

Open-Source CFD simulation package

«OpenHyperFLOW2D»

(User guide)

Version 1.02

(<http://openhyperflow2d.googlecode.com>)

General description of CFD simulation package

OpenHyperFLOW2D it is open-source research-educational code for CFD simulation 2D (flat/axisymmetric) transient, viscous, compressible, multi-components sub/trans/supersonic reacting gas flows.

Solver and pre-processor written in C++ and have the following features:

- Using finite difference method (FDM);
- Use a regular orthogonal (rectangular) Cartesian grid;
- For solution used time-depended method with explicit blended marching finite-difference scheme, second-order central differences in the spatial and first order in time Explicit Euler Method (Forward Euler)
- To capture discontinuities use locally adapted non-linear blending factor function (BFF). The solution is found as linear combination of solutions obtained in the scheme with central differences (high-order scheme with low numerical dissipation) and the Lax-Friedrichs (low-order scheme with a high numerical dissipation)

$$\mathbf{F}_{\text{sol}} = \mathbf{BFF} * \mathbf{F}_{\text{cds}} + (1 - \mathbf{BFF}) * \mathbf{F}_{\text{LxF}}$$

where,

\mathbf{F}_{sol} — general solution obtained as a linear combination of solutions to the scheme with low numerical dissipation and solutions to the scheme with high numerical dissipation.

\mathbf{F}_{cds} — the solution obtained on central differences scheme (CDS).

\mathbf{F}_{LxF} — solution obtained by Lax-Friedrichs scheme (LxF).

\mathbf{BFF} — non-linear blending factor function, depending on local parameters.

- Nonorthogonality of boundaries taken into account through the slope-matrix at the boundary nodes of the grid (Immersed Boundary Method analogue);
- The ability to set the boundary conditions I, II and III-type for any of the dependent variables, assignments mixed boundary conditions;
- Temperature dependence of the physical properties of the gas mixture components;
- Can use various RANS turbulence models
 - Zero-equation models:
 - *Prandtl*;
 - *van Driest*;
 - *Escudier*;
 - *Klebanoff*;
 - *Smagorinsky-Lilly*;
 - One-equation models:
 - *Spalart-Allmaras* model;
 - Two-equations models:
 - Standard (*Spalding*) k - ϵ model;
 - *Chien* k - ϵ model;
 - *Jones-Launder* k - ϵ model;
 - *Launder and Sharma*, with *Yap*-correction k - ϵ model;
 - RNG k - ϵ model;
- Ability to calculate multi-components reacting flows;
- Parallel versions of solvers with automatic spatial domain decomposition with support OpenMP for shared memory systems and with support of MPI (Message Passing Interface) for HPC-clusters (Intel MPI, MVAPICH, OpenMPI, HP MPI). Also available parallel version of solver with support GPU (Nvidia CUDA);
- Saving the results of calculation in ASCII format of [Tecplot](#) post-processor;
- Saving solver state on checkpoints with the possibility the restart of calculating;

Representation of the input data

To store input data for pre-processors and solvers use an **object** representation. Object is identified by its name and type. In the current version of the program (1.02) uses 3 types of storage objects:

1. Storage
2. A single data object
3. Table

Storage - **container** that can contain objects of type data and table

One input file contains a single storage. The syntax of this object in the input data file:

<start/[storage name]>

....

<end/[storage name]>

A single data object — contains a single text (string), integer (int), or real (float) value.

The syntax of this object in the source data file:

<data/[name]=[value]>

Example:

<data/A=1> - object data named «A» have **integer** value 1

<data/B=2.56> - object data named «B» have **real** value 2.56

<data/C=Test> - object data named «C» have **text** value «Test»

These all objects of type data is stored in plain text and if possible, can be converted by reading if such a transformation is correct.

For example <data/A=1> can be read as a text "1" as the integer 1, and as a real 1.0, <data/B=2.56>, as the text "2.56" and as real 2.56, while trying to read the value of this object as an integer will get a message about an incorrect data type.

Table - contains several coupled pairs of real numbers. Used to set the tabulated functions with one argument.

The syntax of this object in the input data file:

<table=[name]/[coupled pair of values (float)]>

....

<endtable>

Example:

<table=D/5>

0.0 2.0

1.0 4.0

2.0 5.0

3.0 5.5

4.0 6.0

<endtable>

The values in the pair may be separated by spaces or tabs, the number of pairs must match the number in the table header. The first column of the table corresponds to the function's arguments, the second, value of the function: $D(0.) = 2$. The argument can be any value, while if the argument falls within the range between the two adjacent values, the result is a linear approximation of the value of the function, such as $D(0.5) = 3$. If the argument is outside the upper and lower bounds of arguments defined in the table, value of the function takes an extreme value in the table, such as $D(-1.) = 2.0$, $D(100) = 6.0$

Any entries in the initial data do not correspond to the syntax will be ignored, lines that contain the symbols of comments; and # are also ignored since the comment character to the end of the line.

