Title

MATFLOW V3.2 MODULE

APPLICATION MANUAL

	Name and Function	Date	Signature
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SUMMARY

This document is the application manual of the MATFLOW 3.2 module.

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MATFLOW V3.2 – Application Manual

This Manual contains task-oriented instructions that show you how to use the MATFLOW module.

Document issue : 1.0

Software version : MATFLOW Version 3.2

The software described is licensed for installation according to the following conditions :

- The software shall not be distributed to third parties,
- Modification of the software is not permitted.

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1 REFERENCE DOCUMENTS

[RD1] "PLUME V3.2" – Interface files definition. P. Chèoux-Damas. Doc. MMS : S413/RT/41.97. 24/10/97

[RD2] "PLUMFLOW V3.2 procedure – Application manual". C. Theroude. Doc. Astrium : MOS.NT.CT.3682776.02, Issue : 01, 14/04/2004.

2 INTRODUCTION

1.1 FUNCTIONAL DESCRIPTION

The MATFLOW computer program is used to extend the expansion of the gas/particles plume from the TPPLUME or NAVIER computation domain to the 'infinity'.

The objective of the MATFLOW module is :

according to :

- the results of TPPLUME or NAVIER computation
- the dimensions of the region to be computed

compute :

- the gas streamlines and to extend they to the free molecular far-field in a manner suitable for the future plume impingement predictions by MATPLIMP.
- the particle streamlines, for the prediction of radiative heat fluxes by PLUMRAD.
- the interface files to the graphical module TRAJET for flow-field visualisations.

1.2 METHOD OF ANALYSIS

- streamlines computation : The streamlines determination is performed by linear interpolation from the points of the L.R.C. net. They are built point after point, being considered as iso-mass-flow-rate lines. Each point of a streamline has the same stream function (the stream function is computed by TPPLUME or NAVIER).
- source-flow method : The streamlines, computed by the M.O.C., are extended in the far flow-field by the source-flow method up to the SMAX distance, defined by the user, as following :

  1. first, the streamlines are extended, by straight lines passing through the source-points. Two source-points are considered :
     - one in the centre of the nozzle exit plan (on the axis) which allows to know the flow up to an angle of $\pi/2$ between the velocity direction and the axis.
     - an other, at the nozzle lip, is used to describe the back-flow.
  2. values of the area ratio along streamlines are then computed (those values are function only of the geometrical pattern of streamlines). Following, flow-field properties such ρ, T, V are computed, using the previously computed area ratio, and assuming isentropic expansion.
  3. to improve the regularity of the streamlines mesh, the points are then re-distributed on each streamline according to a geometrical progression law. The flow parameters are computed at new point by interpolation between two old points.

1.3 SOFTWARE LIMITATIONS

The area of the M.O.C. domain must be large enough to fit with the hypothesis of a source-flow at the boundary.

At the end of a MATFLOW execution, it is recommended to run TRAJET in order to check that the results are consistent.

2 MATFLOW INPUT/OUTPUT

2.1 MATFLOW ARCHITECTURE

The MATFLOW input files are :

File	Function
"thruster name".THERMO	Gas table giving versus the temperature : H, W_{mol}, γ, T, P, C_{p}, μ, Pr.
"thruster name".T45	Flow-field file of characteristic line data giving the temperature , the density, the velocity of the gas and possibly of the particles.
"thruster name".MFI	User input file.

The MATFLOW output files are :

File	Function
"thruster name".FLOW	Flow-field parameters and nozzle geometry.
"thruster name".T47	Coordinates of the points along the L.R.C..
"thruster name".T48	Particle flow-field data along streamlines.
"thruster name".MFO	Output listing file.

All these files are displayed on Figure 2.2-1.

2.2 MATFLOW INPUT FILES DESCRIPTION

2.2.1 .THERMO file

This is the interface file from ODE. Gas table giving, versus the temperature : H, W_{mol}, γ, T, P, C_p, μ, Pr.

2.2.2 .T45 file

This is the interface file from NAVIER or TPPLUME. Flow-field file giving the temperature, the density and the velocity of the gas and possibly particles, along characteristic lines.

