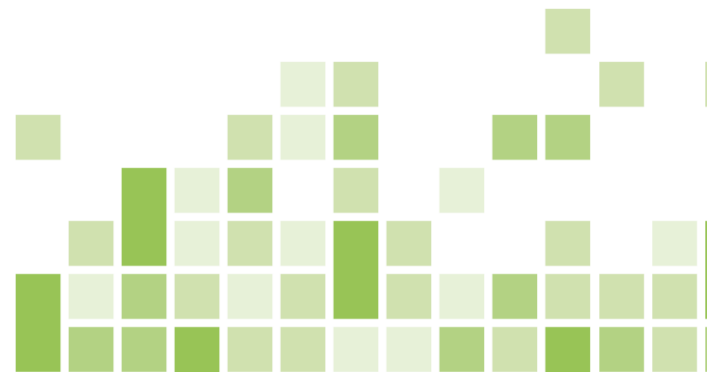




ТОМСКИЙ  
ПОЛИТЕХНИЧЕСКИЙ  
УНИВЕРСИТЕТ



МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ФИЗИЧЕСКИХ  
ПРОЦЕССОВ  
ЛЕКЦИЯ №16

«Математическое описание физико-химических  
процессов в физических установках: применение пакета  
Matlab и его расширения Simulink»

Отделение ядерно-топливного цикла

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Горюнов А.Г.

2020

# План лекции

16.1. Вычислительная статистика в Matlab

(<https://www.youtube.com/watch?v=Qshi5W-p1Jw> )

16.2. Начало работы в Simulink

([https://www.youtube.com/watch?v=\\_gDsgHQ-Y1s](https://www.youtube.com/watch?v=_gDsgHQ-Y1s) )

(<https://www.youtube.com/watch?v=K61lx2WklyI> )

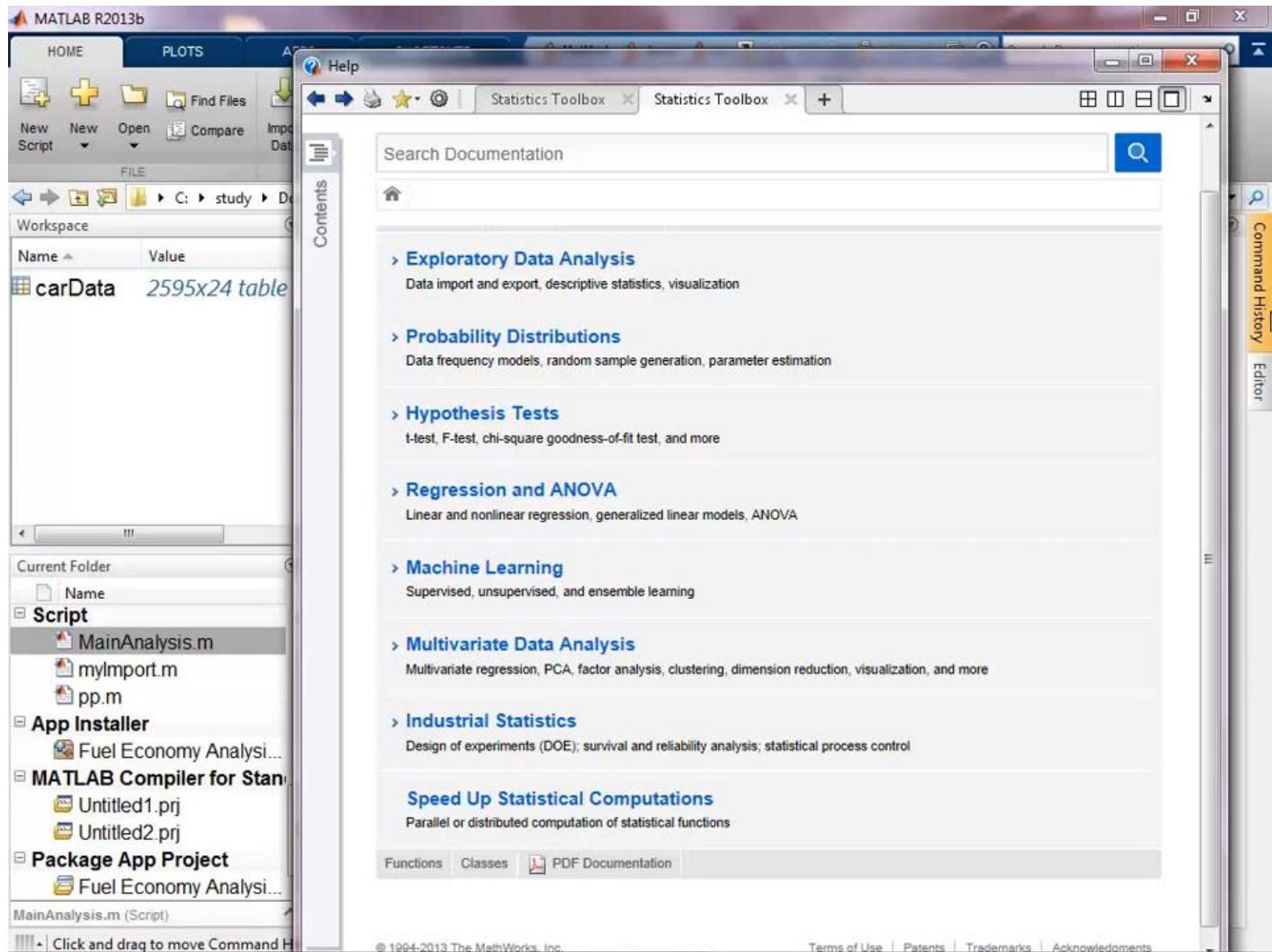
16.3. Пример моделирования физического процесса в Simulink

Информация по курсу:

