame *f2, const mech.frame& t12)

Element connection.

Element connection. This method is used to specify a connection between two element of the system. It is designed to completely specify the relative position and orientation of the two elements. This is obtained by enforcing the constraint

$$U_2 = U_1 U_{2,1} \quad (30)$$

and

$$o_2 = o_1 + U_1 o_{2,1} \quad (31)$$

where (U_1, o_1) and (U_2, o_2) are the first and the second frame, and $(U_{2,1}, o_{2,1})$ is a rigid transformation.

Parameters:

- f1** a pointer to the first frame
- f2** a pointer to the second frame
- t12** a pointer to the rigid transformation

2.8.4

```
void FindWorkingPointInit ()
```

Initialize the search for the working point.

Initialize the search for the working point. There are several actions which must be done:

- The frames are numbered sequentially.
- A vector which contain, in sequential order, all the frames positions is allocated.
- A vector which contain, in sequential order, all the forces which act on the frames is allocated.
- An array which contain the Hessian of the system with rigid constraint removed is allocated.
- The current gravitational force is applied to all the mechanical objects which composes the system
- The degrees of freedom which are irrelevant for the search of working point are freezed, adding additional clamps.
- The degrees of freedom are evaluated and initialized

2.8.5

```
int FindWorkingPoint ()
```

Find working point of the system.

Find working point of the system. The system is relaxed until the mechanical equilibrium configuration is found. Each call to this method is equivalent to a single relaxation step.

Return Value: 1 if the equilibrium position is found, 0 otherwise.

2.8.6

```
void FindWorkingPointEnd ()
```

Termination of the search for the working point.

Termination of the search for the working point. If the debugging is activated some informations about the actual configuration are emitted. At the end of the procedure only the information about the equilibrium position of the frames is preserved, in each frame.

2.8.7

```
void TimeDynamicsInit ()
```

Initialize the linear dynamics.

Initialize the linear dynamics. The working point must be setted correctly. The mass, damping and stiffness array which describe the system are evaluated, and the correct model in the state space is built. Next the model is simplified using the method `ReduceModel()`

2.8.8

```
int TimeDynamics ()
```

Linear dynamics evolution.

Linear dynamics evolution. Each call to this method is equivalent to a step in the evolution of the linearized system.

Return Value: 1 if the evolution is finished, 0 otherwise

2.8.9

```
void TimeDynamicsEnd ()
```

Termination of the linear dynamics evolution.

Termination of the linear dynamics evolution. The memory allocated for the state space description is freed.

2.8.10

```
void BuildStateSpace ()
```

Construction of the system description in the state space.

Construction of the system description in the state space. We start from a knowledge of the mass, damping and stiffness array and we want to obtain a system of first order linear differential equations. We can write

$$\begin{pmatrix} M(n \times n) & 0(n \times n) \\ 0(n \times n) & I(n \times n) \end{pmatrix} \begin{pmatrix} \frac{dv}{dt} \\ \frac{dx}{dt} \end{pmatrix} \quad (32)$$

2.8.11

```
double CurrentTime ()
```

Return the current value of elapsed time in the linear evolution.

Return the current value of elapsed time in the linear evolution.

Return Value: the elapsed time

2.8.12

```
void FrequencyDynamicsInit ()
```

Initialization of the evaluation of system response in the frequency domain.

Initialization of the evaluation of system response in the frequency domain. The working point must be setted correctly.

See Also:

- BuildMassMatrix()
- BuildStiffMatrix()
- BuildDampMatrix()
- BuildInputMap()
- BuildOutputMap()
- ReduceModel()

2.8.13

```
void FrequencyDynamics (double f)
```

Evaluate the response of the system in the frequency domain.

Evaluate the response of the system in the frequency domain.

Parameters: f the frequency which the response must be evaluated at.

2.8.14

```
void FrequencyDynamicsEnd ()
```

Termination of the evaluation of system response in the frequency domain.

Termination of the evaluation of system response in the frequency domain.

2.8.15

```
virtual char* name ()
```

Identificative string.

Identificative string.

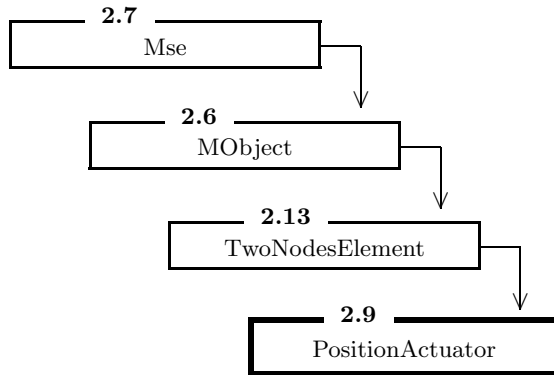
Return Value: the name of the class

2.9

```
class PositionActuator : public TwoNodesElement
```

A position actuator.