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Description of input data for «OpenHyperFLOW2D» solver

OpenHyperFLOW2D solver uses a single input file with one repository (except airfoil cases). In the [Table. 1](#) lists the required that must contain raw data file (for version 1.02 solver, other versions of the solver can have a different set of required objects.) If the source data file is not at least one of the required parameters, or its value is not a valid type/syntax, solver initialization will be interrupted with a corresponding error message. Parameters, highlighted by **gray** color is experimental and for this need additional tests.

OpenHyperFLOW2D solver has 4 versions:

1. Serial solver: used on systems with one processor. Currently, this version is used only for debugging.
2. Parallel solver for systems with shared memory: used on multi-core / multi-processor systems with support OpenMP.
3. Parallel solver for systems with distributed memory: used on computer clusters and multi-core/multi-processor workstation with support MPI libraries and is now the main version.
4. Parallel solver for systems with GPU: used on computers with Nvidia GPU (like Nvidia K80,K40,K20,GTX Titan, etc) with CUDA support. This version of OpenHyperFLOW2D solver is experimental.

Input data file compatible with all versions of the solvers. Specific parameters for different version of solver just ignored in others. All versions of the solver is running on GNU/Linux x86_64.

For viewing and post-processing the results of the calculation in the form of 2D distributions of the parameters it is recommended to use a professional post-processor [Tecplot](#), which is considered the “de facto” standard in the CFD.

Table 1

No	Object type	Object name	Value type	Description
1	storage	<arbitrary>	string	It identifies the <u>name of the data storage</u>
2	data	ProjectName	string	It identifies the <u>name of the project</u> . All files created when using the solver will include this name
3	data	OutputFile	string	Contains output file extension (usually '.plt'). This name is combined with the name of the project to specify the file name of results
4	data	ErrorFile	string	suffix + results file extension for error diagnostics (usually '-err.plt')
5	data	GasSwapFile	string	Extension of swap file, with contents computational area (mesh) for gas (usually .hf2d)
6	data	is_p_asterisk_out	int	Add in to the output file total pressure value instead mu_t/mu value 0 – No 1 – Yes
7	data	isSingleGPU	int	Use only single (first) GPU in multiGPU systems (only CUDA version) 0 – No 1 - Yes
8	data	isAdiabaticWall	int	The model used to calculate the heat transfer on wall: 0 - isothermal 1 - adiabatic (thermally insulated)
9	data	FlowType	int	Type of problem (2D formulation) 0 - flat 1 - axisymmetric
10	data	ProblemType	int	Type of problem (model) 0 – Euler (invisc.) 1 – Navier-Stokes (visc.)
11	data	MaxX	int	The dimension of the grid along the X axis
12	data	MaxY	int	The dimension of the grid along the Y axis
13	data	dx	float	The size of the grid cell along the axis X (m)
14	data	dy	float	The size of the grid cell along the axis Y (m)

Table 1

No	Object type	Object name	Value type	Description
15	data	MonitorIndex	int	Index of monitor, which used for check task convergence: 0 - max residual 1 - ρ residual 2 - ρU residual 3 - ρV residual 4 - ρE residual 5 - Time
16	data	ExitMonitorValue	float	Calculation is stop If exceed value of monitor
17	data	CFL	float	The maximum number of Courant-Friedrichs-Levy (CFL) usually no more than 0.1
18	table	CFL_Scenario		The scenario changes of CFL number, depending on the number of iteration
19	data	beta	float	The base value of the blending factor (proportion by weight of the solution obtained in the CD scheme in the general solution in the steady state) is generally 0.985..0.99. When instability take place, this value can be reduced.
20	table	beta_Scenario		The scenario changes base blending factor (BBF), depending on the number of iteration
21	data	Nmax	int	The number of iterations after which the intermediate results is saved in the file containing the binary image of the computational domain
22	data	NOutStep	int	The number of iterations after which occurs current iteration number, the RMS residual, current calculation speed (iterations / sec) and the current time step
23	data	NSaveStep	int	NoutStep*Nmax - The number of iterations after which the intermediate results is saved in the results file in Tecplot format (ASCII version)
24	data	isVerboseOutput	int	1 – output data described in pp. 15 Tab.1 0 - no data output