<https://portal.tpu.ru/SHARED/a/ALEX1479/study/Matmod/Tab>

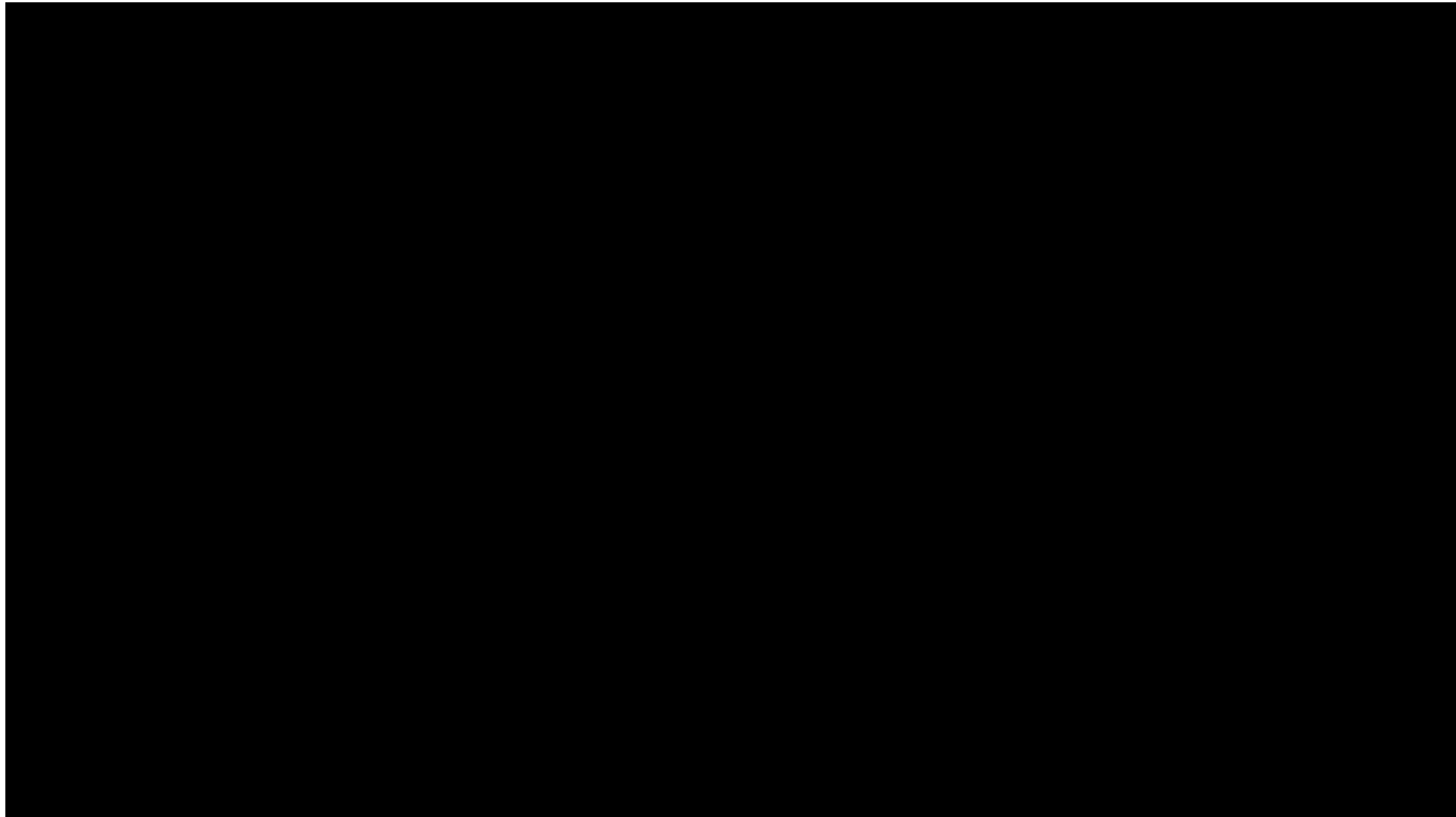
# 16.1 Вычислительная статистика

(<https://www.youtube.com/watch?v=Qshi5W-p1Jw>)