Inheritance



Public Members

2.9.1		PositionActuator ()	<i>Default constructor.</i>	55
2.9.2	virtual int	LinearDim ()	<i>The number of variables in the object.</i>	55
2.9.3	void	set_position (mech_dvec *pos, ComplexType sel=Real)	<i>This method set the six linear displacement of the actuator.</i>	56
2.9.4	void	set_x (double x, ComplexType sel=Real)	<i>This method set the x displacement of the actuator (the realor the imaginary part, when applicable, accordingly to the second argument's value).</i>	56
2.9.5	void	set_y (double y, ComplexType sel=Real)	<i>This method set the y displacement of the actuator (the realor the imaginary part, when applicable, accordingly to the second argument's value).</i>	57
2.9.6	void	set_z (double z, ComplexType sel=Real)	<i>This method set the z displacement of the actuator (the realor the imaginary part, when applicable, accordingly to the second argument's value).</i>	57
2.9.7	void	set_ax (double ax, ComplexType sel=Real)	<i>This method set the x angular displacement of the actuator (the realor the imaginary part, when applicable, accordingly to the second argument's value).</i>	57
2.9.8	void	set_ay (double ay, ComplexType sel=Real)	<i>This method set the y angular displacement of the actuator (the realor the imaginary part, when applicable, accordingly to the second argument's value).</i>	58
2.9.9	void	set_az (double az, ComplexType sel=Real)		

			<i>This method set the z angular displacement of the actuator (the realor the imaginary part, when applicable, accordingly to the second argument's value).</i>	58
2.9.10	void	FindWorkingPointInit ()	<i>Initialize internal structures before the working point search.</i>	58
2.9.11	virtual void	LinearRegimeInit ()	<i>Initialize internal structures before the time domain linearized evolution or the frequency domain transfer function evaluation.</i>	59
2.9.12	virtual char*	name ()	<i>Identificative string.</i>	59
2.9.13	virtual bool	PositionConstrained (int f1, int f2)	<i>Redefinition of PositionConstrained.</i>	59
2.9.14	virtual int	StiffMatrix (double *m)	<i>This is a redefinion of the Stiff matrix for this system.</i>	59

Protected Members

virtual void	psdraw (int i, int j, int lbl)
virtual int	InputMappingArray (double *m)

A position actuator. This object has two coincident frames, whose relative position and orientation cannot be changed during the working point search. During the linear dynamics phase the relative position and orientation between frame 0 and frame 1 can be altered. In this way we can apply an action on the system.

Parameters:

Parameter name & Parameter type & Description & Default value

Name & TYPE_STRING64 & The name of the instance of the class & ""

2.9.1

PositionActuator ()

Default constructor.

Default constructor.

2.9.2

virtual int **LinearDim** ()

The number of variables in the object.

The number of variables in the object. There are two frames and six internal variables (lagrange multipliers), so the total number of variables is 18.

Return Value: the number of variables used to describe the system in the linear regime.

2.9.3

```
void set_position (mech_dvec *pos, ComplexType sel=Real)
```

This method set the six linear displacement of the actuator.

This method set the six linear displacement of the actuator.

Parameters:

- pos** a pointer to the structure containing the six displacements of the actuator (the real or the imaginary part, when applicable, accordingly to the second argument's value).
- sel** select the real or the imaginary part of the six displacements. If sel=Real (default) the real part of the displacements is setted. If sel=Imaginary the imaginary part of the displacements is setted.

2.9.4

```
void set_x (double x, ComplexType sel=Real)
```

This method set the x displacement of the actuator (the real or the imaginary part, when applicable, accordingly to the second argument's value).

This method set the x displacement of the actuator (the real or the imaginary part, when applicable, accordingly to the second argument's value).

Parameters:

- x** is the x displacement of the actuator
- sel** select the real or the imaginary part of the displacement. If sel=Real (default) the real part of the displacement is setted. If sel=Imaginary the imaginary part of the displacement is setted.

2.9.5

```
void set_y (double y, ComplexType sel=Real)
```

This method set the y displacement of the actuator (the real or the imaginary part, when applicable, accordingly to the second argument's value).

This method set the y displacement of the actuator (the real or the imaginary part, when applicable, accordingly to the second argument's value).

Parameters:

- `y` is the y displacement of the actuator
- `sel` select the real or the imaginary part of the displacement. If `sel=Real` (default) the real part of the displacement is setted. If `sel=Imaginary` the imaginary part of the displacement is setted.

2.9.6

void **set_z** (double z, ComplexType sel=Real)

This method set the z displacement of the actuator (the real or the imaginary part, when applicable, accordingly to the second argument's value).

This method set the z displacement of the actuator (the real or the imaginary part, when applicable, accordingly to the second argument's value).

Parameters:

- `z` is the z displacement of the actuator
- `sel` select the real or the imaginary part of the displacement. If `sel=Real` (default) the real part of the displacement is setted. If `sel=Imaginary` the imaginary part of the displacement is setted.

2.9.7

void **set_ax** (double ax, ComplexType sel=Real)

This method set the x angular displacement of the actuator (the real or the imaginary part, when applicable, accordingly to the second argument's value).

This method set the x angular displacement of the actuator (the real or the imaginary part, when applicable, accordingly to the second argument's value).

Parameters:

- `ax` is the x angular displacement of the actuator
- `sel` select the real or the imaginary part of the displacement. If `sel=Real` (default) the real part of the displacement is setted. If `sel=Imaginary` the imaginary part of the displacement is setted.

2.9.8

```
void set_ay (double ay, ComplexType sel=Real)
```

This method set the y angular displacement of the actuator (the realor the imaginary part, when applicable, accordingly to the second argument's value).

This method set the y angular displacement of the actuator (the realor the imaginary part, when applicable, accordingly to the second argument's value).

Parameters:

ay	is the y angular displacement of the actuator
sel	select the real or the imaginary part of the displacement. If sel=Real (default) the real part of the displacement is setted. If sel=Imaginary the imaginary part of the displacement is setted.

2.9.9

```
void set_az (double az, ComplexType sel=Real)
```

This method set the z angular displacement of the actuator (the realor the imaginary part, when applicable, accordingly to the second argument's value).

