User's guide for CERBERE 2.0

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CERBERE is an upgraded post processing tool of the previous rebuilding code (Garcia) working with the VKI boundary layer solver NEBOULA and transport properties library such as PEGASE. The combination of these different code is called CERBOULA The options of CERBERE allows

- to rebuild the enthalpy at the outer edge of the boundary layer by a method based on a wall heat flux measurement
- to compute the properties of the plasma jet
- to compute the catalycity of a material by providing the properties of the plasma jet
- to compute a frozen or equilibrium initial distribution of the properties in the stagnation line

1 Installation

The structure of CERBOULA is illustrated in figure 1. The sources of CERBERE and NEBOULA are respectively in cerberesrc and neboulasrc. Their respective compilation are performed by typing the command *make* in those folders. The object files coming from these compiltation, including the object files of the library, can then be found respectively in *cerbereobj* and *neboulaobj*, the executable are both located in the *exe* file and are respectively called *neboula.exe* and *cerbere.exe*. To run CERBOULA, the user must create a folder like the *testcase1* file illustrated in the same figure. This folder must contain the input and output folders for both CERBERE and NEBOULA code, that is *cerbereinput*, *cerbereoutput*, *neboulainput* and *neboulaoutput*. The detail of the input and output files of the CERBERE program is given in the next section of this user's guide.

2 To run the program

To run the program, the user must be in the folder *testcase1* and run the executable CERBERE.exe from there, that is to type the command *../../cerboula/exe/cerbere.exe*. The graphical interface that the user will see is shown

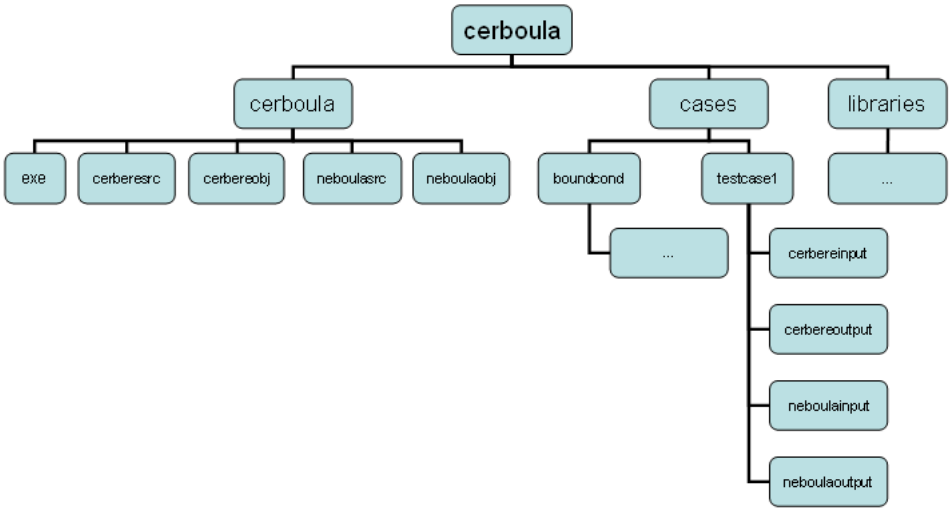

Figure 1: Structure of the CERBOULA code

in figure 4, giving to the user several different options. For each option, there is a corresponding input file, and besides, there are two additional input files common to every options, *convergence.in* (figure 2) and *flags* (figure 3). All the input and output values are given in SI units.

```
1d-6    !Epsilon value, in the computation of the derivative of the residual
.85d0   !alpha, relaxation factor
1d-5    !Error for ending the iterative rebuildings
1d-4    !Max error allowed for Kp
```

Figure 2: convergence.png: The last line is useful only when the Barker effect coefficient is computed

```
0       !flg_anha
1       !flg_oper
0       !flg_termo
0       !flg_traco
1       !flg_stop
1       !flg_mode
```