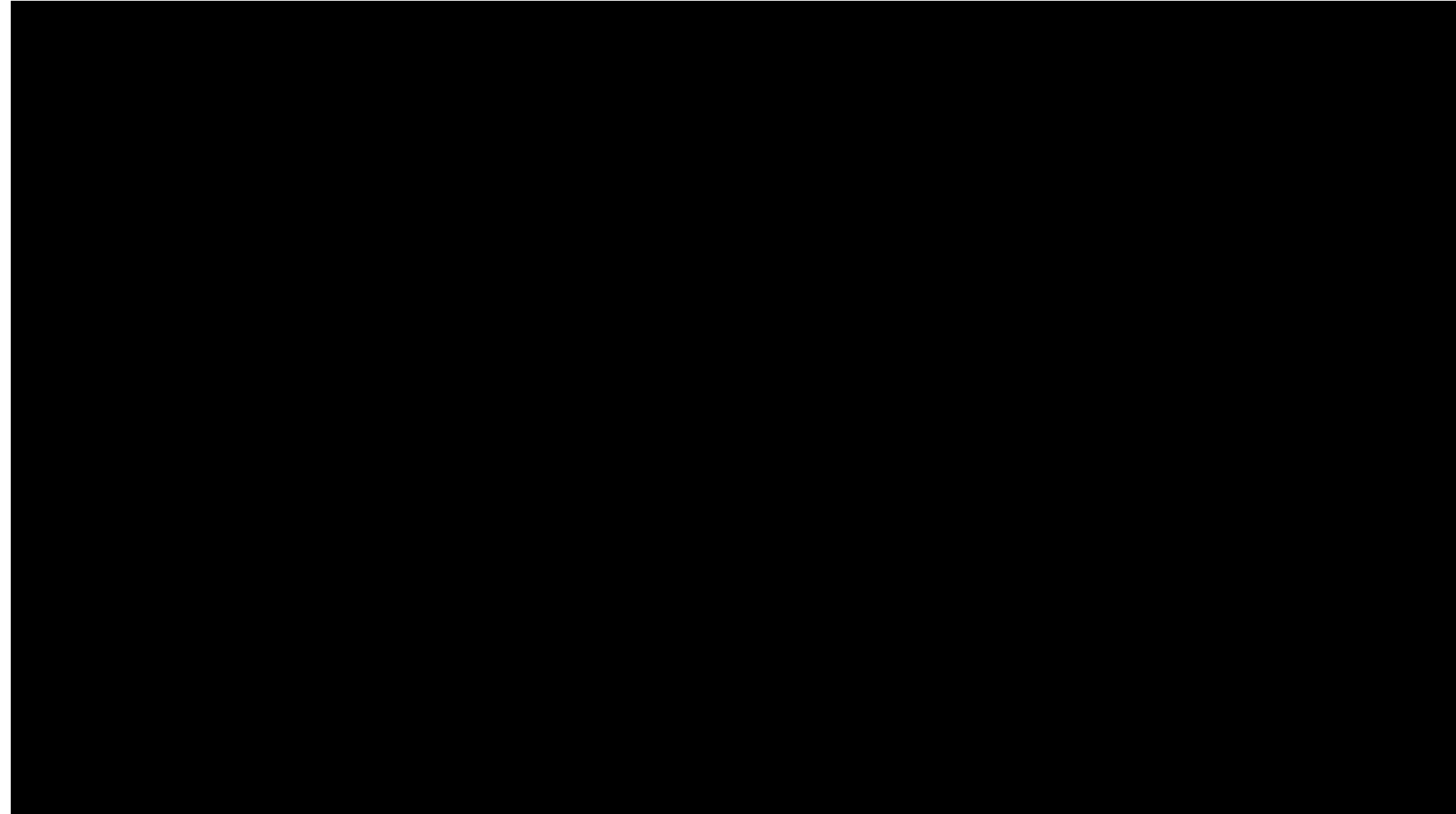
# 16.2 Начало работы в Simulink

([https://www.youtube.com/watch?v=\\_gDsgHQ-Y1s](https://www.youtube.com/watch?v=_gDsgHQ-Y1s) )



# 16.2 Начало работы в Simulink

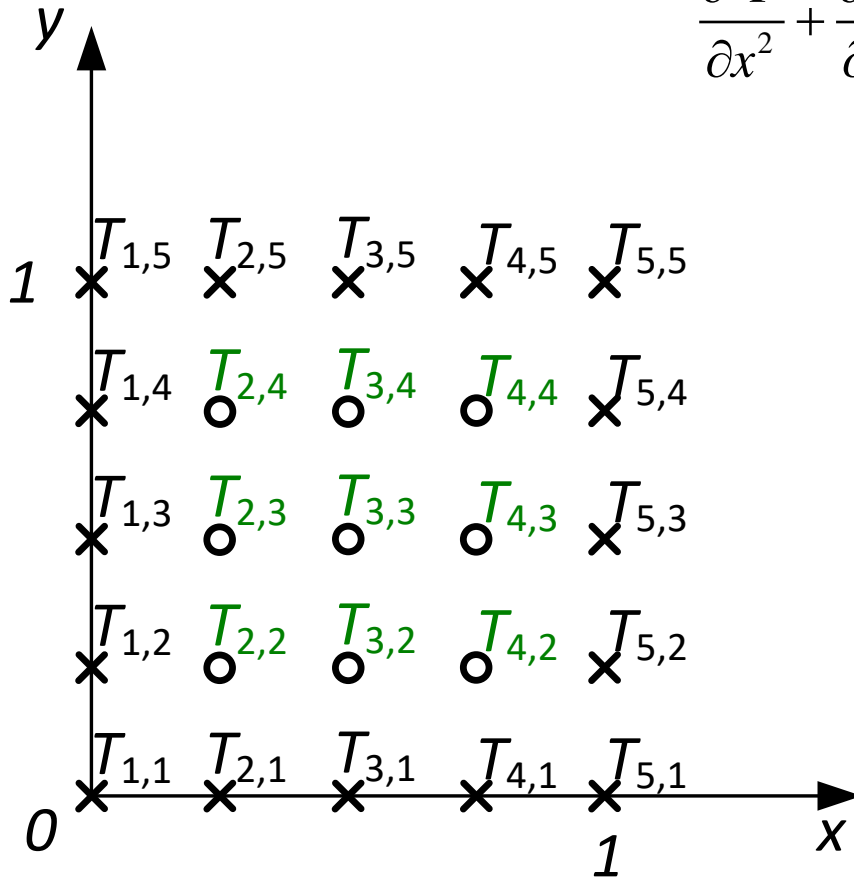
(<https://www.youtube.com/watch?v=K61lx2WklyI> )