2.2.3 .MFI file

This is the user input file of MATFLOW. As shown on Figure 2.2-2 for a bipropellant test thruster, it is composed of one namelist called SLIN.

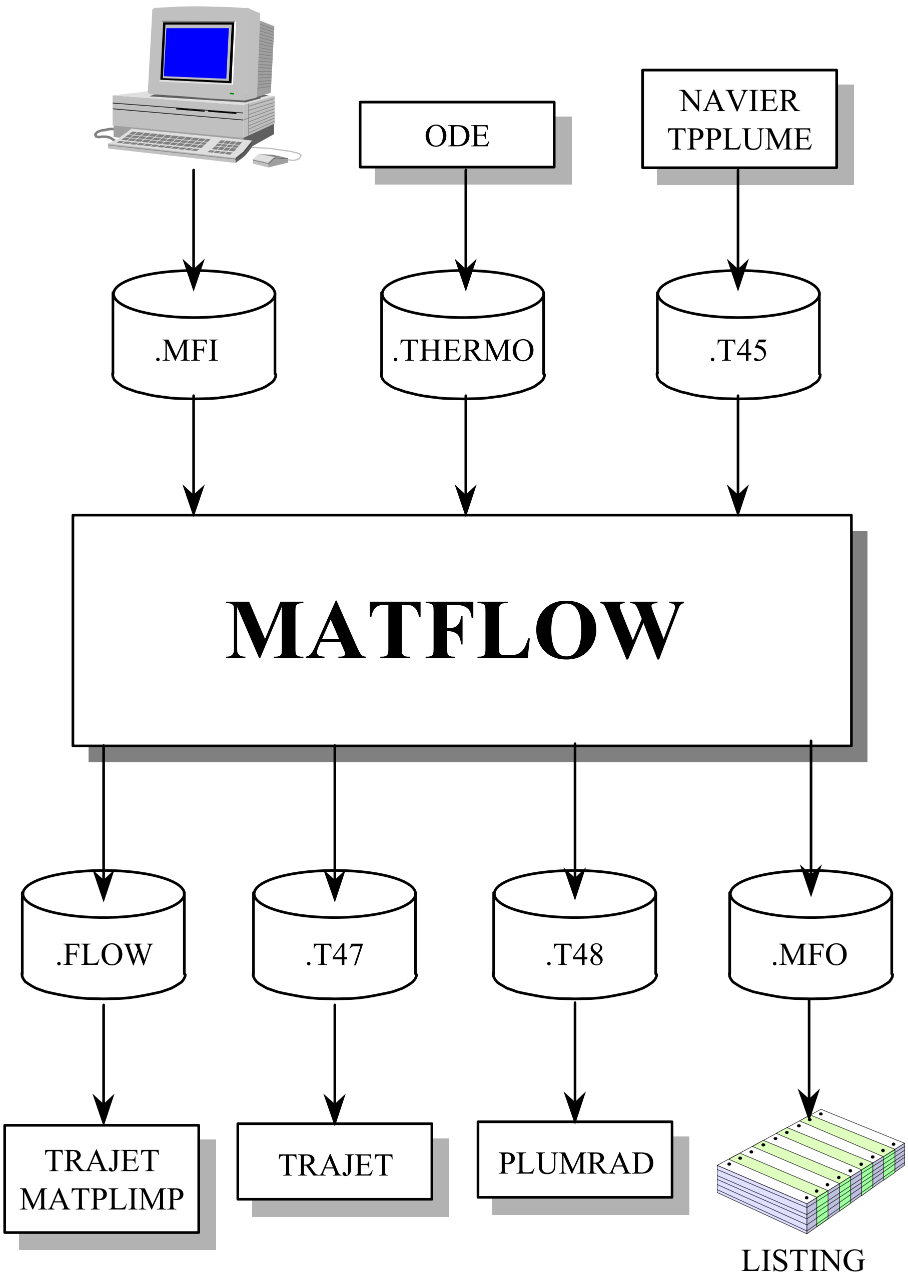

Figure 2.2-1 : MATFLOW architecture.

2.2.3.1 namelist $SLIN

Purpose :

Input data for MATFLOW.