This method set the z angular displacement of the actuator (the realor the imaginary part, when applicable, accordingly to the second argument's value).

Parameters:

az	is the z angular displacement of the actuator
sel	select the real or the imaginary part of the displacement. If sel=Real (default) the real part of the displacement is setted. If sel=Imaginary the imaginary part of the displacement is setted.

2.9.10

```
void FindWorkingPointInit ()
```

Initialize internal structures before the working point search.

Initialize internal structures before the working point search.

2.9.11

```
virtual void LinearRegimeInit ()
```

Initialize internal structures before the time domain linearized evolution or the frequency domain transfer function evaluation.

Initialize internal structures before the time domain linearized evolution or the frequency domain transfer function evaluation.

2.9.12

```
virtual char* name ()
```

Identificative string.

Identificative string.

Return Value: the name of the class

2.9.13

```
virtual bool PositionConstrained (int f1, int f2)
```

Redefinition of PositionConstrained.

Redefinition of PositionConstrained. For a position actuator this function must return true.

Return Value: true if the relative position of frames f1,f2 is constrained, 0 otherwise.

Parameters:
f1 the first frame
f2 the second frame

2.9.14

```
virtual int StiffMatrix (double *m)
```

This is a redefinition of the Stiff matrix for this system.

This is a redefinition of the Stiff matrix for this system. There are 18 variables ($\vec{\lambda}$, \vec{x}_1, \vec{x}_2), where \vec{x}_i correspond to the two clamps and $\vec{\lambda}$ are six internal variables. In block form the stiffness array is

$$K = \begin{pmatrix} 0 & I & -I \\ I & 0 & 0 \\ -I & 0 & 0 \end{pmatrix} \quad (33)$$

where each block is a 6×6 array.

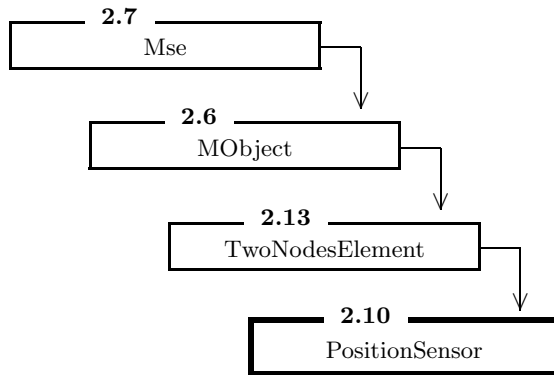
Return Value: the total storage required for the stiffness array (18×18)
Parameters: *m* a pointer to the start of the memory location where the stiffness array must be copied. If *m* is a null pointer no operation is performed, only the total storage required for the stiffness array is returned.

2.10

```
class PositionSensor : public TwoNodesElement
```

A position sensor.

Inheritance



Public Members

2.10.1		PositionSensor ()	<i>Default constructor</i>	61
2.10.2	void	get_position (mech_dvec *pos, ComplexType sel=Real)	<i>Get the positions of the sensor frame relativeto the working point.</i>	61
2.10.3	double	get_x (ComplexType sel=Real)	<i>Get the x position of the sensor frame relativeto the working point.</i>	62
2.10.4	double	get_y (ComplexType sel=Real)	<i>Get the y position of the sensor frame relativeto the working point.</i>	62
2.10.5	double	get_z (ComplexType sel=Real)	<i>Get the z position of the sensor frame relativeto the working point.</i>	62
2.10.6	double	get_ax (ComplexType sel=Real)	<i>Get the angular position of the sensor frame relativeto the working point.</i>	63
2.10.7	double	get_ay (ComplexType sel=Real)		

			<i>Get the angular position of the sensor frame relativeto the working point.</i>	63
2.10.8	double	get_az (ComplexType sel=Real)	<i>Get the angular position of the sensor frame relativeto the working point.</i>	64
2.10.9	virtual char*	name ()	<i>Identificative string.</i>	64

Protected Members

void	psdraw (int i, int j, int lbl)
virtual int	OutputMappingArray (double *m=0)

A position sensor. This object has two frames, which are completely independent, in the sense that no forces and torques can be applied between them. The relative position and orientation can be obtained.

Parameters:

Parameter name & Parameter type & Description & Default value
Name & TYPE_STRING64 & The name of the instance of the class & ””

2.10.1

PositionSensor ()

Default constructor

Default constructor

2.10.2

void get_position (mech_dvec *pos, ComplexType sel=Real)

Get the positions of the sensor frame relativeto the working point.

Get the positions of the sensor frame relativeto the working point. The values returned by this method depend on the current state of the mechanical system. If we are working in the time domain the current linear displacements from the working point position are returned. These are real numbers, so the case **sel=Imaginary** is not applicable. If we are working in the frequency domain the responses at the current frequency are returned, the real part if **sel=Real** and the imaginary part if **sel=Imaginary**.

Parameters:

pos	a pointer to the structure which the current displacements are copied to.
sel	select in the frequency domain if the real (sel=Real) or the imaginary (sel=Imaginary) part is returned.

2.10.3

```
double get_x (ComplexType sel=Real)
```

Get the x position of the sensor frame relativeto the working point.

Get the x position of the sensor frame relativeto the working point. The value returned by this method depends on the current state of the mechanical system. If we are working in the time domain the current linear x displacement from the working point position is returned. This is a real numbers, so the case **sel=Imaginary** is not applicable. If we are working in the frequency domain the x response at the current frequency is returned, the real part if **sel=Real** and the imaginary part if **sel=Imaginary**.