# 16.3 Пример моделирования физического процесса в Simulink

## 16.3.1 Пример моделирования процесса теплопередачи в плоской пластине

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \quad (16.1)$$



$$T_{1,1} = T_{1,2} = T_{1,3} = T_{1,4} = T_{1,5} = 0$$

$$T_{5,1} = T_{5,2} = T_{5,3} = T_{5,4} = T_{5,5} = 100$$

$$T_{2,1} = 25; T_{3,1} = 50; T_{4,1} = 75$$

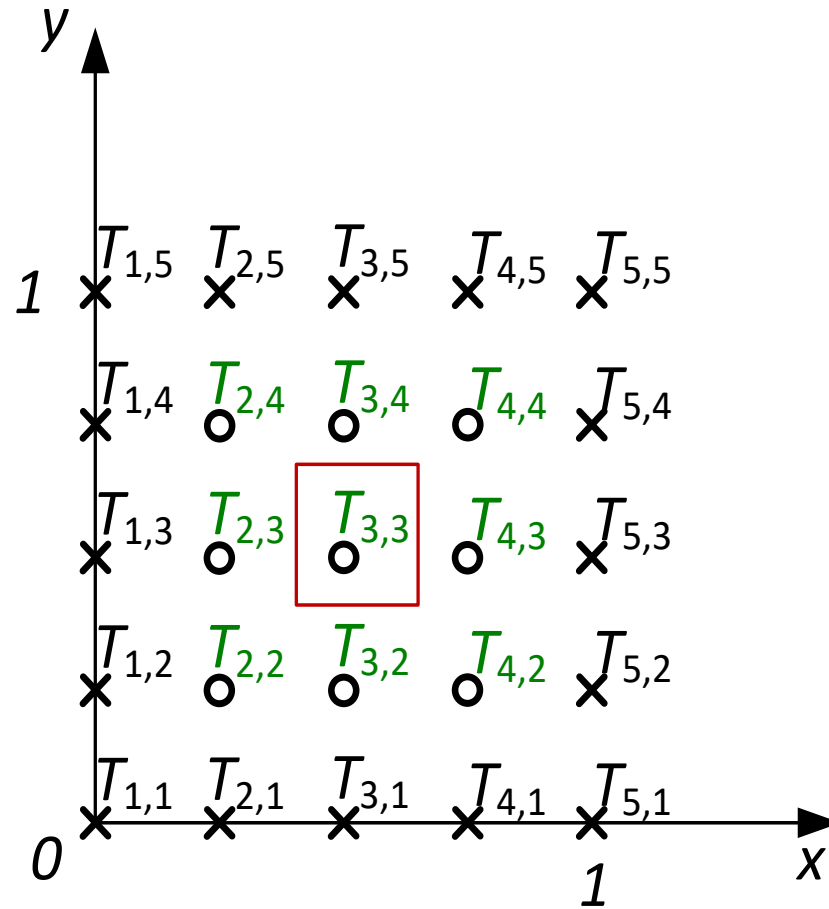
$$T_{2,5} = 6.25; T_{3,5} = 25; T_{4,5} = 56.25$$

$$h = h_x = h_y = 0.25$$

## 16.3.2 Метод конечных разностей и форма Коши

$$\left\{ \begin{array}{l}
 \frac{dT_{2,2}}{dt} = \frac{T_{3,2} - 2T_{2,2} + T_{1,2}}{h^2} + \frac{T_{2,3} - 2T_{2,2} + T_{2,1}}{h^2} \\
 \frac{dT_{3,2}}{dt} = \frac{T_{4,2} - 2T_{3,2} + T_{2,2}}{h^2} + \frac{T_{3,3} - 2T_{3,2} + T_{3,1}}{h^2} \\
 \frac{dT_{4,2}}{dt} = \frac{T_{5,2} - 2T_{4,2} + T_{3,2}}{h^2} + \frac{T_{4,3} - 2T_{4,2} + T_{4,1}}{h^2} \\
 \frac{dT_{2,3}}{dt} = \frac{T_{3,3} - 2T_{2,3} + T_{1,3}}{h^2} + \frac{T_{2,4} - 2T_{2,3} + T_{2,2}}{h^2} \\
 \frac{dT_{3,3}}{dt} = \frac{T_{4,3} - 2T_{3,3} + T_{2,3}}{h^2} + \frac{T_{3,4} - 2T_{3,3} + T_{3,2}}{h^2} \\
 \frac{dT_{4,3}}{dt} = \frac{T_{5,3} - 2T_{4,3} + T_{3,3}}{h^2} + \frac{T_{4,4} - 2T_{4,3} + T_{4,2}}{h^2} \\
 \frac{dT_{2,4}}{dt} = \frac{T_{3,4} - 2T_{2,4} + T_{1,4}}{h^2} + \frac{T_{2,5} - 2T_{2,4} + T_{2,3}}{h^2} \\
 \frac{dT_{3,4}}{dt} = \frac{T_{4,4} - 2T_{3,4} + T_{2,4}}{h^2} + \frac{T_{3,5} - 2T_{3,4} + T_{3,3}}{h^2} \\
 \frac{dT_{4,4}}{dt} = \frac{T_{5,4} - 2T_{4,4} + T_{3,4}}{h^2} + \frac{T_{4,5} - 2T_{4,4} + T_{4,3}}{h^2}
 \end{array} \right. \quad (16.2)$$

### 16.3.3 Учет источник тепла





### 16.3.3 Учет источник тепла

$$\left\{ \begin{array}{l}
 \frac{dT_{2,2}}{dt} = \frac{T_{3,2} - 2T_{2,2} + T_{1,2}}{h^2} + \frac{T_{2,3} - 2T_{2,2} + T_{2,1}}{h^2} \\
 \frac{dT_{3,2}}{dt} = \frac{T_{4,2} - 2T_{3,2} + T_{2,2}}{h^2} + \frac{T_{3,3} - 2T_{3,2} + T_{3,1}}{h^2} \\
 \frac{dT_{4,2}}{dt} = \frac{T_{5,2} - 2T_{4,2} + T_{3,2}}{h^2} + \frac{T_{4,3} - 2T_{4,2} + T_{4,1}}{h^2} \\
 \frac{dT_{2,3}}{dt} = \frac{T_{3,3} - 2T_{2,3} + T_{1,3}}{h^2} + \frac{T_{2,4} - 2T_{2,3} + T_{2,2}}{h^2} \\
 \frac{dT_{3,3}}{dt} = \frac{T_{4,3} - 2T_{3,3} + T_{2,3}}{h^2} + \frac{T_{3,4} - 2T_{3,3} + T_{3,2}}{h^2} + \frac{Q}{m_q \cdot C_p} \\
 \frac{dT_{4,3}}{dt} = \frac{T_{5,3} - 2T_{4,3} + T_{3,3}}{h^2} + \frac{T_{4,4} - 2T_{4,3} + T_{4,2}}{h^2} \\
 \frac{dT_{2,4}}{dt} = \frac{T_{3,4} - 2T_{2,4} + T_{1,4}}{h^2} + \frac{T_{2,5} - 2T_{2,4} + T_{2,3}}{h^2} \\
 \frac{dT_{3,4}}{dt} = \frac{T_{4,4} - 2T_{3,4} + T_{2,4}}{h^2} + \frac{T_{3,5} - 2T_{3,4} + T_{3,3}}{h^2} \\
 \frac{dT_{4,4}}{dt} = \frac{T_{5,4} - 2T_{4,4} + T_{3,4}}{h^2} + \frac{T_{4,5} - 2T_{4,4} + T_{4,3}}{h^2}
 \end{array} \right. \quad (16.3)$$

$Q$  – источник тепла, Вт (Дж/с),  
 $m_q$  – масса источника тепла, кг,  
 $C_p$  – теплоемкость материала,  
 Дж/(кг·°С)