Format of the file :

```
$SLIN

[NSL=nsl]          [NSP=nsp]          PSI=psi
[PLIM=plim]        [MRAD=mrad]        [TCHA=tcha]
[LISSE=lisse]      [PRINTF=printf]    [PRINTG=printg]
[PRINTP=printp]    [DSMIN=dsmin]      [SMAX=smax]

$END
```

Description :

NSL — Number of gas streamlines.

Type	: integer
Range	: 2 ≤ nsl ≤ 40
Default	: 25

NSP — Number of particles streamlines.

Type	: integer
Range	: 2 ≤ nsl ≤ 40
Default	: 15

PSI — Gas stream function for each streamline, no dimension.

Type	: real
Range	: 0 ≤ psi ≤ 1
Default	: linear distribution by MATFLOW
Note	: nsl values are given, up to 40 values can be specified, separated by commas

PLIM specifies whether the interface file with MATPLIMP is created.

Range : T, F

Default : T

MRAD specifies whether the interface file with PLUMRAD is created.

Range : T, F

Default : F

TCHA specifies whether the characteristic lines file (.T47) for TRAJET is created.

Range : T, F

Default : F

LISSE specifies whether the values are to be smoothed on the streamlines.

Range : T, F

Default : T

PRINTF specifies whether the data from TPPLUME or NAVIER are to be printed.

Range : T, F

Default : F

PRINTG specifies whether the result from the gas streamlines computation have to be printed.

Range : T, F

Default : F

PRINTP specifies whether the result from the particles streamlines computation have to be printed.

Range : T, F

Default : F

Note : only to be specified if MRAD=TRUE.

DSMIN specifies the minimal distance, between two points of a streamline to keep the second point, adim (*).

Type : real

Range : > 0

Default : 0.02

SMAX specifies the distance to the exit section up to which the flow is to be extended by the source-point method, adim (*).

Type : real

Range : > 0

Default : 2000

Remarks :

The "adim (*)" note means the parameters are normalised by the throat radius RSTAR (see namelist $GEONOZ).

```
$SLIN
 NSL = 23 ,
 PSI = .00 , .01 , .04 ,.100 ,.200,.300 ,.400 ,.500 ,.600 ,.700 ,
      .80 , .88 , .93 ,.96  ,.98 ,.99  ,.996 ,.998 ,.999 ,.9997,
      .99989 ,.99995 ,.99999
 PLIM  = T ,  SMAX = 20000. , DSMIN = 0.1 ,
 LISSE = T, TCHA=F, PRINTG=F,
 $END
```

Figure 2.2-2 : test.MFI : example of input file for MATFLOW.

2.3 MATFLOW OUTPUT FILES DESCRIPTION

2.3.1 .FLOW file

This is an interface file to TRAJET and MATPLIMP, it contains the nozzle and flow parameters arranged by streamlines.

2.3.2 .T47 file

This is an interface file to TRAJET, it contains the coordinates of the points along the L.R.C..

Note : this file is created only if the user has specified it in the MATFLOW input file.

2.3.3 .T48 file

This is the interface file to PLUMRAD, it contains the particle flow description along the streamlines.

2.3.4 .MFO file

This is the listing file of MATFLOW.

The output listing file is composed of six parts, described on Figure 2.3-1 to Figure 2.3-5, depending on the values of the printing parameters : PRINTF, PRINTG, PRINTP and a review of the input file "thruster name".MFI.(see Figure 2.3-1) :

1. Printing of the namelist $SLIN. The meaning of the parameters is given in the input file description.
2. summary of ODE results (conditions in the chamber) and nozzle geometry (see Figure 2.3-2).
3. printing of the file "thruster name".T45, if PRINTF = F (see Figure 2.3-3).

   LRC : number of the current L.R.C..

   MS : parameter defining the L.R.C. :

   MS =-1 : the L.R.C. comes from the transonic region,

   MS = 0 : the L.R.C. is the start line,

   MS = 1 : the current L.R.C. is inside the nozzle,

   MS = 2 : the L.R.C. is in the free plume.

   JP : number of points on the L.R.C..

   J : index of the point on the L.R.C..

   Z/R*, R/R* : axial and radial coordinate normalized by the throat radius.

   ID : point identification :

   ID = 2 : current point,

ID = 3 : axis point,

ID = 5 : wall point.