Return Value: the current x displacement relative to the working point position
Parameters: **sel** select in the frequency domain if the real (**sel=Real**) or the imaginary (**sel=Imaginary**) part is returned.

2.10.4

```
double get_y (ComplexType sel=Real)
```

Get the y position of the sensor frame relativeto the working point.

Get the y position of the sensor frame relativeto the working point. The value returned by this method depends on the current state of the mechanical system. If we are working in the time domain the current linear y displacement from the working point position is returned. This is a real numbers, so the case **sel=Imaginary** is not applicable. If we are working in the frequency domain the y response at the current frequency is returned, the real part if **sel=Real** and the imaginary part if **sel=Imaginary**.

Return Value: the current y displacement relative to the working point position
Parameters: **sel** select in the frequency domain if the real (**sel=Real**) or the imaginary (**sel=Imaginary**) part is returned.

2.10.5

```
double get_z (ComplexType sel=Real)
```

Get the z position of the sensor frame relativeto the working point.

Get the z position of the sensor frame relativeto the working point. The value returned by this method depends on the current state of the mechanical system. If we are working in the time domain the current linear z displacement from the working point position is returned. This is a real numbers, so the case **sel=Imaginary** is not applicable. If we are working in the frequency domain the z response at the current frequency is returned, the real part if **sel=Real** and the imaginary part if **sel=Imaginary**.

Return Value: the current z displacement relative to the working point position
Parameters: `sel` select in the frequency domain if the real (`sel=Real`) or the imaginary (`sel=Imaginary`) part is returned.

2.10.6

```
double get_ax (ComplexType sel=Real)
```

Get the angular position of the sensor frame relativeto the working point.

Get the angular position of the sensor frame relativeto the working point. The value returned by this method depends on the current state of the mechanical system. If we are working in the time domain the current angular displacement around the x axis, relative to the working point position, is returned. This is a real numbers, so the case `sel=Imaginary` is not applicable. If we are working in the frequency domain the angular response around the x axis at the current frequency is returned, the real part if `sel=Real` and the imaginary part if `sel=Imaginary`.

Return Value: the current angular displacement around the x axis relative to the working point position
Parameters: `sel` select in the frequency domain if the real (`sel=Real`) or the imaginary (`sel=Imaginary`) part is returned.

2.10.7

```
double get_ay (ComplexType sel=Real)
```

Get the angular position of the sensor frame relativeto the working point.

Get the angular position of the sensor frame relativeto the working point. The value returned by this method depends on the current state of the mechanical system. If we are working in the time domain the current angular displacement around the y axis, relative to the working point position, is returned. This is a real numbers, so the case `sel=Imaginary` is not applicable. If we are working in the frequency domain the angular response around the y axis at the current frequency is returned, the real part if `sel=Real` and the imaginary part if `sel=Imaginary`.

Return Value: the current angular displacement around the y axis relative to the working point position
Parameters: `sel` select in the frequency domain if the real (`sel=Real`) or the imaginary (`sel=Imaginary`) part is returned.

2.10.8

```
double get_az (ComplexType sel=Real)
```

Get the angular position of the sensor frame relativeto the working point.

Get the angular position of the sensor frame relativeto the working point. The value returned by this method depends on the current state of the mechanical system. If we are working in the time domain the current angular displacement around the z axis, relative to the working point position, is returned. This is a real numbers, so the case `sel=Imaginary` is not applicable. If we are working in the frequency domain the angular response around the z axis at the current frequency is returned, the real part if `sel=Real` and the imaginary part if `sel=Imaginary`.

Return Value: the current angular displacement around the z axis relative to the working point position

Parameters: `sel` select in the frequency domain if the real (`sel=Real`) or the imaginary (`sel=Imaginary`) part is returned.

2.10.9

```
virtual char* name ()
```

Identificative string.

Identificative string.

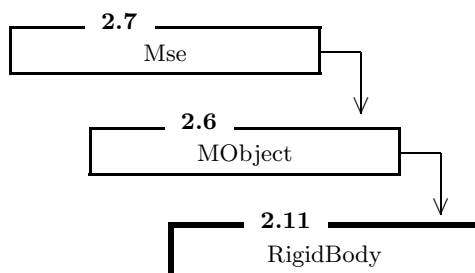
Return Value: the name of the class

2.11

```
class RigidBody : public MObject
```

A rigid body without internal structure.

Inheritance



Public Members

2.11.1	RigidBody ()	<i>Default constructor</i>	65
2.11.2	RigidBody (const mech_frame& pos0)	<i>Constructor with initial position</i>	66
2.11.3	RigidBody (double mass, double *Iij)	<i>Constructor with parameters</i>	66
2.11.4	RigidBody (double mass, double *Iij, const mech_frame& pos0)	<i>Constructor with parameters and initial position</i>	66
2.11.5	virtual char* name ()	<i>Identificative string.</i>	66

Protected Members

	virtual void	ApplyGravity (double ax, double ay, double az)	
	virtual void	UpdateForces (bool EvalJacobian=true)	
2.11.6	virtual int	MassMatrix (double *m=0)	
		<i>This method evaluate the current mass matrix for the system.</i>	67
2.11.7	virtual double	cm (int i)	
		<i>This method gives the position of the center of mass of the object relative to the frame 0.</i>	67
	void	psdraw (int i, int j, int lbl)	

A rigid body without internal structure.