## 16.3.4 Формируем граничные и начальные условия

The screenshot displays the MATLAB Editor interface with a script named 'create\_T.m'. The script defines a 5x5 matrix T with specific boundary and initial conditions. Below the editor, the Command Window shows the execution of the script, and the Workspace window shows the resulting matrix T. The Variables window provides a detailed view of the matrix T.

```

1 - clc;
2 - T = zeros(5,5);
3
4 - T(1,1) = 0; T(1,2) = 0; T(1,3) = 0; T(1,4) = 0; T(1,5) = 0;
5 - T(5,1) = 100; T(5,2) = 100; T(5,3) = 100; T(5,4) = 100; T(5,5) = 100;
6 - T(2,1) = 25; T(3,1) = 50; T(4,1) = 75;
7 - T(2,5) = 6.25; T(3,5) = 25; T(4,5) = 56.25;
8

```

**Workspace:**

Name	Value
T	<5x5 double>

**Variables - T:**

	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0				
2	25	0	0	0	6.2500				
3	50	0	0	0	25				
4	75	0	0	0	56.2500				
5	100	100	100	100	100				
6									
7									
8									
9									

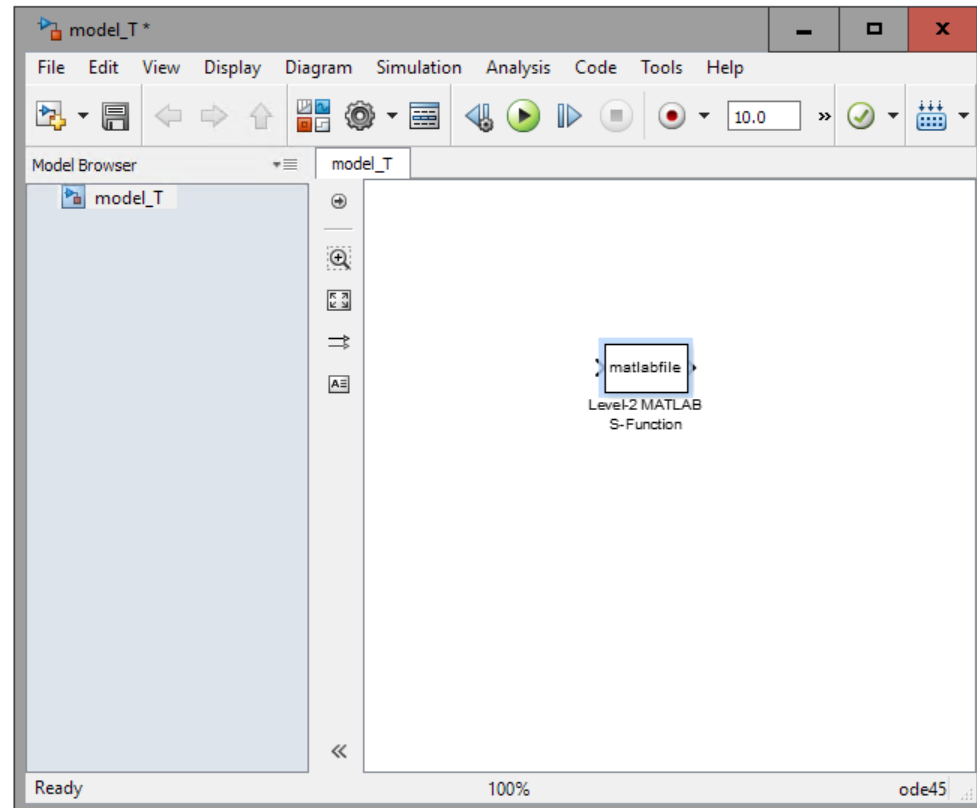
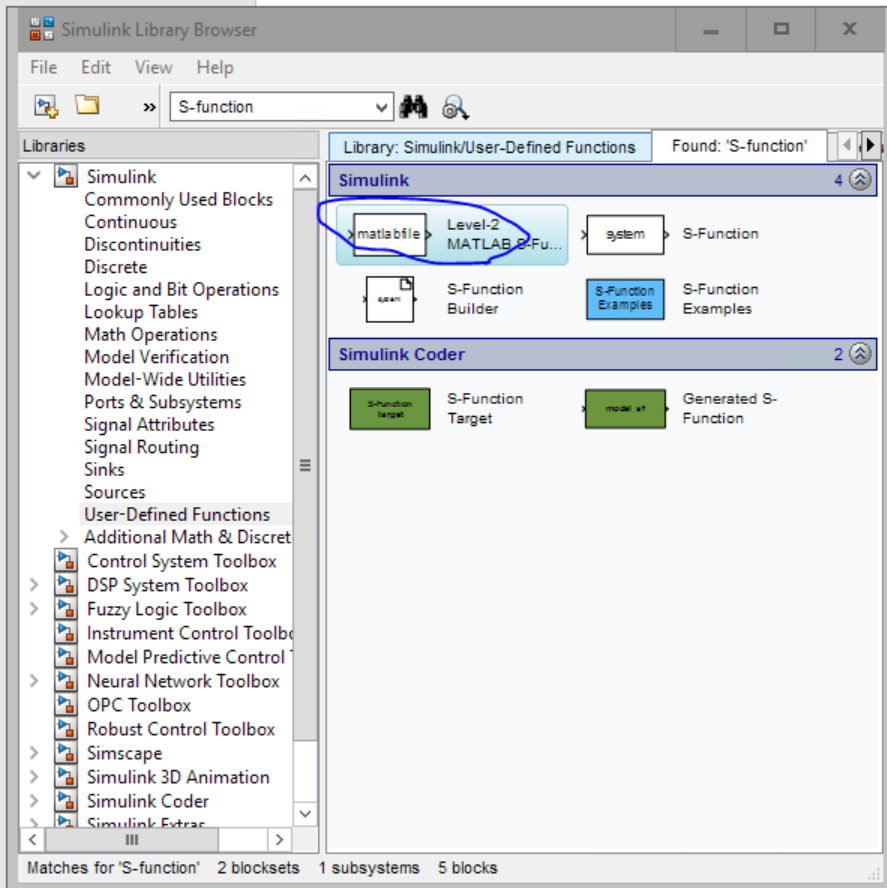
**Command History:**

```

-- $-- 16.12.2020 19:11
    create_T

```

## 16.3.5 Создание S-функции в Simulink



## 16.3.5 Создание S-функции в Simulink

The image displays the Simulink environment with a model window titled 'model\_T'. The Model Browser on the left shows the 'model\_T' block. The main workspace contains a 'matlabfile' block, which is a Level-2 MATLAB S-Function. A dialog box titled 'Function Block Parameters: Level-2 MATLAB S-Function' is open, showing the 'M-S-Function' configuration. The 'S-function name' field is set to 'mymodel', and the 'Parameters' field is empty. The dialog box includes 'OK', 'Cancel', 'Help', and 'Apply' buttons.