P : gas pressure.

RHO : gas density.

ANGLE : angle between the gas velocity and the axis.

V : radial coordinate of the gas velocity.

PSI : stream function.

4. computed mass flow rates and thrust (see Figure 2.3-4).

   The thrust value computed in MATFLOW is different from that computed in TPPLUME and NAVIER. When using MATFLOW, the integration is done on the first L.R.C., taking into account the boundary layer effect and the Prandtl-Meyer fan at the nozzle lip while TPPLUME computes with the last L.R.C. of the replaced nozzle contour.

   The table MASS FLOW RATE CONSERVATION shows the importance of the flow rate loss, integrated at a given point of the streamlines meshing, due to the accumulated inaccuracies of the M.O.C. computation and linear interpolations during the streamlines calculation and the remeshing of the points.

   The source-flow method insures the rigorous mass flow rate conservation.

5. printing of the gas streamlines, if PRINTG = T (see Figure 2.3-5).

   I : number of the point.

   Z/R*, R/R* : axial and radial coordinate normalized by the throat radius.

   RHO : gas density.

   T : gas temperature.

   P : gas pressure.

   VEL : velocity of the gas flow.

   ANGLE : angle between the gas velocity and the axis.

   BIRD : Bird parameter (for the transitional regime).

6. printing of the particle streamlines, if PRINTP = T.

   The particles streamlines are arranged by group, corresponding to a given diameter.

   These parameters are described below :

   I : number of the current point.

   Z/Z*, R/R* : axial and radial coordinates normalized by the throat radius.

   T : temperature of the particles.

   RHO : density of the particles set.

   V : velocity of the particles.

The following example of listing is coming from the bipropellant test thruster computation.

```
 -----------------------------------------------------------------------------------------------------------------------------
---
          TITLE OF ODE INPUT FILE :     Bi-propellant test thruster for PLUMFLOW demonstration                 DATE : 14-Apr-
2004
 -----------------------------------------------------------------------------------------------------------------------------
---



                                                NAMELIST SLIN
                                                -------------



          NUMBER OF GAS STREAMLINES                             NSL    =   23
          NUMBER OF PARTICLE STREAMLINES                        NSP    =   15
          GAS STREAM FUNCTION                                   PSI    =    0.0000  0.0100  0.0400  0.1000  0.2000  0.3000
                                                                            0.4000  0.5000  0.6000  0.7000  0.8000  0.8800
                                                                            0.9300  0.9600  0.9800  0.9900  0.9960  0.9980
                                                                            0.9990  0.9997  0.9999  0.9999  1.0000
          FLOW COMPUTATION FOR MATPLIMP                         PLIM   =  TRUE
          NO INTERFACE FILE WITH PLUMRAD                        MRAD   =  FALSE
          LRC ARE NOT STORED                                    TCHA   =  FALSE
          THE STREAMLINE VALUES ARE POLISHED                    LISSE  =  TRUE
          THE DATA FROM TPPLUME ARE PRINTED                     PRINTF =  TRUE
          THE GAS STREAMLINES ARE PRINTED                       PRINTG =  TRUE
          THE PARTICLE STREAMLINES ARE NOT PRINTED              PRINTP =  FALSE
          MINIMAL DISTANCE BETWEEN 2 POINTS OF A STREAMLINE     DSMIN  =    0.1000
          FLOW FIELD EXTENSION LENGTH                           SMAX   =  20000.00
```

Figure 2.3-1 : test.MFO : echo of the user input file : namelist $SLIN

```
------------------------------------------------------------------------------------------------------------------------------
--
          TITLE OF ODE INPUT FILE :     Bi-propellant test thruster for PLUMFLOW demonstration                 DATE : 14-Apr-
2004
 -----------------------------------------------------------------------------------------------------------------------------
---



     FLOW PARAMETERS ARE COMPUTED BY NAVIER





     IDEAL GAS : CP AND GAMMA ARE CONSTANT

                         CONDITION IN THE CHAMBER :
                         ------------------------

               PRESSURE                 PC     =    6.38000  (BAR)
               TEMPERATURE              TC     = 1120.00000  (DEG K)
               DENSITY                  RHOG0 =    0.73309  (KG/M3)
               GAS CONSTANT             RGAS  =  777.04767  (J/KG/DEG K)
               SPECIFIC HEAT RATIO      GAMMA =    1.35700
               GAS SPECIFIC HEAT        CPGAS = 2953.65186  (J/KG/DEG K)


                         NOZZLE GEOMETRY :
                         ---------------

               THROAT RADIUS            RSTAR =    0.00079  (M)
               EXIT RADIUS              REXIT =    0.00563  (M)
               DISTANCE THROAT-EXIT           =    0.01212  (M)
```