Table 1

No	Object type	Object name	Value type	Description
25	data	BFF	int	Blending Factor Function (BFF). Type of function, which is calculated by a local blending factor, in this version of the program available numbers from 0 to 5 (recommended values: 4 for transient problems, 5 for steady state problems).
26	data	TurbulenceModel	int	The type of turbulence model ¹
27	data	isTurbulenceReset	int	1 - reinitialize turbulence model (if there was a new set) 0 - use a turbulence model, stored in the binary image of the computational domain
28	data	SigW	float	Factor for adjustment total (molecular+turbulent) viscosity in the parietal cells $\mu_{\text{new}} = \text{SigW} * \mu_{\text{old}}$
29	data	SigF	float	Factor for adjustment total (molecular+turbulent) viscosity in the core stream $\mu_{\text{new}} = \text{SigF} * \mu_{\text{old}}$
30	data	delta_bl	float	The estimated thickness of the boundary layer (m), is used in some models of turbulence
31	data	TurbStartIter	int	Iteration number from which to solve the equation(s) selected turbulence model
32	data	TurbExtModel	int	Extended number of turbulence model ⁱ
33	data	NumMonitorPoints	int	Number of monitoring points
34	data	Point-[n].X	float	X coordinate of monitoring poin № [n] (m)
35	data	Point-[n].Y	float	Y coordinate of monitoring poin № [n] (m)
36	data	InitTime	float	Ititial time value (sec)

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- 1 0 — turbulence model is not used (laminar)
 1 — The integrated model (used to calculate the heat transfer with using criterial equations)
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 3 — RANS models 1st equation ([Spalart-Allmaras](#) model, [Sekundov Nut-92](#) model)
 4 — RANS models with 2 equations ([k-ε](#), [k-ω](#))

Table 1

No	Object type	Object name	Value type	Description
37	data	Ts0	float	The wall temperature, K
38	data	K0	float	Stoichiometric ratio (used in the combustion problems)
39	data	gamma	float	Factor "completion" of a chemical reaction: 1.0 - no combustion 0.0 - complete combustion (used in the combustion problems)
40	data	Tf	float	Ignition temperature, K (used in the combustion problems)
41	data	NumSrc	int	The number of gas sources ("Src" objects)
42	data	Src[n]².GasSrcSX	int	[n] — number (index) of the gas source. The X coordinate (index of X coordinate in nodes) <u>starting point</u> of the segment along which introduces additional source terms
43	data	Src[n]³.GasSrcSY	int	[n] — number (index) of the gas source. The Y coordinate (index of Y coordinate in nodes) <u>starting point</u> of the segment along which introduces additional source terms
44	data	Src[n]⁴.GasSrcEX	int	[n] — number (index) of the gas source. The X coordinate (index of X coordinate in nodes) <u>end point</u> of the segment along which introduces additional source terms
45	data	Src[n]⁵.GasSrcEY	int	[n] — number (index) of the gas source. The Y coordinate (index of Y coordinate in nodes) <u>end point</u> of the segment along which introduces additional source terms

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- 2 **[n]** — number (index) of the object "Src", 1..n
3 **[n]** — number (index) of the object "Src", 1..n
4 **[n]** — number (index) of the object "Src", 1..n
5 **[n]** — number (index) of the object "Src", 1..n

Table 1

No	Object type	Object name	Value type	Description
46	data	Src[n].GasSrcIndex	int	[n] — number (index) of the gas source. GasSrcIndex — number (index) component received through this source 0 - "fuel" 1- "oxidizer" 2 – "combustion products" 3 - "inert ingredient" 4 - mixture of 4 above mentioned components in predetermined proportions
47	data	Src[n].Msrc	float	Mass flow component source in Src[n], kg/sec
48	data	Src[n].Tsrc	float	The temperature of the feed component source in Src[n], K
49	data	Src[n].Tf_src	float	Ignition temperature in source Src[n], K
50	data	Src[n].Y_cp	float	The relative concentration of combustion products in source Src[n] (feeding a mixture of components).
51	data	Src[n].Y_air	float	The relative concentration of the inert component (e.g. air) in source Src[n] (feeding a mixture of components).
52	data	Src[n].Y_fuel	float	The relative concentration of fuel in source Src[n] (feeding a mixture of components).
53	data	Src[n].Y_ox	float	The relative concentration of the oxidizer in source Src[n] (feeding a mixture of components).
54	data	NumFlow	int	The number of objects "Flow" (deprecated)
55	data	Flow[n]⁶.CompIndex	int	CompIndex — index of the integral component: 0 - "fuel" 1- "oxidizer" 2 – "combustion products" 3 - "inert ingredient"
56	data	Flow[n]⁷.p	float	p — static pressure (Pa) associated with the object "Flow"

