LAMPIRAN

LAMPIRAN A

COMSOL Multiphysics 3.4

Gambar A.1 Logo COMSOL Multiphysics

COMSOL Multiphysics is a powerful interactive environment for modeling and solving all kinds of scientific and engineering problems based on partial differential equations (PDEs). With this software you can easily extend conventional models for one type of physics into multiphysics models that solve coupled physics phenomena—and do so simultaneously. Accessing this power does not require an in-depth knowledge of mathematics or numerical analysis. Thanks to the built-in *physics modes* it is possible to build models by defining the relevant physical quantities—such as material properties, loads, constraints, sources, and fluxes—rather than by defining the underlying equations. COMSOL Multiphysics then internally compiles a set of PDEs representing the entire model. You access the power of COMSOL Multiphysics as a standalone product through a flexible graphical user interface, or by script programming in the COMSOL Script language or in the MATLAB language.

As noted, the underlying mathematical structure in COMSOL Multiphysics is a system of partial differential equations. We provide three ways of describing PDEs through the following mathematical application modes:

- *Coefficient form,* suitable for linear or nearly linear models
- *General form*, suitable for nonlinear models
- *Weak form*, for models with PDEs on boundaries, edges, or points, or for models using terms with mixed space and time derivatives. (The weak form provides many additional benefits, and we review them in the context of specific models in other books in this documentation set.)

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Using these application modes, you can perform various types of analysis including:

- Stationary and time-dependent analysis
- Linear and nonlinear analysis
- Eigenfrequency and modal analysis

When solving the PDEs, COMSOL Multiphysics uses the proven *finite element method (FEM)*. The software runs the finite element analysis together with adaptive meshing and error control using a variety of numerical solvers. A more detailed description of this mathematical and numerical foundation appears in the *COMSOL Multiphysics User's Guide* and in the *COMSOL Multiphysics Modeling Guide.*

PDEs form the basis for the laws of science and provide the foundation for modeling a wide range of scientific and engineering phenomena. Therefore you can use COMSOL Multiphysics in many application areas, just a few examples being:

- Acoustics
- Bioscience
- Chemical reactions
- Diffusion
- Electromagnetics
- Fluid dynamics
- Fuel cells and electrochemistry
- Geophysics
- Heat transfer
- Microelectromechanical systems (MEMS)
- Microwave engineering
- Optics
- Photonics
- Porous media flow
- Quantum mechanics
- Radio-frequency components
- Semiconductor devices
- Structural mechanics
- Transport phenomena
- Wave propagation

Many real-world applications involve simultaneous couplings in a system of PDEs —*multiphysics*. For instance, the electrical resistance of a conductor often varies with temperature, and a model of a conductor carrying current should include resistive-heating effects. This book provides an introduction to multiphysics modeling in the section "Thermal Effects in Electronic Conductors" on page 33. In addition, the *COMSOL Multiphysics Modeling Guide* covers

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multiphysics modeling techniques in the section "Creating Multiphysics Models" on page 270. The "Multiphysics" chapter in the *COMSOL Multiphysics Model Library* also contains several examples.

Along these lines, one unique feature in COMSOL Multiphysics is something we refer to as *extended multiphysics*: the use of coupling variables to connect PDE models in different geometries. This represents a step toward system-level modeling.

Another unique feature is the ability of COMSOL Multiphysics to mix domains of different space dimensions in the same problem. This flexibility not only simplifies modeling, it also can decrease execution time.

In its base configuration, COMSOL Multiphysics offers modeling and analysis power for many application areas. For several of the key application areas we also provide optional modules. These application-specific modules use terminology and solution methods specific to the particular discipline, which simplifies creating and analyzing models. The COMSOL 3.2 product family includes the following modules:

- Chemical Engineering Module
- Earth Science Module
- Electromagnetics Module
- Heat Transfer Module
- MEMS Module
- Structural Mechanics Module

The CAD Import Module provides the possibility to import CAD data using the following formats: IGES, SAT (Acis), Parasolid, and Step. Additional add-ons provide support for CATIA V4, CATIA V5, Pro/ENGINEER, Autodesk Inventor, and VDA-FS.