The MATLAB Editor window is also visible, showing the file 'mymodel.m' in the editor. The editor has a menu bar with 'EDITOR', 'PUBLISH', and 'VIEW' tabs. The toolbar includes icons for 'New', 'Open', 'Save', 'Find Files', 'Compare', 'Print', 'Insert', 'Comment', 'Indent', 'Go To', 'Find', 'Breakpoints', 'Run', 'Run and Time', 'Run and Advance', and 'Run Section'. The editor content shows a single line of code at line 1.

## 16.3.5 Создание S-функции в Simulink (настройка входов и выходов)

```
mymodel.m* x
1  function mymodel(block)
2  -   setup(block);
3  function setup(block)
4  %% Register number of input and output ports
5  -   block.NumInputPorts = 1;
6  -   block.NumOutputPorts = 9;
7
8  %% Setup functional port properties to dynamically
9  %% inherited.
10 -   block.SetPreCompInpPortInfoToDynamic;
11 -   block.SetPreCompOutPortInfoToDynamic;
12
13 -   block.InputPort(1).SamplingMode = 'Sample';
14 -   block.InputPort(1).Dimensions = 1;
15
16 -   block.OutputPort(1).SamplingMode = 'Sample';
17 -   block.OutputPort(1).Dimensions = 1;
18 -   block.OutputPort(2).SamplingMode = 'Sample';
19 -   block.OutputPort(2).Dimensions = 1;
20 -   block.OutputPort(3).SamplingMode = 'Sample';
21 -   block.OutputPort(3).Dimensions = 1;
22 -   block.OutputPort(4).SamplingMode = 'Sample';
23 -   block.OutputPort(4).Dimensions = 1;
24 -   block.OutputPort(5).SamplingMode = 'Sample';
25 -   block.OutputPort(5).Dimensions = 1;
26 -   block.OutputPort(6).SamplingMode = 'Sample';
27 -   block.OutputPort(6).Dimensions = 1;
```

## 16.3.5 Создание S-функции в Simulink (настройка входов и выходов)

```
mymodel.m* x
28 - block.OutputPort(7).SamplingMode = 'Sample';
29 - block.OutputPort(7).Dimensions = 1;
30 - block.OutputPort(8).SamplingMode = 'Sample';
31 - block.OutputPort(8).Dimensions = 1;
32 - block.OutputPort(9).SamplingMode = 'Sample';
33 - block.OutputPort(9).Dimensions = 1;
34 - %% Set block sample time to inherited
35 - block.SampleTimes = [0 0];
36 -
37 - %% Register methods
38 - block.RegBlockMethod('InitializeConditions', @InitConditions);
39 - block.RegBlockMethod('Outputs', @Output);
40 - block.RegBlockMethod('Derivatives', @Derivatives);
41 - block.NumContStates = 9;
42 - %% endfunction
43
44
```

## 16.3.5 Создание S-функции в Simulink (настройка инициализации, начальные условия)

```
mymodel.m x
40 - block.RegBlockMethod('Derivatives', @Der:
41 - block.NumContStates = 9;
42   %% endfunction
43
44
45
46 - function InitConditions(block)
47   %% Initialize Dwork
48 - T = evalin('base','T');
49 - block.ContStates.Data(1) = T(2,2);
50 - block.ContStates.Data(2) = T(3,2);
51 - block.ContStates.Data(3) = T(4,2);
52 - block.ContStates.Data(4) = T(2,3);
53 - block.ContStates.Data(5) = T(3,3);
54 - block.ContStates.Data(6) = T(4,3);
55 - block.ContStates.Data(7) = T(2,4);
56 - block.ContStates.Data(8) = T(3,4);
57 - block.ContStates.Data(9) = T(4,4);
58
```