Figure 3: flags.png: Flags for the PEGASE routines

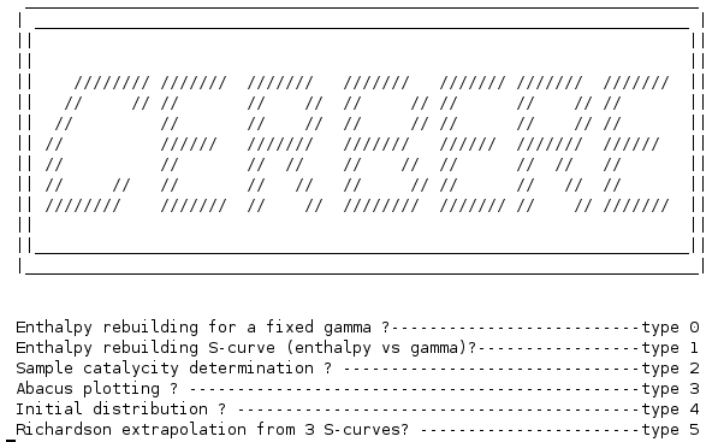

Figure 4: CERBOULA interface

- **0: Enthalpy rebuilding for a fixed gamma** This option aims to rebuild the enthalpy at the outer edge of the boundary layer, mainly by providing the wall heat flux and dynamic pressure experimental measurement. The structure of the input file *rebuilding.in* is shown in figure 5. The output file *rebuilding.out* is shown in figure 6.

```
1.1                          !Barker effect correction
1                            !gamma
350                          !Wall temperature
19.                          !Dynamic pressure
20000                        !Static pressure
57.5d-3 785.9d3              !Probe radius & Heat flux
0.2859  0.2724  0.5979  0.2241  0.3955  !delta & u1e & u1y & V & NDP5
```

Figure 5: rebuilding.in: gamma, beween 0 and 1, is the catalycity (1 for fully catalytic, 0 for frozen). The last line corresponds to the NDP provided by means of the ICP code.

```
Te          4477.8386771894
Pe         10000.0000000000
he       9583024.3731801530
rhoe           0.0063692952
mue            0.0001452743
ce             0.0012004289
ce             0.7488712304
ce             0.0114975272
ce             0.0000305790
ce             0.2255702393
ce             0.0128299945
ce             0.0000000006
Tw           350.0000000000
hw        449561.4700000000
Vs           69.6622387755
Kp            1.1000000000
gam_w            1.0000000000
```

Figure 6: rebuilding.out: The subscript e and w refers respectively to the outer edge and the wall. T is the temperature, P, the static pressure, h, the enthalpy, rho, the specific mass, mu, the dynamic viscosity, ce, the species mass fraction, Vs, the free stream velocity, Kp, the Barker effect coefficient and gam_w, the gamma value used in the computation.

- **1: Enthalpy rebuilding S-curve (enthalpy vs gamma)** This option aims to give the data to build a enthaly rebuilding curve, for a catalycity ranging from the first to second value of the input file *enthalpy_S-curve.in*. This file is shown in figure 7. The output file is, using the example of input

```
-5.d0                          !Minimum log(gamma)
 0.0d0                         !Maximum log(gamma)
1.1                            !Barker effect correction
30                             !Number of points in the S-curve
350                            !Wall temperature
17.0                           !Dynamic pressure
10000.                         !Static pressure
57.5d-3 218.d3                 !Probe radius 1 & Heat flux 1
0.5430  0.2188  0.2335  0.2882  0.4061 !delta & u1e & u1y & V & NDP5
probe_EQ.out                   !output name
```

Figure 7: enthalpy_S-curve.in

  file enthalpy_S-curve.in, *probe_EQ.out*. Each line of the file corresponds to one gamma value. The first column corresponds to gamma, the second, to the outer temperature, the third, to the outer enthalpy, the fourth, to the wall heat flux, the fifth, to the conductive wall heat flux, the sixth, to the diffusive heat flux, the seventh, to the outer specific mass, the eigth, to the outer dynamic viscosity, the ninth, to the free stream velocity and the last, to the barker effect coefficient.