Parameters:

Parameter name & Parameter type & Description & Default value

Name & TYPE_STRING64 & The name of the instance of the class & ""

Mass & TYPE_DOUBLE & The total mass of the body & 0.0

Ixx & TYPE_DOUBLE & The I_{xx} component of the inertia tensor of the body & 0.0

Ixy & TYPE_DOUBLE & The I_{xy} component of the inertia tensor of the body & 0.0

Ixz & TYPE_DOUBLE & The I_{xz} component of the inertia tensor of the body & 0.0

Iyy & TYPE_DOUBLE & The I_{yy} component of the inertia tensor of the body & 0.0

Iyz & TYPE_DOUBLE & The I_{yz} component of the inertia tensor of the body & 0.0

Izz & TYPE_DOUBLE & The I_{zz} component of the inertia tensor of the body & 0.0

2.11.1**RigidBody** ()

Default constructor

Default constructor

2.11.2**RigidBody** (const mech_frame& pos0)*Constructor with initial position*

Constructor with initial position

2.11.3**RigidBody** (double mass, double *Iij)*Constructor with parameters*

Constructor with parameters

2.11.4**RigidBody** (double mass, double *Iij, const mech_frame& pos0)*Constructor with parameters and initial position*

Constructor with parameters and initial position

2.11.5virtual char* **name** ()*Identificative string.*

Identificative string.

Return Value: the name of the class

2.11.6

```
virtual int MassMatrix (double *m=0)
```

This method evaluate the current mass matrix for the system.

This method evaluate the current mass matrix for the system. The space for the data must be allocated and the used space is returned. The array has 6 rows and 6 columns. The mass matrix is of the following form:

$$M = \begin{pmatrix} m & 0 & 0 & 0 & -mz_{cm} & my_{cm} \\ 0 & m & 0 & mz_{cm} & 0 & -mx_{cm} \\ 0 & 0 & m & -my_{cm} & mx_{cm} & 0 \\ 0 & mz_{cm} & -my_{cm} & I_{xx} & I_{xy} & I_{xz} \\ -mz_{cm} & 0 & mx_{cm} & I_{xy} & I_{zz} & I_{yz} \\ my_{cm} & -mx_{cm} & 0 & I_{xz} & I_{yz} & I_{zz} \end{pmatrix} \quad (34)$$

where m is the total mass, (x_{cm}, y_{cm}, z_{cm}) is the current position of the center of mass relative to the frame, and I_{ij} is the inertia tensor of the body (with the current orientation). Note that in our case the frame is coincident by definition with the center of mass of the object, so the mass matrix does not mix angular and linear variables.

Return Value: the total storage used in the workspace m
Parameters: m a pointer to the workspace where the mass matrix must be copied. If $m=0$ (default) only the total storage is evaluated and returned

2.11.7

```
virtual double cm (int i)
```

This method gives the position of the center of mass of the object relative to the frame 0.

This method gives the position of the center of mass of the object relative to the frame 0.

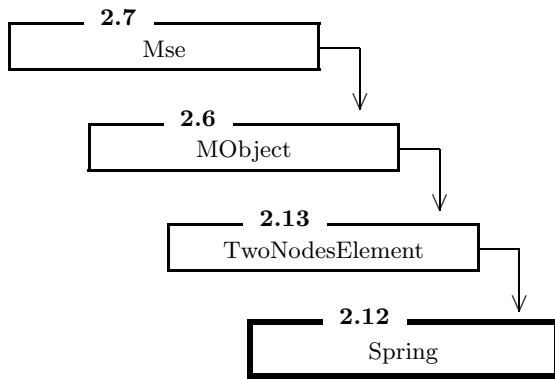
Return Value: the component of the displacement vector
Parameters: i the index of the component of the displacement vector

2.12

```
class Spring : public TwoNodesElement
```

This is the model for a simple spring.

Inheritance



Public Members

2.12.1	Spring ()	<i>Default constructor.</i>	68
2.12.2	Spring (double length, double k)	<i>Constructor with parameters.</i>	69
2.12.3	virtual char* name ()	<i>Identificative string.</i>	69

Protected Members

	virtual void UpdateForces (bool EvalJacobian=true)		
	virtual void psdraw (int i, int j, int lbl)		
2.12.4	virtual void FindWorkingPointInit ()	<i>This method must be called before the simulation-phase.</i>	69
	virtual int StiffMatrix (double *m=0)		

This is the model for a simple spring.

Parameters:

Parameter name & Parameter type & Description & Default value
Name & TYPE_STRING64 & The name of the instance of the class & ""
Separation & TYPE_DOUBLE & Length of the spring at rest & 1.0
K & TYPE_DOUBLE & Stiffness of the spring & 1.0

2.12.1

Spring ()

Default constructor.

Default constructor.

2.12.2

```
Spring (double length, double k)
```

Constructor with parameters.

Constructor with parameters.

2.12.3

```
virtual char* name ()
```

Identificative string.

Identificative string.

Return Value: the name of the class

2.12.4

```
virtual void FindWorkingPointInit ()
```

This method must be called before the simulationphase.

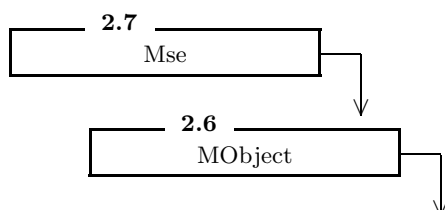
This method must be called before the simulationphase.