Figure 2.3-2 : test.MFO : summary of the chamber conditions and nozzle geometry

```
-----------------------------------------------------------------------------------------------------------------------------
--
          TITLE OF ODE INPUT FILE :     Bi-propellant test thruster for PLUMFLOW demonstration                 DATE : 14-Apr-
2004
 ----------------------------------------------------------------------------------------------------------------------------
---

  LRC =  25    MS = 0  JP = 49
   J    Z/R*      R/R*  ID    T(K)    RHO(KG/M3)    ANGLE      V(M/S)     PSI
   1   0.0000   0.0000  1    977.154 0.4974E+00 0.0000E+00 0.9210E+03 0.000000
   2   0.0000   0.0722  1    976.919 0.4969E+00-0.2386E+00 0.9219E+03 0.005480
   3   0.0000   0.1393  1    976.299 0.4958E+00-0.4601E+00 0.9239E+03 0.020396
   4   0.0000   0.2017  1    975.301 0.4942E+00-0.6532E+00 0.9270E+03 0.042740
   5   0.0000   0.2596  1    974.018 0.4920E+00-0.8233E+00 0.9312E+03 0.070832
   6   0.0000   0.3135  1    972.502 0.4895E+00-0.9671E+00 0.9361E+03 0.103267
   7   0.0000   0.3635  1    970.808 0.4867E+00-0.1088E+01 0.9416E+03 0.138875
   8   0.0000   0.4101  1    968.980 0.4836E+00-0.1186E+01 0.9475E+03 0.176682
   9   0.0000   0.4533  1    967.050 0.4803E+00-0.1262E+01 0.9538E+03 0.215883
  10   0.0000   0.4934  1    965.056 0.4769E+00-0.1319E+01 0.9603E+03 0.255815
  11   0.0000   0.5308  1    963.033 0.4733E+00-0.1357E+01 0.9669E+03 0.295939
  12   0.0000   0.5654  1    960.996 0.4696E+00-0.1378E+01 0.9736E+03 0.335816
  13   0.0000   0.5977  1    958.986 0.4659E+00-0.1383E+01 0.9804E+03 0.375095
  14   0.0000   0.6276  1    957.008 0.4621E+00-0.1375E+01 0.9871E+03 0.413499
  15   0.0000   0.6554  1    955.096 0.4582E+00-0.1354E+01 0.9937E+03 0.450812
  16   0.0000   0.6813  1    953.256 0.4544E+00-0.1322E+01 0.1000E+04 0.486872
  17   0.0000   0.7053  1    951.512 0.4505E+00-0.1280E+01 0.1006E+04 0.521561
  18   0.0000   0.7277  1    949.861 0.4466E+00-0.1229E+01 0.1013E+04 0.554794
  19   0.0000   0.7484  1    948.323 0.4428E+00-0.1171E+01 0.1018E+04 0.586522
  20   0.0000   0.7677  1    946.899 0.4390E+00-0.1107E+01 0.1024E+04 0.616715
  21   0.0000   0.7856  1    945.591 0.4352E+00-0.1037E+01 0.1029E+04 0.645368
  22   0.0000   0.8023  1    944.388 0.4315E+00-0.9640E+00 0.1034E+04 0.672492
  23   0.0000   0.8178  1    943.288 0.4278E+00-0.8879E+00 0.1039E+04 0.698112
  24   0.0000   0.8322  1    942.281 0.4243E+00-0.8087E+00 0.1044E+04 0.722267
  25   0.0000   0.8455  1    941.369 0.4207E+00-0.7281E+00 0.1049E+04 0.745008
  26   0.0000   0.8589  1    940.445 0.4171E+00-0.6394E+00 0.1054E+04 0.768017
  27   0.0000   0.8713  1    939.629 0.4135E+00-0.5477E+00 0.1057E+04 0.789586
  28   0.0000   0.8828  1    938.933 0.4100E+00-0.4565E+00 0.1061E+04 0.809770
  29   0.0000   0.8935  1    938.317 0.4066E+00-0.3658E+00 0.1063E+04 0.828625
  30   0.0000   0.9034  1    937.783 0.4033E+00-0.2769E+00 0.1065E+04 0.846213
```