You can build models of all types in the COMSOL Multiphysics user interface. For additional flexibility, COMSOL also provides its own scripting language, COMSOL Script, where you can access the model as a Model M-file or a data structure. COMSOL Multiphysics also provides a seamless interface to MATLAB. This gives you the freedom to combine PDE-based modeling, simulation, and analysis with other modeling techniques. For instance, it is possible to create a model in COMSOL Multiphysics and then export it to Simulink as part of a control-system design.

LAMPIRAN B

Transduser Ultrasonik (TO19967) ORION4 - 70

Type of probe	:	Single angle
Frequency +/- 10% (MHz)	:	4
Beam angle +/- 2 (^{o})	:	70
Crystal shape	:	Circular
Crystal size (mm)	:	10
Crystal material	:	PZT
Probe Dimensions (mm)	:	17x34x25.5
Probe Weight (g)	:	36
Connector type	:	LEMO 00
Connector position	:	Rear
Wedge material	:	Perspex
Index point (mm)	:	12.5

Test Results

Peak frequency	:	4.07 MHz
Centre frequency	:	3.78 MHz
Near field length	:	31.3 mm
Pulse duration	:	0.75 µs
Peak to peak voltage	:	363.0 mV
Angle	:	70.2^o
-6dB upper	:	4.98 MHz
-6dB lower	:	2.87 MHz
Bandwidth	:	2.11 MHz

Test Conditions

Instrument used	:	Masterscan 330
Pulse width	:	120 ns
Pulse impedance	:	50 Ohms
Inspector name	:	David Waller

Dickens Road, Old Wolverton, Milton Keynes, MK12 5QQ, England
Registered in England No. 1961000
Web : www.sonatest-plc.com

LAMPIRAN C

Transduser Ultrasonik (TO19966) ORION4 - 70

Type of probe	:	Single angle
Frequency +/- 10% (MHz)	:	4
Beam angle +/- 2 (^{o})	:	70
Crystal shape	:	Circular
Crystal size (mm)	:	10
Crystal material	:	PZT
Probe Dimensions (mm)	:	17x34x25.5
Probe Weight (g)	:	36
Connector type	:	LEMO 00
Connector position	:	Rear
Wedge material	:	Perspex
Index point (mm)	:	12.5

Test Results

Peak frequency	:	3.74 MHz
Centre frequency	:	3.73 MHz
Near field length	:	28.7 mm
Pulse duration	:	0.84 µs
Peak to peak voltage	:	219.0 mV
Angle	:	70.2^o
-6dB upper	:	4.84 MHz
-6dB lower	:	2.87 MHz
Bandwidth	:	1.97 MHz

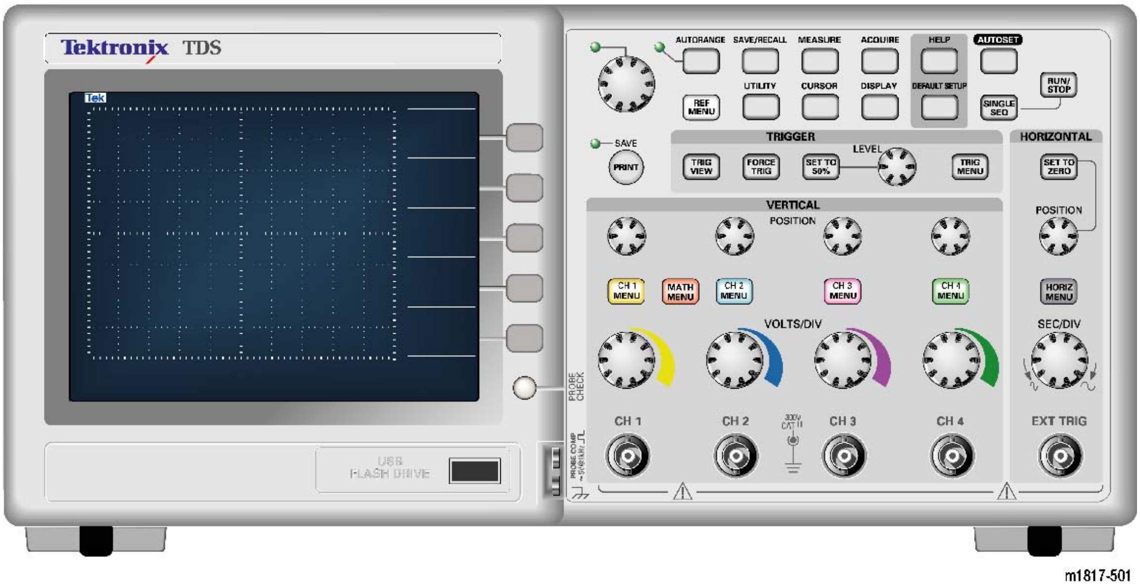
Test Conditions

Instrument used	:	Masterscan 330
Pulse width	:	120 ns
Pulse impedance	:	50 Ohms
Inspector name	:	David Waller