## 16.3.5 Создание S-функции в Simulink (запись системы уравнений в форме Коши)

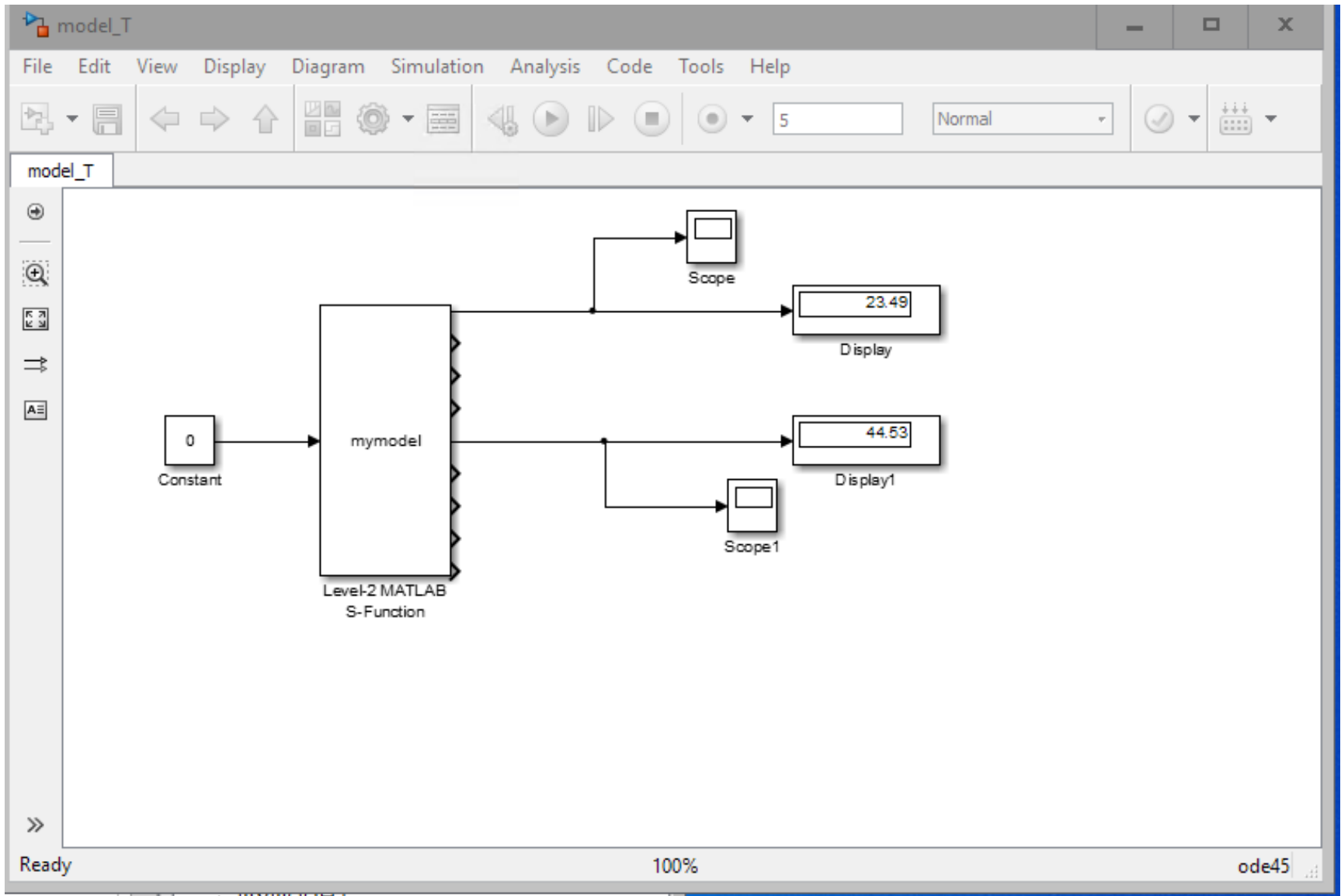
```
58
59 function Derivatives(block)
60 - T = evalin('base','T');
61 - h = 0.25;
62 - m = 0.02; Cp = 460;
63 - T(2,2) = block.ContStates.Data(1);
64 - T(3,2) = block.ContStates.Data(2);
65 - T(4,2) = block.ContStates.Data(3);
66 - T(2,3) = block.ContStates.Data(4);
67 - T(3,3) = block.ContStates.Data(5);
68 - T(4,3) = block.ContStates.Data(6);
69 - T(2,4) = block.ContStates.Data(7);
70 - T(3,4) = block.ContStates.Data(8);
71 - T(4,4) = block.ContStates.Data(9);
72
73 Q = block.InputPort(1).Data;
74 - dT22_dt = (T(3,2)-2*T(2,2)+T(1,2))/h^2 + (T(2,3)-2*T(2,2)+T(2,1))/h^2;
75 - dT32_dt = (T(4,2)-2*T(3,2)+T(2,2))/h^2 + (T(3,3)-2*T(3,2)+T(3,1))/h^2;
76 - dT42_dt = (T(5,2)-2*T(4,2)+T(3,2))/h^2 + (T(4,3)-2*T(4,2)+T(4,1))/h^2;
77 - dT23_dt = (T(3,3)-2*T(2,3)+T(1,3))/h^2 + (T(2,4)-2*T(2,3)+T(2,2))/h^2;
78 - dT33_dt = (T(4,3)-2*T(3,3)+T(2,3))/h^2 + (T(3,4)-2*T(3,3)+T(3,2))/h^2 + Q/(m*Cp);
79 - dT43_dt = (T(5,3)-2*T(4,3)+T(3,3))/h^2 + (T(4,4)-2*T(4,3)+T(4,2))/h^2;
80 - dT24_dt = (T(3,4)-2*T(2,4)+T(1,4))/h^2 + (T(2,5)-2*T(2,4)+T(2,3))/h^2;
81 - dT34_dt = (T(4,4)-2*T(3,4)+T(2,4))/h^2 + (T(3,5)-2*T(3,4)+T(3,3))/h^2;
82 - dT44_dt = (T(5,4)-2*T(4,4)+T(3,4))/h^2 + (T(4,5)-2*T(4,4)+T(4,3))/h^2;
83
```