6 [n] — number (index) of the object "Flow", 1..n

7 [n] — number (index) of the object "Flow", 1..n

Table 1

No	Object type	Object name	Value type	Description
57	data	Flow[n]⁸.Type	int	Type - How to set the speed of the object "Flow": 0 - absolute value of speed 1 - relative critical velocity - λ
58	data	Flow[n]⁹.W	float	W – absolute value of velocity, m/sec ⁱⁱ
59	data	Flow[n]¹⁰.Lam	float	Lam – value of relative critical velocity
60	data	Flow[n]¹¹.T	float	T – static temperature value, K
61	data	NumFlow2D	int	The number of objects "Flow2D"
62	data	Flow2D-[n]¹².CompIndex	int	CompIndex — index of the integral component: 0 - "fuel" 1- "oxidizer" 2 – "combustion products" 3 - "inert ingredient"
63	data	Flow2D-[n]¹³.Mode	int	Mode of definition object "Flow2D" 0 - Set static values p,T and velocity components magnitude (U,V) 1 – Set total values p*,T* and velocity components magnitude (U,V) 2 -Reserved 3 – Set Mach number, total values p*,T* and flow direction by velocity components (U,V)
64	data	Flow2D-[n]¹⁴.p	float	p — static/total pressure (Pa) associated with the object "Flow2D"
65	data	Flow2D-[n]¹⁵.T	float	T – static/total temperature value, (K) для Flow2D
66	data	Flow2D-[n]¹⁶.U	float	The component of the velocity along the X-axis (for flat flow) or The axial component of the velocity (axi-symmetric flow), m/s

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- 8 [n] — number (index) of the object "Flow", 1..n
9 [n] — number (index) of the object "Flow", 1..n
10 [n] — number (index) of the object "Flow", 1..n
11 [n] — number (index) of the object "Flow", 1..n
12 [n] — number (index) of the object "Flow2D", 1..n
13 [n] — number (index) of the object "Flow2D", 1..n
14 [n] — number (index) of the object "Flow2D", 1..n
15 [n] — number (index) of the object "Flow2D", 1..n
16 [n] — number (index) of the object "Flow2D", 1..n

Table 1

No	Object type	Object name	Value type	Description
67	data	Flow2D-[n]¹⁷.V	float	The component of the velocity along the Y-axis (for flat flow) or The radial velocity component (for axi-symmetric flow), m/s
68	data	NumRects	int	The number of macro-objects of solid type "Rect" (rectangle)
69	data	Rect[n]¹⁸.Xstart	float	Coordinate X (m) of the lower left corner of the object "Rect"
70	data	Rect[n]¹⁹.Ystart	float	Coordinate Y (m) of the lower left corner of the object "Rect"
71	data	Rect[n]²⁰.DX	float	Vertical (along coordinate Y) size of the object "Rect" (m)
72	data	Rect[n]²¹.DY	float	Horizontal (along the coordinate X) size of the object "Rect" (m)
73	data	Rect[n]²².Flow2D	int	The index (number) of an object "Flow2D" for parameters initialized boundary of object "Rect"
74	data	Rect[n]²³.TurbulenceModel	int	The type of turbulence models ²⁴ on the border of the object "Rect"
75	data	NumCircles	int	The number of macro-objects of type "Circle"
76	data	Circle[n]²⁵.X0	float	Coordinate X (m) the center of solid macro-object type "Circle"
77	data	Circle[n]²⁶.Y0	float	Coordinate Y (m) the center of solid macro-object type "Circle"
78	data	Circle[n]²⁷.Xstart	float	Coordinate X (m) starting point solid macro-object type "Circle" ²⁸

17 [n] — number (index) of the object "Flow2D", 1..n

18 [n] — number (index) of the object "Rect", 1..n

19 [n] — number (index) of the object "Rect", 1..n

20 [n] — number (index) of the object "Rect", 1..n

21 [n] — number (index) of the object "Rect", 1..n

22 [n] — number (index) of the object "Rect", 1..n

23 [n] — number (index) of the object "Rect", 1..n

24 0 — turbulence model is not used (laminar)

1 — The integrated model (used to calculate the heat transfer with using criterial equations)

2 — [algebraic](#) RANS models (Zero equation models)

3 — RANS models 1st equation ([Spalart-Allmaras](#) model, [Sekundov Nut-92](#) model)

4 — RANS models with 2 equations ([k-ε](#), [k-ω](#))