Dickens Road, Old Wolverton, Milton Keynes, MK12 5QQ, England
Registered in England No. 1961000
Web : www.sonatest-plc.com

LAMPIRAN D

Osiloskop Tektronix TDS 2014



Gambar D.1 Osiloskop Tektronix TDS 4 Channel

Table 1: Acquisition Specifications

Characteristic	Description	
Acquisition Modes	Sample, Peak Detect, and Average	
Acquisition Rate, typical	Up to 180 waveforms per second, per channel (Sample acquisition mode, no measurements)	
Single Sequence	*Acquisition Mode*	*Acquisition Stops After*
	Sample, Peak Detect	Single acquisition, all channels simultaneously
	Average	N acquisitions, all channels simultaneously, N is selectable from 4, 16, 64, and 128

Table 2: Input Specifications

Characteristic	Description			
Input Coupling	DC, AC, or Ground			
Input Impedance, DC Coupled	1 MΩ ±2% in parallel with 20 pF ±3 pF			
P2220 Probe Attenuation	1X, 10X			
Supported Voltage Probe Attenuation Factors	1X, 10X, 20X, 50X, 100X, 500X, 1000X			
Supported Current Probe Scales	5 V/A, 1 V/A, 500 mV/A, 200 mV/A, 100 mV/A, 20 mV/A, 10 mV/A, 1 mV/A			
Maximum Voltage Between Signal and Reference at input BNC	*Overvoltage Category*		*Maximum Voltage*	
	CAT I and CAT II		300 V_{RMS}	
	CAT III		150 V_{RMS}	
	Installation Category II; derate at 20 dB/decade above 100 kHz to 13 V peak AC at 3 MHz [1] and above. For non-sinusoidal waveforms, peak value must be less than 450 V. Excursion above 300 V should be less than 100 ms duration and the duty factor is limited to ≤ 44%. RMS signal level including any DC component removed through AC coupling must be limited to 300 V. If these values are exceeded, damage to the instrument may result. Refer to the *Overvoltage Category* description above.			
Channel Common Mode Rejection, typical	*TDS1001B*	*TDS1002B, 2002B, 2004B*	*TDS1012B, 2012B, 2014B, 2022B, 2024B*	
	100:1 at 60 Hz, 20:1 at 20 MHz [1,2]	100:1 at 60 Hz, 20:1 at 30 MHz [1,2]	100:1 at 60 Hz, 10:1 at 50 MHz [1,2]	
	Measured on MATH Ch1 - Ch2 waveform, with test signal applied between signal and common of both channels, and with the same VOLTS/DIV and coupling settings on each channel			
	Measured on MATH Ch3 - Ch4 waveform for 4-channel models			
Channel-to-Channel Crosstalk	*TDS1001B*	*TDS1002B, 2002B, 2004B*	*TDS1012B, 2012B, 2014B*	*TDS2022B, 2024B*
	≥ 100:1 at 20 MHz [1,2]	≥ 100:1 at 30 MHz [1,2]	≥ 100:1 at 50 MHz [1,2]	≥ 100:1 at 100 MHz [1,2]
	Measured on one channel, with test signal applied between signal and common of the other channel, and with the same VOLTS/DIV and coupling settings on each channel			

1 Bandwidth reduced to 6 MHz with a 1X probe.

2 Does not include probe related effects.

Table 3: Vertical Specifications [1]