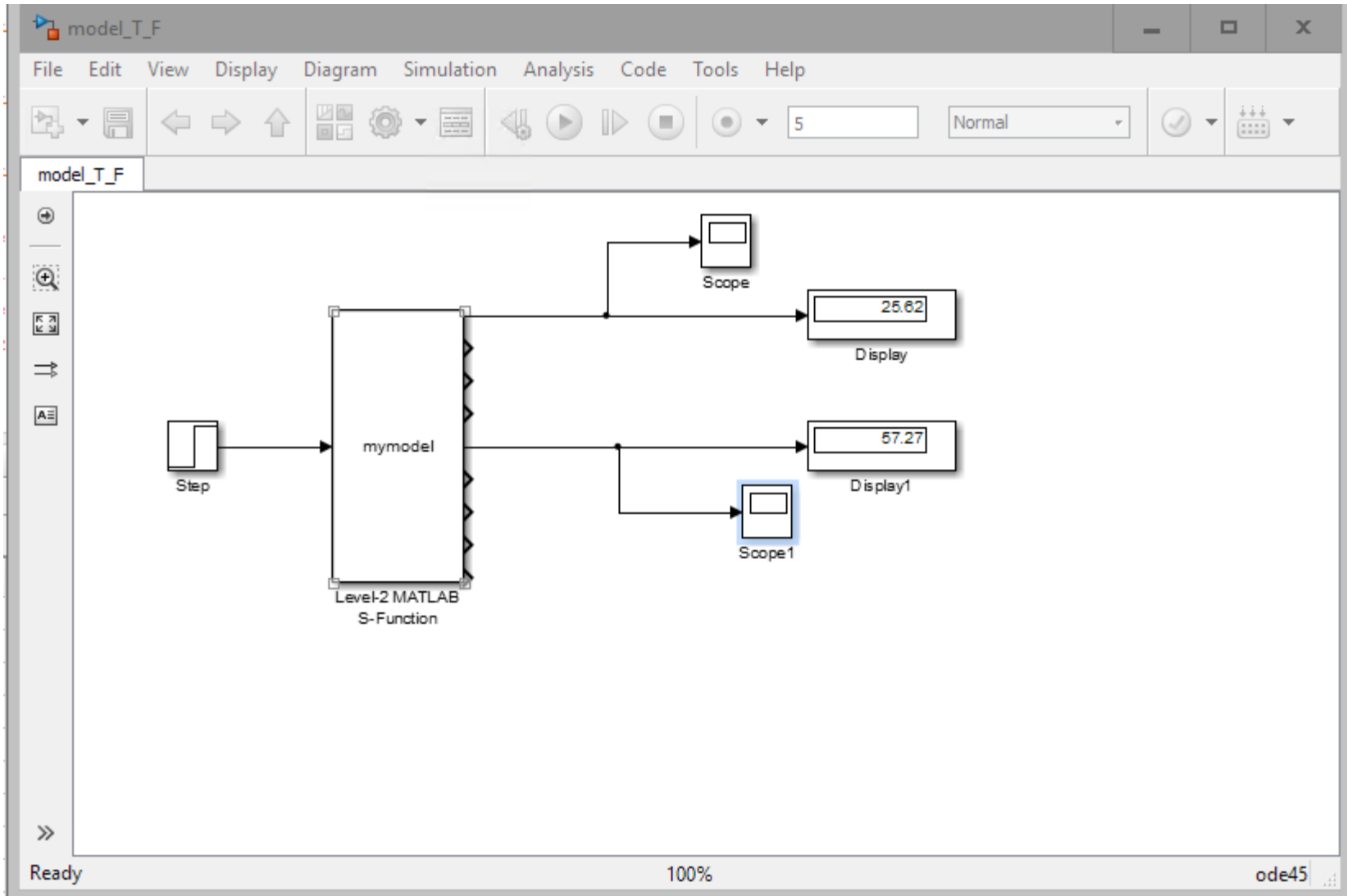
## 16.3.5 Создание S-функции в Simulink (запись системы уравнений в форме Коши)

```
mymodel.m x
78 - dT33_dt = (T(4,3)-2*T(3,3)+T(2,3))/h^2 + (T(3,4)-2*T(2,4)+T(1,4))/h^2 + (T(3,5)-2*T(2,5)+T(1,5))/h^2
79 - dT43_dt = (T(5,3)-2*T(4,3)+T(3,3))/h^2 + (T(4,4)-2*T(3,4)+T(2,4))/h^2 + (T(4,5)-2*T(3,5)+T(2,5))/h^2
80 - dT24_dt = (T(3,4)-2*T(2,4)+T(1,4))/h^2 + (T(2,5)-2*T(1,5)+T(1,4))/h^2 + (T(2,3)-2*T(1,3)+T(1,2))/h^2
81 - dT34_dt = (T(4,4)-2*T(3,4)+T(2,4))/h^2 + (T(3,5)-2*T(2,5)+T(1,5))/h^2 + (T(3,3)-2*T(2,3)+T(1,3))/h^2
82 - dT44_dt = (T(5,4)-2*T(4,4)+T(3,4))/h^2 + (T(4,5)-2*T(3,5)+T(2,5))/h^2 + (T(4,3)-2*T(3,3)+T(2,3))/h^2
83
84 - block.Derivatives.Data(1) = dT22_dt;
85 - block.Derivatives.Data(2) = dT32_dt;
86 - block.Derivatives.Data(3) = dT42_dt;
87 - block.Derivatives.Data(4) = dT23_dt;
88 - block.Derivatives.Data(5) = dT33_dt;
89 - block.Derivatives.Data(6) = dT43_dt;
90 - block.Derivatives.Data(7) = dT24_dt;
91 - block.Derivatives.Data(8) = dT34_dt;
92 - block.Derivatives.Data(9) = dT44_dt;
93
94
95 - function Output(block)
96 -     block.OutputPort(1).Data = block.ContStates.Data(1); %%T(2,2)
97 -     block.OutputPort(2).Data = block.ContStates.Data(2); %%T(3,2)
98 -     block.OutputPort(3).Data = block.ContStates.Data(3); %%T(4,2)
99 -     block.OutputPort(4).Data = block.ContStates.Data(4); %%T(2,3)
100 -     block.OutputPort(5).Data = block.ContStates.Data(5); %%T(3,3)
101 -     block.OutputPort(6).Data = block.ContStates.Data(6); %%T(4,3)
102 -     block.OutputPort(7).Data = block.ContStates.Data(7); %%T(2,4)
103 -     block.OutputPort(8).Data = block.ContStates.Data(8); %%T(3,4)
104 -     block.OutputPort(9).Data = block.ContStates.Data(9); %%T(4,4)
105
```

## 16.3.6 Работа с моделью в Simulink



## 16.3.6 Работа с моделью в Simulink



## 16.3.6 Работа с моделью в Simulink

The image displays the Simulink software interface. The main window shows a Simulink model named "model\_T\_F". The model consists of a "Step" block, a "mymodel" block (labeled as "Level-2 MATLAB S-Function"), and a "Scope2" block. The "Step" block is connected to the input of "mymodel". The output of "mymodel" is connected to "Scope2".

The "Source Block Parameters: Step" dialog box is open, showing the following parameters:

- Step: Output a step.
- Parameters:
- Step time: 2
- Initial value: 0
- Final value: 5000
- Sample time: 0
- Interpret vector parameters as 1-D
- Enable zero-crossing detection

The dialog box has "OK", "Cancel", "Help", and "Apply" buttons at the bottom.

# 16.3.6 Работа с моделью в Simulink