Figure 2.3-3 : test.MFO : printing of the file "thruster name".T45

```
-----------------------------------------------------------------------------------------------------------------------------
--
          TITLE OF ODE INPUT FILE :     Bi-propellant test thruster for PLUMFLOW demonstration                 DATE : 14-Apr-
2004
 ----------------------------------------------------------------------------------------------------------------------------
---



                         COMPUTED MASS FLOW RATES AND THRUST
                         -----------------------------------



     MASS FLOW RATE =  0.9047E-03 KG/S     THRUST =  0.2093E+01 N

                    MASS FLOW RATE CONSERVATION:

              1.0000    1.0023    1.0044    1.0056    1.0065
              1.0068    1.0075    1.0088    1.0111    1.0112
              1.0110    1.0100    1.0098    1.0119    1.0097
              1.0115    1.0054    1.0066    1.0105    1.0212
              1.0375    1.0554    1.0582    1.0505    1.0476
              1.0539    1.0608    1.0581    1.0550    1.0542
              1.0561    1.0561    1.0561    1.0561    1.0562
              1.0562    1.0562    1.0562    1.0562    1.0563
              1.0563    1.0563    1.0563    1.0563    1.0563
              1.0564    1.0564    1.0564    1.0564    1.0564
              1.0564    1.0564    1.0564    1.0564    1.0564
              1.0564    1.0564    1.0564    1.0564    1.0564
              1.0564    1.0564    1.0564    1.0564    1.0564
              1.0564    1.0564    1.0564    1.0564    1.0564
              1.0564    1.0564    1.0564    1.0564    1.0564
              1.0564    1.0564    1.0564    1.0564    1.0564
              1.0564    1.0564    1.0564    1.0564    1.0564
              1.0564    1.0564


                         MASS FLOW RATIO PER STREAMLINE
                         ------------------------------


                                  0.9592    0.9777
                                  1.0265    1.0508
                                  1.0617    1.0936
                                  1.0992    1.0974
                                  1.0642    1.0947
                                  1.0388    0.9894
                                  0.9902    0.9740
                                  0.9507    0.8892
                                  1.2750    0.9559
                                  0.9977    0.9897
                                  1.0317    1.1207
```

Figure 2.3-4 : test.MFO : mass flow rate conservation

TITLE OF ODE INPUT FILE : Bi-propellant test thruster for PLUMFLOW demonstration DATE : 14-Apr-2004