Characteristic	Description			
Digitizers	8-bit resolution (except when set to 2 mV/div), each channel sampled simultaneously			
VOLTS/DIV Range	2 mV/div to 5 V/div at input BNC			
Position Range	2 mV/div to 200 mV/div ±2 V > 200 mV/div to 5 V/div, ±50 V			
Analog Bandwidth in Sample and Average modes at BNC or with P2220 probe set to 10X, DC Coupled	*TDS1001B*	*TDS1002B, 2002B, 2004B*	*TDS1012B, 2012B, 2014B*	*TDS2022B, 2024B*
	40 MHz [2,3]	60 MHz [2,3]	100 MHz [2,3]	200 MHz [2,3] 0 °C to +35 °C (32 °F to +95 °F) 160 MHz [2,3] 0 °C to +50 °C (32 °F to 122 °F)
	20 MHz [2] (when vertical scale is set to < 5 mV)			
Analog Bandwidth in Peak Detect mode (50 s/div to 5 µs/div [4]), typical	*TDS1001B*	*TDS1002B, 2002B, 2004B*	*TDS1012B, 2012B, 2014B, 2022B, 2024B*	
	30 MHz [2,3]	50 MHz [2,3]	75 MHz [2,3]	
	20 MHz [2] (when vertical scale is set to < 5 mV)			
Selectable Analog Bandwidth Limit, typical	20 MHz [2]			
Lower Frequency Limit, AC Coupled	≤ 10 Hz at BNC ≤ 1 Hz when using a 10X passive probe			
Rise Time at BNC, typical	*TDS1001B*	*TDS1002B, 2002B, 2004B*	*TDS1012B, 2012B, 2014B*	*TDS2022B, 2024B*
	< 8.4 ns	< 5.8 ns	< 3.5 ns	< 2.1 ns
Peak Detect Response [4]	Captures 50% or greater amplitude of pulses ≥12 ns wide typical (50 s/div to 5 ms/div) in the center 8 vertical divisions			
DC Gain Accuracy	±3% for Sample or Average acquisition mode, 5 V/div to 10 mV/div			
	±4% for Sample or Average acquisition mode, 5 mV/div and 2 mV/div			

Table 3: Vertical Specifications [1] (cont.)

Characteristic	Description	
DC Measurement Accuracy, Average Acquisition Mode	*Measurement Type*	*Accuracy*
	Average of ≥ 16 waveforms with vertical position at zero	±(3% × reading + 0.1 div + 1 mV) when 10 mV/div or greater is selected
	Average of ≥ 16 waveforms with vertical position with Vertical Scale 2 mV/div to 200 mV/div and –1.8 V < Vertical Position < 1.8V	±[3% × (reading + vertical position) + 1% of vertical position + 0.2 div + 7 mV]
	Average of ≥ 16 waveforms with vertical position with Vertical Scale > 200 mV/div and –45 V < Vertical Position < 45 V	±[3% × (reading + vertical position) + 1% of vertical position + 0.2 div + 175 mV]
Volts Measurement Repeatability, Average Acquisition Mode	Delta volts between any two averages of ≥ 16 waveforms acquired under the same setup and ambient conditions	±(3% × reading + 0.05 div)

1 Specifications are with the Probe ▶ Voltage ▶ Attenuation option set to 1X.

2 Bandwidth reduced to 6 MHz with a 1X probe.

3 When vertical scale is set to > 5 mV.

4 The oscilloscope reverts to Sample mode when the SEC/DIV (horizontal scale) is set from 2.5 ms/div to 5 ns/div on 1 GS/s models, or from 2.5 ms/div to 2.5 ns/div on 2 GS/s models. The Sample mode can still capture 10 ns glitches.

Table 4: Horizontal Specifications

Characteristic	Description	
Sample Rate Range	*TDS1001B, 1002B, 1012B, 2002B, 2004B, 2012B, 2014B*	*TDS2022B, 2024B*
	5 S/s to 1 GS/s	5 S/s to 2 GS/s
Waveform Interpolation	(sin x)/x	
Record Length	2500 samples for each channel	
SEC/DIV Range	*TDS1001B, 1002B, 1012B, 2002B, 2004B, 2012B, 2014B*	*TDS2022B, 2024B*
	5 ns/div to 50 s/div, in a 1, 2.5, 5 sequence	2.5 ns/div to 50 s/div, in a 1, 2.5, 5 sequence
Sample Rate and Delay Time Accuracy	±50 parts per million over any ≥1 ms time interval	
Delta Time Measurement Accuracy (Full Bandwidth)	*Conditions*	*Accuracy*
	Single-shot, Sample mode	±(1 sample interval + 100 parts per million × reading + 0.6 ns)
	> 16 averages	±(1 sample interval + 100 parts per million × reading + 0.4 ns)
	Sample interval = s/div ÷ 250	
Position Range	*TDS1001B, 1002B, 1012B, 2002B, 2004B, 2012B, 2014B 2022B, 2024B*	
	5 ns/div to 10 ns/div	(-4 div × s/div) to 20 ms
	25 ns/div to 100 µs/div	(-4 div × s/div) to 50 ms
	250 ms/div to 50 s/div	(-4 div × s/div) to 50 s
	TDS2022B, 2024B	
	2.5 ns/div	(-4 div × s/div) to 20 ms