25 [n] — number (index) of the object "Circle", 1..n

26 [n] — number (index) of the object "Circle", 1..n

27 [n] — number (index) of the object "Circle", 1..n

28 An object of type "Circle" is a circle with the boundary of the "no-slip wall" and filled the interior of the cells of the "solid". Circle center has the coordinates X0, Y0. The radius of the circle $R = \sqrt{(X0 - Xstart)^2 + (Y0 - Ystart)^2}$. Starting point from which a circle is drawn has the

Table 1

No	Object type	Object name	Value type	Description
79	data	Circle[n]²⁹.Ystart	float	Coordinate Y (m) starting point solid macro-object type "Circle"
80	data	Circle[n]³⁰.TurbulenceModel	int	The type of turbulence model ³¹ on the border of the object "Circle"
81	data	Circle[n]³².MaterialID	int	Index of material, which fill internal area of object "Circle" 0 – Gas 1 – Solid
82	data	Circle[n]³³.Flow2D	int	The index (number) of an object "Flow2D" for parameters initialized boundary of object "Circle"
83	data	NumAirfoils	int	The number of macro-objects of solid type "Airfoil"
84	data	Airfoil[n]³⁴.Type		Airfoil geometry setting method 0 – Embedded NACA XXYY airfoil 1 – Setting from external file
85	data	Airfoil[n]³⁵.Xstart	float	Coordinate X (m) starting point solid macro-object type "Airfoil"
86	data	Airfoil[n]³⁶.Ystart	float	Coordinate Y (m) starting point solid macro-object type "Airfoil"
87	data	Airfoil[n]³⁷.pp	float	«X» (only for Type=0)
88	data	Airfoil[n]³⁸.mm	float	«Y» (only for Type=0)
89	data	Airfoil[n]³⁹.thick	float	Airfoil thickness (%) «ZZ» (only for Type=0)

coordinates Xstart, Ystart

29 [n] — number (index) of the object Circle,1..n

30 [n] — number (index) of the object Circle,1..n

31 0 — turbulence model is not used (laminar)

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32 [n] — number (index) of the object Circle,1..n

33 [n] — number (index) of the object Circle,1..n

34 [n] — number (index) of the object Airfoil,1..n

35 [n] — number (index) of the object Airfoil,1..n

36 [n] — number (index) of the object Airfoil,1..n

37 [n] — number (index) of the object Airfoil,1..n

38 [n] — number (index) of the object Airfoil,1..n

39 [n] — number (index) of the object Airfoil,1..n

Table 1

No	Object type	Object name	Value type	Description
90	data	Airfoil[n]⁴⁰.InputData	string	External file name with airfoil data*
91	data	Airfoil[n]⁴¹.scale	float	Airfoil scale (corresponding to the length of the chord, m)
92	data	Airfoil[n]⁴².attack_angle	float	The angle of attack of macro-object "Airfoil"
93	data	Airfoil[n]⁴³.Flow2D	int	The index (number) of an object "Flow2D" for parameters initialized boundary of object "Airfoil"
94	data	Airfoil[n]⁴⁴.TurbulenceModel	int	The type of turbulence model ⁴⁵ on the border of the object "Airfoil"
95	data	isOutHeatFluxX	int	1 - output file HeatFlux-X-<project name>.plt maximum heat flux (W/m ²) on the walls along the coordinates X (m) 0 – no output
96	data	isOutHeatFluxY	int	1 - output file HeatFlux-Y-<project name>.plt maximum heat flux (W/m ²) on the walls along the coordinates Y (m) 0 – no output
97	data	y_max	int	Upper (max) limit of zone for output heat flux along X direction (in nodes). Affected only if isOutputHeatFluxX=1
98	data	y_min	int	Lower (min) limit of zone for output heat flux along X direction (in nodes). Affected only if isOutputHeatFluxX=1
99	data	NumSingleBounds	int	The number of objects "single boundary"

40 [n] — number (index) of the object Airfoil,1..n

41 [n] — number (index) of the object Airfoil,1..n

42 [n] — number (index) of the object Airfoil,1..n

43 [n] — number (index) of the object Airfoil,1..n

44 [n] — number (index) of the object "Airfoil"

45 0 — turbulence model is not used (laminar)