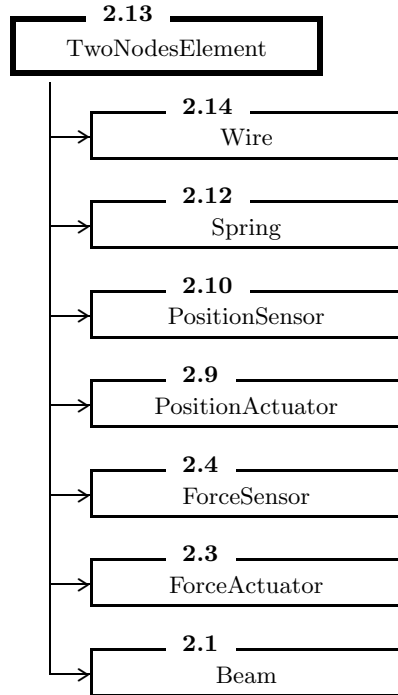
2.13

```
class TwoNodesElement : public MObject
```

Base class for all the mechanical object with twoframes.

Inheritance





Public Members

2.13.1	TwoNodesElement ()	<i>Default constructor.</i>	70
2.13.2	virtual char* name ()	<i>Identificative string.</i>	71

Base class for all the mechanical object with twoframes.

Parameters:

Parameter name & Parameter type & Description & Default value
Name & TYPE_STRING64 & The name of the instance of the class & ""

2.13.1

TwoNodesElement ()

Default constructor.

Default constructor.

2.13.2

virtual char* **name** ()

Identificative string.

Identificative string.

Return Value: the name of the class

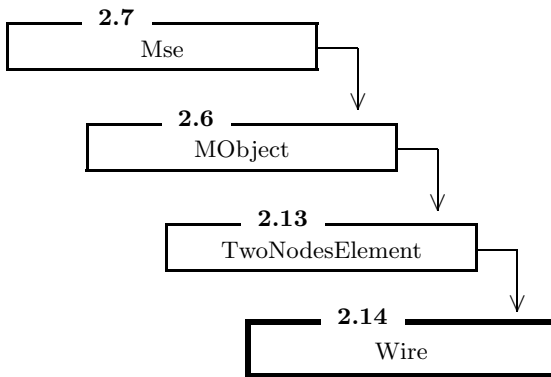
```

2.14
class Wire : public TwoNodesElement

```

This is the model for a simple wire with torsional stiffness.

Inheritance



Public Members

2.14.1	Wire ()	<i>Default constructor.</i>	72
2.14.2	Wire (double length, double r, double youngm, double poissonr)	<i>Constructor with parameters.</i>	72
2.14.3	virtual char* name ()	<i>Identificative string.</i>	72

Protected Members

```

virtual void UpdateForces (bool EvalJacobian=true)
virtual void psdraw (int i, int j, int lbl)

```

This is the model for a simple wire with torsional stiffness.

The model is defined by a potential of the form

$$U = \frac{k_1}{2} (|o_1 - o_2| - l_0)^2 + \frac{k_2}{2} (\omega \cdot n)^2 \quad (35)$$

where ω is the rotation vector between the two frames of the wire.

Parameters:

Parameter name	Parameter type	Description	Default value
Name	TYPE_STRING64	The name of the instance of the class	""
Separation	TYPE_DOUBLE	Length of the wire at rest	1.0
Young Modulus	TYPE_DOUBLE	Young's modulus of the material	1.0×10^8
Poisson Ratio	TYPE_DOUBLE	Poisson's ratio of the material	0.5
Radius	TYPE_DOUBLE	Radius of the wire circular section	1.0

2.14.1

Wire ()

Default constructor.

Default constructor.

2.14.2

Wire (double length, double r, double youngm, double poissonr)

Constructor with parameters.

Constructor with parameters.

2.14.3

virtual char* name ()

Identificative string.

Identificative string.

Return Value: the name of the class

Low level library

The reference documentation for the utility library

Names

	struct	_mech_dvec	
	struct	_mech_vec	
	struct	_mech_mat	
	struct	_mech_frame	
	struct	_mech_hess	
	typedef struct	double l0	
	extern C void	mech_beam_force (mech_dvec *f, mech_hess *h, mech_frame *r1, mech_frame *r2, beam_local_parameters *bp)	
3.1	extern C void	mech_rotation_mat (mech_vec *v, mech_mat *e) <i>Extraction of angular velocity.</i>	75
	extern C void	mech_mat_rotation_ordered (mech_mat *e, double wx, double wy, double wz)	
	extern C void	mech_mat_rotation (mech_mat *e, double wx, double wy, double wz)	
	extern C void	mech_dvec_random (mech_dvec *dv, double eps)	
	extern C void	mech_dvec_randomize (mech_dvec *dv, double eps)	
	extern C double	mech_dvec_square (mech_dvec *dv)	
	extern C void	mech_integrate_velocity (mech_frame *fm, mech_dvec *v, double feps, double steps)	
	extern C mech_frame	mech_mech_frame (double o1, double o2, double o3, double a1, double a2, double a3)	
3.2	extern C void	mech_sum_force (mech_frame *res, const mech_frame *op, const mech_frame *src) <i>This operation evaluate the total force and torque applied on a givenpoint</i>	75
3.3	extern C void	mech_compose_hessian (mech_hess *hres, mech_hess *h, mech_dvec *f, mech_frame *f1, mech_frame *f1_0, mech_frame *f2, mech_frame *f2_0) <i>Composition of frame Hessians into dof Hessians.</i>	76
3.4	extern C void	mech_add_element_block (double *dst, int dst_base, int dst_ld, double *src, int src_base, int src_ld, mech_frame *f1, mech_frame *f1_master, mech_frame *f2, mech_frame *f2_master, mech_dvec *v)	