LAMPIRAN E

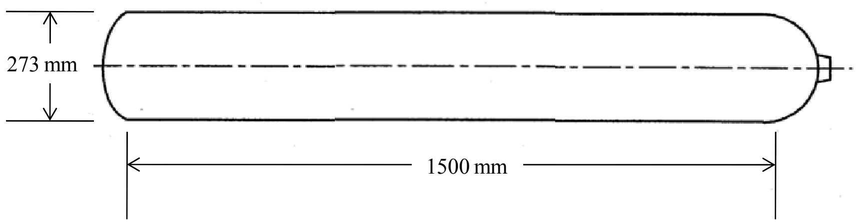
Tabung Gas CNG Untuk Sektor Transportasi

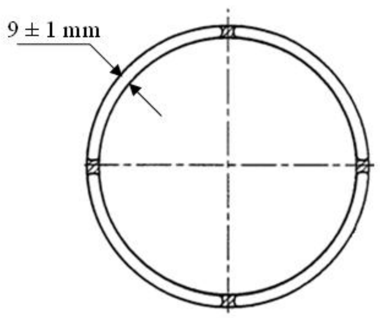
Gambar E.1 Tabung-tabung CNG

Tabung gas CNG yang merupakan tabung NGV (*Natural Gas as fuel for automotive Vehicles*) dan yang telah diperiksa berdasarkan standar internasional ini didesain dan dicocokkan dengan ISO 11439 dan ISO 9809-1. Tipe tabung ini adalah CNG-1 metal karena kesemua bahannya terbuat dari logam/*metal* dan dapat dibuat dari logam campuran / *alloy* yang telah memenuhi standar kualifikasi desain tabung CNG NGV internasional. Tabung CNG yang digunakan pada penelitian ini memiliki spesifikasi sbb :

a. Desain, konstruksi dan kekuatan tarik sesuai dengan **ISO 9809-1**
   Dimensi lihat gambar E.2
b. Material (**ISO 11439**)
   Tabung CNG ini berbahan *Carbon Manganese Steel* (CMn).
   Dengan toleransi kandungan kimia sbb

Element	Maximum content	Permissible range
Carbon	< 0,30 % ≥ 0,30 %	0,06 % 0,07 %
Manganese	All values	0,30 %





Gambar E.2 Diagram skematik Tabung CNG

Sedangkan komposisi dari *steel* yang direkomendasikan menjadi standar internasional adalah sbb

Element	**Steel grade and conditions**
	CMn (Q & T)
Carbon	0,38 max. %
Silicon	0,1 to 0,35 %
Manganese	1,35 to 1,75 %
Phosphorus	0,020 max.%
Sulfur	0,020 max.%
Chromium	
Molybdenum	
NOTE The actual range for each element shall be in accordance with 6.2.1 and 6.2.2, and good steel making practice. In particular the limits specified in Table 2 take precedence over the ranges given in this table.	

Berikut merupakan data properti material yang digunakan dalam simulasi dan eksperimen.

Material	**Longitudinal Velocity**		**Shear Velocity**		**Density**	**Acoustic Impedance**	**Young Modulus**	**Shear Modulus**	**Poisson ratio**
	cm/ms	**In/ms**	**cm/ms**	**In/ms**	**g/cm^3**	**g/cm^2-sec (x 10^5)**	**GPa**	**GPa**	
Steel, 4340	.585	.2303	.128	.0504	7.80	45.63	210	76	0.29