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Table 1

No	Object type	Object name	Value type	Description
100	table	SingleBound[n]ⁱⁱⁱ.Points	-	Points — coordinates of the starting and end coordinates (m) of the segment in the form: $\begin{matrix} X_{\text{start}} & Y_{\text{start}} \\ X_{\text{end}} & Y_{\text{end}} \end{matrix}$
101	data	SingleBound[n]^{iv}.Cond	string	BC ^v defined along the object SingleBound
102	data	SingleBound[n]^{vi}.Flow2D	int	The index (number) of an object “Flow2D” for parameters initialized boundary of object SingleBound
103	data	SingleBound[n]^{vii}.TurbulenceModel	int	The type of turbulence models ⁴⁶ on the border of the object “SingleBound”
104	data	SingleBound[n]^{viii}.MaterialID	int	Bound material ID 0 – Gas 1 – Solid
105	data	SingleBound[n]^{ix}.isReset	int	1 - reinitialize the object “SingleBound[n]” in restarting solver 0 — do not reinitialize the object “SingleBound[n]” in restarting solver
106	data	NumContour	int	The number of objects “Contour” (many boundaries united in a closed loop)
107	table	Contour[n]⁴⁷	-	The coordinates of the boundaries in closed loop
108	data	Contour[n]⁴⁸.Bound[m]⁴⁹.Cond	string	BC ^x defined along a segment of the object “Contour[n]” number [m]
110	data	Contour[n]⁵⁰.Bound[m].Flow2D	int	The index (number) of an object “Flow2D”, associated with the segment “Bound[m]” of object “Contour[n]”

- 46 0 — turbulence model is not used (laminar)
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- 47 [n] — number (index) of the object “Contour”
- 48 [n] — number (index) of the object “Contour”
- 49 [m] — number (index) of the object “Bound” in object “Contour”
- 50 [n] — number (index) of the object “Contour”

Table 1

No	Object type	Object name	Value type	Description
111	data	Contour[n]⁵¹.Bound[m].TurbulenceModel	int	The type of turbulence models ⁵² along of the segment “Bound[m]” of object “Contour[n]”
112	data	Contour[n]⁵³.Bound[m].isReset	int	1 - reinitialize the segment “Bound[m]” of object “Contour[n]” in restarting solver 0 — do not reinitialize the segment “Bound[m]” of object “Contour[n]” in restarting solver
113	data	Contour[n]⁵⁴.Bound[m].MaterialID	int	Bound material ID 0 – Gas 1 – Solid
114	data	NumArea	int	The number of objects “Area”
115	table	Area[n]	-	The coordinates of the beginning of the initialization object “Area” with index [n] (x,y) in nodes !
116	data	Area[n].MaterialID	int	Material ID of solid body nodes (only for Type = 0)
117	data	Area[n].Type	int	Type of initialized nodes 0 — «solid» 1 — «gas»
118	data	Area[n].Flow2D	int	The index (number) of an object “Flow2D” which parameters is initialized object “Area[n]” (only for “gas” nodes)
119	data	Area[n].Turbulence	int	The type of turbulence model ⁵⁵ in object “Area[n]”(only for “gas” nodes)
120	data	H_cp	float	The heat of formation of combustion products (J/kg)

51 [n] — number (index) of the object “Contour”

52 0 — turbulence model is not used (laminar)

1 — The integrated model (used to calculate the heat transfer with using criterial equations)

2 — [algebraic](#) RANS models (Zero equation models)

3 — RANS models 1st equation ([Spalart-Allmaras](#) model, [Sekundov Nut-92](#) model)

4 — RANS models with 2 equations ([k-ε](#), [k-ω](#))

53 [n] — number (index) of the object “Contour”

54 [n] — number (index) of the object “Contour”

55 0 — turbulence model is not used (laminar)

1 — The integrated model (used to calculate the heat transfer with using criterial equations)

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4 — RANS models with 2 equations ([k-ε](#), [k-ω](#))

Table 1

No	Object type	Object name	Value type	Description
121	data	R_cp	float	The gas constant of the combustion products (J/(kg*K))
122	table	lam_cp	-	The thermal conductivity of the combustion products as a function of temperature (J/(kg*K))
123	table	mu_cp	-	The dynamic viscosity of the products of combustion as a function of temperature (Pa*sec)
124	table	Cp_cp	-	The heat capacity of combustion products at constant pressure as a function of temperature (J/(kg*K))
125	data	H_Fuel	float	The heat of formation of fuel (J/kg)
126	data	R_Fuel	float	The gas constant of fuel (J/(kg*K))
127	table	lam_Fuel	-	The thermal conductivity of fuel as a function of temperature (J/(kg*K))
128	table	mu_Fuel	-	The dynamic viscosity of fuel as a function of temperature (Pa*sec)
129	table	Cp_Fuel	-	The heat capacity of fuel at constant pressure as a function of temperature (J/(kg*K))
130	data	H_OX	float	The heat of formation of oxidizer (J/kg)
131	data	R_OX	float	The gas constant of oxidizer (J/(kg*K))
132	table	lam_OX	-	The thermal conductivity of oxidizer as a function of temperature (J/(kg*K))
133	table	mu_OX	-	The dynamic viscosity of oxidizer as a function of temperature (Pa*sec)
134	table	Cp_OX	-	The heat capacity of oxidizer at constant pressure as a function of temperature (J/(kg*K))
135	data	H_air	float	The heat of formation of inert component (e.g. air) (J/kg)
136	data	R_air	float	The gas constant of inert component (e.g. air) (J/(kg*K))
137	table	lam_air	-	The thermal conductivity of inert component (e.g. air) as a function of temperature (J/(kg*K))