		<i>Add an element to the linear representation. . .</i>	76
	extern C void	mech_right_transform (double *base, int rows, int ld, mech_frame *slave, mech_frame *master)	
	extern C void	mech_left_transform (double *base, int cols, int ld, mech_frame *slave, mech_frame *master)	
3.5	extern C void	mech_apply (mech_frame *res, const mech_frame *op, const mech_frame *src) <i>This operation apply a transformation to a refer- ence frame.</i>	77
3.6	extern C void	mech_connection12 (mech_frame *f2_1, const mech_frame *f1, const mech_frame *f2) <i>This operation evaluate the frame f2 in the refer- ence frame of f1.</i>	77
3.7	extern C void	mech_compose_connection (mech_frame *f3_1, const mech_frame *f3_2, const mech_frame *f2_1) <i>This operation find the frame f3 in the reference frame of f1, given the frame f3 in the reference frame f2 and the frame f2 in the reference frame f1.</i>	78
3.8	extern C void	mech_invert_connection (mech_frame *f1_2, const mech_frame *f2_1) <i>This operation evaluate the frame 1 in the refer- ence frame 2, given the frame 2 in the reference frame 1.</i>	78
3.9	extern C void	mech_identity_array (mech_mat *r) <i>This operation build a 3x3 identity matrix. . .</i>	79
3.10	extern C void	mech_mat_euler (mech_mat *r, double a1, double a2, double a3) <i>This operation build a rotation array parametrized by three Euler's angles.</i>	79
3.11	extern C void	mech_copy_array (mech_mat *dest_array, const mech_mat *src_array) <i>This operation copy a source 3x3 array in a des- tination 3x3 array.</i>	79
	extern C void	mech_mul_mat_mat (mech_mat *array, const mech_mat *m1, const mech_mat *m2)	
	extern C void	mech_mul_mat_matT (mech_mat *array, const mech_mat *m1, const mech_mat *m2)	
	extern C void	mech_mul_matT_mat (mech_mat *array, const mech_mat *m1, const mech_mat *m2)	
	extern C void	mech_mul_matT_matT (mech_mat *array, const mech_mat *m1, const mech_mat *m2)	
	extern C void	mech_mul_mat_vec (mech_vec *vec, const mech_mat *a, const mech_vec *v)	
	extern C void	mech_mul_matT_vec (mech_vec *vec, const mech_mat *a, const mech_vec *v)	

```

extern C void mech_copy_vec (mech_vec *dst, const mech_vec *src)
extern C void mech_transpose (mech_mat *dst, const mech_mat *src)
extern C void mech_array_copy (int m, int n, double *a, int lda, double *b, int ldb)
3.12 extern C void mech_array_copy_lc (int m, int n, double *a, int lda, double *b,
                                     int ldb, double alpha, double beta)
                                     Linear combination. ..... 80
extern C void mech_array_print (int m, int n, double *a, int tda)

```

3.1

```
extern C void mech_rotation_mat (mech_vec *v, mech_mat *e)
```

Extraction of angular velocity.

Extraction of angular velocity. A rotation array can be represented as a rotation of a finite angle around a given axis. This routine, given a rotation array calculate the fixed axis and the rotation angle around it.

Parameters:

- v a pointer to the results, which is a vector directed along the rotation axis with length equal to the rotation angle.
- e a pointer to the rotation array.

3.2

```
extern C void mech_sum_force (mech_frame *res, const mech_frame *op, const
                               mech_frame *src)
```

This operation evaluate the total force and torque applied on a givenpoint

This operation evaluate the total force and torque applied on a givenpoint

3.3

```
extern C void mech_compose_hessian (mech_hess *hres, mech_hess *h, mech_dvec *f,
                                     mech_frame *f1, mech_frame *f1_0, mech_frame
                                     *f2, mech_frame *f2_0)
```

Composition of frame hessians into dof hessians.

Composition of frame Hessians into dof Hessians. In order to construct the Hessian array of the constrained system, with dof entries, starting from the Hessian of the unconstrained system, with frame entries, we use

$$H^{(D1,D2)} = \sum_{F_1} \sum_{F_2} R^{(F1)} H^{(F1,F2)} T^{(F2)} \quad (36)$$

with $F_1 \in D_1$ and $F_2 \in D_2$. Here D_1 and D_2 are dofs, and F_1, F_2 are frames. The array $T^{(F)}$ is given by

$$T^{(F)} = \begin{pmatrix} I & -\vec{\sigma}^\wedge \\ 0 & I \end{pmatrix}$$

and the array $R^{(D)}$ is

$$R^{(F)} = \begin{pmatrix} I & 0 \\ \vec{\sigma}^\wedge & I \end{pmatrix} \quad (37)$$

where $\vec{\sigma}$ is the displacement between the frame F and the master frame. This routine evaluate one term of the sum.

Parameters:

hres	a pointer to the result
h	a pointer to the unconstrained hessian between the frames f1 and f2
f1	a pointer to the frame f1
f1_0	a pointer to the master frame of frame f1
f2	a pointer to the frame f2
f2_0	a pointer to the master frame of frame f2

3.4

```
extern C void mech_add_element_block ( double *dst, int dst_base, int dst_ld, double *src, int src_base, int src_ld, mech_frame *f1, mech_frame *f1_master, mech_frame *f2, mech_frame *f2_master, mech_dvec *v )
```

Add an element to the linear representation.

Add an element to the linear representation.