LAMPIRAN F

COMSOL MULTIPHYSICS Model M – File

```
% COMSOL Multiphysics Model M-file
% Generated by COMSOL 3.4 (COMSOL 3.4.0.248, $Date: 2007/10/10
16:07:51 $)

flclear fem

% COMSOL version
clear vrsn
vrsn.name = 'COMSOL 3.4';
vrsn.ext = '';
vrsn.major = 0;
vrsn.build = 248;
vrsn.rcs = '$Name:  $';
vrsn.date = '$Date: 2007/10/10 16:07:51 $';
fem.version = vrsn;

% Geometry
g1=rect2(2.14,0.7,'base','center','pos',[0.03,0.04]);
g2=rect2('.0482','0.009','base','corner','pos',{'0','0'},'rot','0'
);
carr={curve2([2.0E-
4,0.0102],[0.009000000000000001,0.009000000000000001],[1,1]), ...
  curve2([0.0102,0.0102],[0.009000000000000001,0.0134],[1,1]), ...
  curve2([0.0102,0.009000000000000001],[0.0134,0.0134],[1,1]), ...
  curve2([0.009000000000000001,2.0E-
4],[0.0134,0.009000000000000001],[1,1])};
g3=geomcoerce('solid',carr);
gg=geomedit(g3);
gg{2}=beziercurve2([2.0E-4,0.0172],[0.0090,0.0090],[1,1]);
gg{3}=beziercurve2([0.0090,0.0172],[0.0134,0.0134],[1,1]);
gg{4}=beziercurve2([0.0172,0.0172],[0.0090,0.0134],[1,1]);
g4=geomedit(g3,gg);
g4=move(g4,[0.0308,0]);
carr={curve2([0.048,0.031],[0.009000000000000001,0.009000000000000
001],[1,1]), ...
  curve2([0.031,0.031],[0.009000000000000001,0.0134],[1,1]), ...
  curve2([0.031,0.0392],[0.0134,0.0134],[1,1]), ...
  curve2([0.0392,0.048],[0.0134,0.009000000000000001],[1,1])};
g5=geomcoerce('solid',carr);
g4=move(g4,[-0.0308,0]);

% Constants
fem.const = {'fc','5e06', ...
  'bw','2e06', ...
  'A','((log(2))^0.5)/(pi*bw)', ...
  'to','1e-06'};

% Geometry

% Analyzed geometry
clear s
```

```
s.objs={g2,g4,g5};
s.name={'Steel','Transmitter','Receiver'};
s.tags={'g2','g4','g5'};

fem.draw=struct('s',s);
fem.geom=geomcsg(fem);

% Initialize mesh
fem.mesh=meshinit(fem, ...
                  'hmax',[0.000119], ...
                  'hmaxfact',0.15, ...
                  'hcurve',0.2, ...
                  'hgrad',1.2, ...
                  'hcutoff',0.0001);

% (Default values are not included)

% Application mode 1
clear appl
appl.mode.class = 'Wave';
appl.assignsuffix = '_waeq';
clear bnd
bnd.r = {0,0,'cos(2*pi*fc*t)*exp((-(t-t0)^2)/(4*(A^2)))*(t<1)'};
bnd.type = {'dir','neu','dir'};
bnd.ind = [2,1,1,3,2,1,1,1,1,2,1,1,1,2];
appl.bnd = bnd;
clear equ
equ.f = 0;
equ.c = {'5850^2','2760^2'};
equ.ind = [1,2,2];
appl.equ = equ;
fem.appl{1} = appl;
fem.frame = {'ref'};
fem.border = 1;
clear units;
units.basesystem = 'SI';
fem.units = units;

% ODE Settings
clear ode
clear units;
units.basesystem = 'SI';
ode.units = units;
fem.ode=ode;
% Multiphysics
fem=multiphysics(fem);

% Extend mesh
fem.xmesh=meshextend(fem);

% Solve problem
fem.sol=femtime(fem, ...
                'solcomp',{'u'}, ...
                'outcomp',{'u'}, ...
                'tlist',[0:0.05e-06:13e-06], ...
                'maxorder',2, ...
                'tout','tlist');
```

```
% Save current fem structure for restart purposes
fem0=fem;

% Plot solution
postplot(fem, ...
         'tridata',{'u','cont','internal'}, ...
         'trimap','jet(1024)', ...
         'solnum','end', ...
         'title','Time=1.3e-5    Surface: u', ...
         'axis',[-0.00241000003874302,0.05061000008136034,-
0.006992458973522527,0.020392458562250478]);
```