- **2: Sample catalycity determination** This option aims to compute the catalycity of a material, by the IPM methodology. This method uses one probe with a known catalycity value to compute the enthalpy of the jet (this step is strictly equivalent to the option 0), and by placing a second probe in the same plasma jet, that is the one for which the enthalpy

has been computed, the catalycity of this second probe is deduced. The input file *identification.in* is shown in figure 8. The output file is called

```
1.1                          !Barker effect correction
1                            !gamma (reference)
24                           !Dynamic pressure
10000.                       !Static pressure
25.d-3  510.d3  350          !Probe radius & Heat flux & Wall temp(ref)
25.d-3  223.5d3 1514         !Probe radius & Heat flux & Wall temp(sample)
0.4596  0.2041  0.3489  0.2483 0.2483   !delta & u1e & u1y & V & NDP5 (ref)
0.4596  0.2041  0.3489  0.2483 0.2483   !delta & u1e & u1y & V & NDP5 (sample)
```

Figure 8: identification.in: The values of the second probe, that is the probe for which the catalycity will be computed, are the *sample* values.

rebuilding.out and is exactly the same than the output file of the 0-option, except that there is one more line which contains the value of the second probe catalycity.

- **3: Abacus plotting** This option aims to build an abacus. The abacus is a plot of the wall heat flux with respect to the wall temperature, using the catalycity as a parameter, for a given plasma jet and a given probe geometry. The input file *abacus.in* is shown in figure 9. All the numbers after *number of gamma plotted* are the values of gamma for which the computation will performed. Because the value of *number of gamma plotted* is 5, there must be 5 gamma values afterwards. There are as many output

```
1.1                          !Barker effect correction
9576273.0                    !Enthalpy
10000                        !Static pressure
69.64                        !Outer velocity
25.d-3  400.d3  350          !Probe radius & Heat flux & Wall temp
.5043 .2384 .4092 .3271 .5086   !delta & u1e & u1y & V & NDP5
1e-4                         !enthalpy error
1e-3                         !enthalpy epsilon
1e-2                         !enthalpy alpha
4475                         !Outer temperature
300     1500                 !Min & Max outer temperatures
5                            !Number of temperatures plotted
5                            !Number of gamma plotted
1                            !Gamma values
.1
.01
.001
0
```

Figure 9: abacus.in

files than the number of catalycity values. They are called *out_neq**.out*, the ** are two digits to distinguish the different output files. the 01 file corresponds to the values computed with the first catalycity value, the 02 file, the second, ... The structure of an out_neq file is shown in figure 10. The first column contains the temperature, the second, the outer enthalpy, the last, the wall heat flux.

```
 300.0000000000   398056.4170000000   401815.4000000000
 600.0000000000   711637.6040000000   388980.4000000000
 900.0000000000  1044030.1300000000   375690.4000000000
1200.0000000000  1394898.7300000000   361951.9000000000
1500.0000000000  1758886.1200000000   347900.3000000000
```

Figure 10: out_neq file

- **4: Initial distribution** This option aims to create an initial distribution for the stagnation line in a frozen or equilibrium boundary layer. The input file *initial_distribution.in* is shown in figure 11. The output file is *bc_ini.in* in the neboulainput folder.

```
350                          !Wall temperature
14934208.0                   !Enthalpy
10000                        !Static pressure
95.68                        !Outer velocity
0.4596  0.2041  0.3489  0.2483 0.2483   !delta & u1e & u1y & V & NDP5
1.1                          !Barker effect
25.d-3                       !Probe radius
1e-4                         !enthalpy error
1e-3                         !enthalpy epsilon
1e-2                         !enthalpy alpha
5439                         !Outer temperature
1                            !1=> Equilibrium 0=> Frozen initial distribution
```

Figure 11: initial_distribution.in: The outer temperature is the temperature at the outer edge of the boundary layer.

- **5: Richardson extrapolation from 3 S-curves** This option aims to extrapolate an equilibrium boundary layer from three enthalpy rebuilding curves of three probes with different geometries submitted in the same plasma jet. The user can find more details about this method in *Procedures for the determination of cold copper catalycity - VKI PR 2006-18* The enthalpy rebuilding curves must be computed for exactly the same gamma. The input file *equilibrium_extrapolation.in* is shown in figure 12. The output file *extrapolated_enthalpy.out* contains two columns. The first is the catalycity, the second is the extrapolated enthalpy.

```
30              !Number of gamma
probe_ST.out    !Name file for the first probe
probe_FR.out    !Name file for the second probe
probe_EQ.out    !Name file for the third probe
.2384   25.d-3  !u1e & probe radius (1st probe)
.2103   15.d-3  !u1e & probe radius (2nd probe)
.2188   57.5d-3 !u1e & probe radius (3rd probe)
```

Figure 12: equilibrium_extrapolation.in