Parameters:	dst	is a pointer to the base of the linear array of the system
	dst_base	is an offset to the position of the block in the linear array of the system
	dst_ld	is the leading dimension of the linear array of the system
	src	is a pointer to the array which describe the element
	src_base	is an offset to the base of the array which describe the element
	src_ld	is the leading dimension of the array which describe the element
	f1	the first frame
	f1_master	the master frame of the degree of freedom the f1 frame belongs to
	f2	the second frame
	f2_master	the master frame of the degree of freedom the f2 frame belongs to
	v	a pointer to first order variation

3.5

```
extern C void mech_apply (mech_frame *res, const mech_frame *op, const mech_frame
                          *src)
```

This operation apply a transformation to a reference frame.

This operation apply a transformation to a reference frame. If $F_1 = (o_1, R_1)$ is the reference frame and $O = (o, R)$ the operation the transformed reference frame is defined by

$$F_1^* = (o_1 + o, RR_1) \quad (38)$$

Parameters:	res	a pointer to the result (transformed frame)
	op	a pointer to the transformation
	src	a pointer to the frame that must be transformed

3.6

```
extern C void mech_connection12 (mech_frame *f2_1, const mech_frame *f1, const
                                  mech_frame *f2)
```

This operation evaluate the frame f2 in the reference frame of f1.

This operation evaluate the frame f2 in the reference frame of f1. If $F_1 = (o_1, R_1)$ and $F_2 = (o_2, R_2)$ we have

$$F_{2,1} = (R_1^T(o_2 - o_1), R_1^T R_2) \quad (39)$$

Parameters:

- `f2_1` a pointer to the result (the reference 2 from the reference 1)
- `f1` a pointer to the reference frame f1
- `f2` a pointer to the reference frame f2

3.7

```
extern C void mech_compose_connection (mech_frame *f3_1, const mech_frame *f3_2,
                                         const mech_frame *f2_1)
```

This operation find the frame f3 in the reference frame of f1, given the frame f3 in the reference frame f2 and the frame f2 in the reference frame f1.

This operation find the frame f3 in the reference frame of f1, given the frame f3 in the reference frame f2 and the frame f2 in the reference frame f1. If $F_{2,1} = (b_{2,1}, R_{2,1})$ and $F_{3,2} = (b_{3,2}, R_{3,2})$ we have

$$F_{3,1} = (b_{2,1} + R_{2,1}b_{3,2}, R_{2,1}R_{3,2}) \quad (40)$$

Parameters:

- `f3_1` a pointer to the result (the reference 3 from the reference 1)
- `f3_2` the reference 3 from the reference 2
- `f2_1` the reference 2 from the reference 1

3.8

```
extern C void mech_invert_connection (mech_frame *f1_2, const mech_frame *f2_1)
```

This operation evaluate the frame 1 in the reference frame 2, given the frame 2 in the reference frame 1.

This operation evaluate the frame 1 in the reference frame 2, given the frame 2 in the reference frame 1. If $F_{2,1} = (b_{2,1}, R_{2,1})$ we have

$$F_{1,2} = (-R_{2,1}^T b_{2,1}, R_{2,1}^T) \quad (41)$$

Parameters:

- `f1_2` a pointer to the result (the reference 1 from the reference 2)
- `f2_1` a pointer to the reference 2 from the reference 1

3.9

```
extern C void mech_identity_array (mech_mat *r)
```

This operation build a 3x3 identity matrix.

This operation build a 3x3 identity matrix. This correspond to no rotations.

Parameters: `r` a pointer to the result

3.10

```
extern C void mech_mat_euler (mech_mat *r, double a1, double a2, double a3)
```

This operation build a rotation array parametrized by three Euler's angles.

This operation build a rotation array parametrized by three Euler's angles. The array can be written as

$$\begin{pmatrix} \cos \alpha_1 \cos \alpha_3 - \cos \alpha_2 \sin \alpha_1 \sin \alpha_3 & \cos \alpha_3 \sin \alpha_1 + \cos \alpha_1 \cos \alpha_2 \sin \alpha_3 & \sin \alpha_2 \sin \alpha_3 \\ -\cos \alpha_2 \cos \alpha_3 \sin \alpha_1 - \cos \alpha_1 \sin \alpha_3 & \cos \alpha_1 \cos \alpha_2 \cos \alpha_3 - \sin \alpha_1 \sin \alpha_3 & \cos \alpha_3 \sin \alpha_2 \\ \sin \alpha_1 \sin \alpha_2 & -\cos \alpha_1 \sin \alpha_2 & \cos \alpha_2 \end{pmatrix} \quad (42)$$

where α_1, α_2 and α_3 are the three Euler's angles.

Parameters:

- `r` a pointer to the result
- `a1` the first Euler's angle
- `a2` the second Euler's angle
- `a3` the third Euler's angle

3.11

```
extern C void mech_copy_array (mech_mat *dest_array, const mech_mat *src_array)
```

This operation copy a source 3x3 array in a destination 3x3 array.

This operation copy a source 3x3 array in a destination 3x3 array. The memory space for the result must be allocated yet.

Parameters:

- `src_array` a pointer to the array that must be copied
- `dest_array` a pointer to where the array must be copied into

3.12

```
extern C void mech_array_copy_lc (int m, int n, double *a, int lda, double *b, int ldb,  
                                   double alpha, double beta)
```

Linear combination.

Linear combination. The following operation is executed:

$$A \rightarrow \alpha A + \beta B \quad (43)$$

Parameters:

m	is the number of rows of A and B
n	is the number of columns of A and B
a	the matrix A
lda	the leading dimension of A
b	the matrix B
ldb	the leading dimension of B
alpha	the value of α
beta	the value of β

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