Table 1

No	Object type	Object name	Value type	Description
138	table	mu_air	-	The dynamic viscosity of inert component (e.g. air) as a function of temperature (Pa*sec)
139	table	Cp_air	-	The heat capacity of inert component (e.g. air) at constant pressure as a function of temperature (J/(kg*K))
140	data	Cp_Flow_index	int	The index (number) of an object “Flow2D” for calculating pressure coefficient along walls, Cp = (effected only if isOutputHeatFluxX=1)
141	data	is_Cx_calc	int	Calculate the drag coefficient 0 – No 1 – Yes
142	data	x_body	float	Initial X coordinate (m) of the region containing the test body to calculate the drag coefficient (effected only if is_Cx_calc=1)
143	data	y_body	float	Initial Y coordinate (m) of the region containing the test body to calculate the drag coefficient (effected only if is_Cx_calc=1)
144	data	dx_body	float	Size of the region containing the test body in the X coordinate (m) to calculate the drag coefficient (effected only if is_Cx_calc=1)
145	data	dy_body	float	Size of the region containing the test body in the Y coordinate (m) to calculate the drag coefficient (effected only if is_Cx_calc=1)
146	data	Cx_Flow_index	int	The index (number) of an object “Flow2D” for calculating drag coefficient
147	data	is_Cd_calc	int	Calculate the discharge coefficient Cd (for nozzle) 0 – No 1 – Yes
148	data	x_nozzle	float	Initial X coordinate (m) of tested nozzle
149	data	y_nozzle	float	Initial Y coordinate (m) of tested nozzle
150	data	dy_nozzle	float	Cross-section size of tested nozzle (m)

Table 1

No	Object type	Object name	Value type	Description
151	data	Cd_Flow_index	int	The index (number) of an object “Flow2D” for calculating discharge coefficient
152	data	p_ambient	float	Reference ambient pressure for calculating velocity coefficient C_v (for nozzle)
153	data	NumXCut	int	Number of probed cross-sections along the X axis
154	data	CutX-[n].x0	float	Coordinate X (m) of the start cross-section with the index [n]
155	data	CutX-[n].y0	float	Coordinate Y (m) of the start cross-section with the index [n]
156	data	CutX-[n].dy	float	Size of cross-section(m) along the Y axis with the index [n]

- 0 — algebraic model of Prandtl (the mixing length model)
- 1 — Van Driest algebraic model
- 2 — Eskudier algebraic model
- 3 — Klebanoff algebraic model
- 4 — Standard $k-\epsilon$ Spalding model
- 5 — Chien $k-\epsilon$ model
- 6 — Jones-Launder $k-\epsilon$ model
- 7 — Launder-Sharma $k-\epsilon$ model with Yapp correction
- 8 — RNG $k-\epsilon$ model
- 9 — Spalart-Allmaras model
- ii For object “Flow” velocity component along the axis X (or axial) equals the value of W, and a velocity component along the axis Y (or radial) equals 0
- iii [n] — The index (number) of an object “SingleBound”
- iv [n] — The index (number) of an object “SingleBound”
- v BC may have the following values:

Base BC:
 - CT_NO_COND_2D - BC not defined
 - CT_Ro_CONST_2D - $\rho = \text{const}$
 - CT_U_CONST_2D - $\rho U = \text{const}$
 - CT_V_CONST_2D - $\rho V = \text{const}$
 - CT_T_CONST_2D - $\rho E = \text{const}$
 - CT_Y_CONST_2D - $\rho Y = \text{const}$
 - CT_dRdx_NULL_2D - $d\rho/dx = 0$
 - CT_dUdx_NULL_2D - $d\rho U/dx = 0$
 - CT_dVdx_NULL_2D - $d\rho V/dx = 0$
 - CT_dTdx_NULL_2D - $d\rho E/dx = 0$
 - CT_dYdx_NULL_2D - $d\rho Y/dx = 0$
 - CT_dRdy_NULL_2D - $d\rho/dy = 0$
 - CT_dUdy_NULL_2D - $d\rho U/dy = 0$
 - CT_dVdy_NULL_2D - $d\rho V/dy = 0$
 - CT_dTdy_NULL_2D - $d\rho E/dy = 0$
 - CT_dYdy_NULL_2D - $d\rho Y/dy = 0$
 - CT_d2Rdx2_NULL_2D - $d^2\rho/dx^2 = 0$
 - CT_d2Udx2_NULL_2D - $d^2\rho U/dx^2 = 0$
 - CT_d2Vdx2_NULL_2D - $d^2\rho V/dx^2 = 0$
 - CT_d2Tdx2_NULL_2D - $d^2\rho E/dx^2 = 0$
 - CT_d2Ydx2_NULL_2D - $d^2\rho Y/dx^2 = 0$
 - CT_d2Rdy2_NULL_2D - $d^2\rho/dy^2 = 0$
 - CT_d2Udy2_NULL_2D - $d^2\rho U/dy^2 = 0$
 - CT_d2Vdy2_NULL_2D - $d^2\rho V/dy^2 = 0$
 - CT_d2Tdy2_NULL_2D - $d^2\rho E/dy^2 = 0$
 - CT_d2Ydy2_NULL_2D - $d^2\rho Y/dy^2 = 0$
 - CT_WALL_NO_SLIP_2D — BC «no-slip wall»
 - CT_WALL_LAW_2D — BC «wall law»

BC definition as combination of base BC

NT_FC_2D: (Dirichlet BC)

- CT_Ro_CONST_2D
- CT_U_CONST_2D
- CT_V_CONST_2D
- CT_Y_CONST_2D
- CT_T_CONST_2D

NT_D0X_2D: (Neumann BC, gradientless flow in X direction)

- CT_dRox_NULL_2D
- CT_dUdx_NULL_2D
- CT_dVdx_NULL_2D
- CT_dTdx_NULL_2D
- CT_dYdx_NULL_2D

NT_D2X_2D: (Cauchy BC in X direction)

- CT_d2Rox2_NULL_2D
- CT_d2Udx2_NULL_2D
- CT_d2Vdx2_NULL_2D
- CT_d2Tdx2_NULL_2D
- CT_d2Ydx2_NULL_2D

NT_D0Y_2D: (Neumann BC, gradientless flow in Y/R direction)

- CT_dRody_NULL_2D
- CT_dUdy_NULL_2D
- CT_dVdy_NULL_2D
- CT_dTdy_NULL_2D
- CT_dYdy_NULL_2D

NT_D2Y_2D:(Cauchy BC in Y/R direction)

- CT_d2Rody2_NULL_2D
- CT_d2Udy2_NULL_2D
- CT_d2Vdy2_NULL_2D
- CT_d2Tdy2_NULL_2D
- CT_d2Ydy2_NULL_2D

NT_AY_2D: (Symmetry BC along the Y axis)

- CT_NODE_IS_SET_2D
- NT_D0X_2D
- CT_U_CONST_2D

NT_AX_2D: (Symmetry BC along the Y axis)

- CT_NODE_IS_SET_2D
- NT_D0Y_2D
- CT_V_CONST_2D

NT_WALL_LAW_2D: (wall law)

- CT_WALL_LAW_2D

NT_WNS_2D: (no-slip wall)

- CT_WALL_NO_SLIP_2D
- CT_U_CONST_2D
- CT_V_CONST_2D

NT_S_2D: (solid body)

- CT_SOLID_2D

- vi [n] — The index (number) of an object “SingleBound”
vii [n] — The index (number) of an object “SingleBound”
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CT_dTdx_NULL_2D - $d\rho E/dx = 0$
CT_dYdx_NULL_2D - $d\rho Y/dx = 0$
CT_dRody_NULL_2D - $d\rho/dy = 0$
CT_dUdy_NULL_2D - $d\rho U/dy = 0$
CT_dVdy_NULL_2D - $d\rho V/dy = 0$
CT_dTdy_NULL_2D - $d\rho E/dy = 0$
CT_dYdy_NULL_2D - $d\rho Y/dy = 0$
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CT_d2Ydx2_NULL_2D - $d^2\rho Y/dx^2 = 0$
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- CT_d2Vdx2_NULL_2D
- CT_d2Tdx2_NULL_2D
- CT_d2Ydx2_NULL_2D

NT_D0Y_2D: (Neumann BC, gradientless flow in Y/R direction)

- CT_dRody_NULL_2D
- CT_dUdy_NULL_2D
- CT_dVdy_NULL_2D
- CT_dTdy_NULL_2D
- CT_dYdy_NULL_2D

NT_D2Y_2D:(Cauchy BC in Y/R direction)

- CT_d2Rody2_NULL_2D
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- CT_NODE_IS_SET_2D
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- CT_V_CONST_2D

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