LINE N0 1 MASS FRACTION : 0.000000 NUMBER OF POINTS OF THE M.O.C. : 65

I	Z/R*	R/R*	RHO (KG/M3)	T (DEG K)	P (PA)	VEL (M/S)	ANGLE (DEG)	BIRD
1	15.9	0.0	.136E-02	120.50	.127E+03	2430.63	0.00	0.00
2	16.4	0.0	.128E-02	118.01	.117E+03	2433.71	0.00	0.00
3	16.9	0.0	.120E-02	115.43	.107E+03	2436.84	0.00	0.00
4	17.5	0.0	.111E-02	112.79	.977E+02	2440.05	0.00	0.00
5	18.1	0.0	.103E-02	110.04	.884E+02	2443.39	0.00	0.00
6	18.8	0.0	.955E-03	107.06	.795E+02	2446.84	0.00	0.00
7	19.5	0.0	.881E-03	104.07	.712E+02	2450.38	0.00	0.01
8	20.3	0.0	.809E-03	101.06	.636E+02	2453.99	0.00	0.01
9	21.2	0.0	.742E-03	98.03	.565E+02	2457.64	0.00	0.01
10	22.2	0.0	.678E-03	94.95	.500E+02	2461.30	0.00	0.01
11	23.3	0.0	.618E-03	91.82	.441E+02	2464.91	0.00	0.01
12	24.5	0.0	.562E-03	88.73	.388E+02	2468.41	0.00	0.01
13	25.8	0.0	.511E-03	85.87	.341E+02	2471.73	0.00	0.01
14	27.2	0.0	.469E-03	83.38	.304E+02	2474.84	0.00	0.01
15	28.8	0.0	.427E-03	81.07	.269E+02	2477.57	0.00	0.01
16	30.6	0.0	.389E-03	77.86	.235E+02	2479.22	0.00	0.00
17	32.5	0.0	.375E-03	78.06	.228E+02	2477.83	0.00	0.00
18	34.6	0.0	.341E-03	75.71	.201E+02	2468.78	0.00	0.00
19	37.0	0.0	.373E-03	62.54	.181E+02	2445.80	0.00	0.02
20	39.5	0.0	.913E-03	114.33	.811E+02	2408.63	0.00	0.02
21	42.3	0.0	.259E-02	184.88	.372E+03	2368.85	0.00	0.00
22	45.4	0.0	.433E-02	218.72	.737E+03	2341.46	0.00	0.00
23	48.8	0.0	.431E-02	219.21	.734E+03	2333.95	0.00	0.00
24	52.6	0.0	.315E-02	198.00	.484E+03	2344.00	0.00	0.00
25	56.7	0.0	.215E-02	170.64	.285E+03	2363.94	0.00	0.00
26	61.3	0.0	.150E-02	149.17	.174E+03	2386.45	0.00	0.00
27	66.3	0.0	.106E-02	131.77	.108E+03	2407.30	0.00	0.00
28	71.8	0.0	.790E-03	118.53	.728E+02	2425.19	0.00	0.00
29	77.8	0.0	.602E-03	107.48	.503E+02	2440.36	0.00	0.00
30	84.4	0.0	.452E-03	96.83	.340E+02	2453.28	0.00	0.00
31	91.8	0.0	.342E-03	87.35	.232E+02	2464.17	0.00	0.00
32	99.8	0.0	.264E-03	79.81	.164E+02	2472.90	0.00	0.00
33	108.6	0.0	.206E-03	73.15	.117E+02	2479.22	0.00	0.00
34	118.4	0.0	.166E-03	67.54	.873E+01	2485.72	0.00	0.00
35	129.1	0.0	.135E-03	62.57	.658E+01	2491.47	0.00	0.01
36	140.9	0.0	.111E-03	58.07	.499E+01	2496.66	0.00	0.01
37	153.8	0.0	.906E-04	53.94	.380E+01	2501.41	0.00	0.01
38	168.1	0.0	.743E-04	50.13	.290E+01	2505.79	0.00	0.01
39	183.7	0.0	.610E-04	46.60	.221E+01	2509.83	0.00	0.01
40	201.0	0.0	.502E-04	43.33	.169E+01	2513.58	0.00	0.01
41	219.9	0.0	.412E-04	40.30	.129E+01	2517.04	0.00	0.01
42	240.8	0.0	.339E-04	37.48	.988E+00	2520.26	0.00	0.01
43	263.7	0.0	.279E-04	34.87	.756E+00	2523.23	0.00	0.01
44	289.0	0.0	.230E-04	32.45	.579E+00	2526.00	0.00	0.01
45	316.7	0.0	.189E-04	30.19	.444E+00	2528.56	0.00	0.01
46	347.3	0.0	.156E-04	28.10	.340E+00	2530.94	0.00	0.01
47	380.9	0.0	.128E-04	26.16	.261E+00	2533.15	0.00	0.01
48	417.8	0.0	.106E-04	24.35	.200E+00	2535.20	0.00	0.01
49	458.5	0.0	.872E-05	22.67	.154E+00	2537.11	0.00	0.02
50	503.2	0.0	.719E-05	21.10	.118E+00	2538.88	0.00	0.02
51	552.4	0.0	.593E-05	19.65	.905E-01	2540.52	0.00	0.02

Figure 2.3-5 : test.MFO : printing of the gas streamlines

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