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# CHEASE

## User's Manual

H. Lütjens

# C H E A S E

**[1]** H.Lütjens et al., Comput. Phys. Commun. **69** (1992) 287.
**[2]** H.Lütjens, PHD thesis, LRP 470/92

# USER MANUAL

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## 1. List of parameters in common block COMDIM.inc :

The following parameters define the array dimensions of the executable file of CHEASE. To every parameter corresponds a namelist variable which is given in brackets. All namelist variables **must be less or equal** to their corresponding parameters. In the following, **U.M.** stands for **User Manual**, and **[1]**, **[2]** are the 2 references given on the cover page.

MPSMAX (MSMAX) : Maximum number of Fourier modes in the poloidal plane used by the stability code MARS (see [1] Appendix C.2 or [2] Appendix C.2).

NPBLC0 (NBLC0) : Maximum number of the integration constants $\chi_0$ used for the calculation of the ballooning energy integral (see [1] Appendix C or [2] Section 3.7).

NPBPS (NBPS) : Maximum number of (R,Z) coordinates used for the reconstruction of the plasma boundary when it is defined by points (See Section 3.6 of U.M.).

NPCHI (NCHI) : Maximum number of angular $\chi$-intervals used for the ballooning stability calculation and/or the mappings for ERATO, LION and MARS. The number of $\chi$-intervals used by PENN **must be less or equal to NPCHI/NMGAUS** (see [1] Section 4.1 or [2] Section 3.2).

NPPSI (NPSI) : Maximum number of radial s-intervals for the stability meshes (see [1] Section 4.1 or [2] Section 3.2).

NPS (NS) : Maximum number of radial $\sigma$-intervals for the equilibrium mesh (see [1] Section 2 or [2] Section 2.1).

NPSMAX (NSMAX) : Maximum number of toroidal modes used by the Fourier stability code MARS.

NPT (NT) : Maximum number of angular $\theta$-intervals for the equilibrium mesh (see [1] Section 2 or [2] Section 2.1).

NPTURN (NTURN) : Maximum number of $2\pi$ intervals used to perform the ballooning energy integral (see [1] Appendix C or [2] Section 3.7).

NPV (NV) : Maximum number of radial intervals for MARS stability mesh in the vacuum (see [2] Appendix C.2).

NPMGS (NMGAUS) : Maximum number of Gaussian quadrature points used to perform the line integrals along constant poloidal magnetic flux surfaces (see [1] Section 4.1 or [2] Section 3.3).

NPSGS (NSGAUS) : Maximum number of Gaussian quadrature points used solve the equilibrium in the radial $\sigma$-direction (see [1] Appendix A or [2] Section 2.2).

NPTGS (NTGAUS) : Maximum number of Gaussian quadrature points used solve the equilibrium in the angular $\theta$-direction (see [1] Appendix A or [2] Section 2.2).

## 2.Namelist

### 2.1.Shape of Namelist

The file containing the Namelist of CHEASE must always begin with 4 character*80 lines, which can be used as a caption for the output and the plots. If the stability calculation is done with ERATO, the shape of this record must be

C These are
C the four
C character*80
C lines
$EQDATA
ALPHA0=...,AP(1)=...,etc. Only namelist variables which are different than the default values must be specified here.
$END OF CHEASE NAMELIST
$NEWRUN
These variables are required as input for ERATO.
$END OF ERATO NAMELIST

For the computation of equilibrium quantities required by other codes (MARS, LION, NOVA-W, PEST3.4 or PENN), the namelist $NEWRUN can be omitted.

## 2.2.Namelist variables :

In the following, the numbers in the parentheses are the default values of the Namelist variables.

| | | | |
|---|---|---|---|
| AFBS | (10*0.) | : | Used only if NBSOPT=1 and NBSTRP=2. Specification of the fraction of bootstrap current. See Section 4.1.1.3.2.2 of U.M. |
| AFBS2 | (10*0.) | : | Used only if NBSOPT=1 and NBSTRP=2. Specification of the fraction of bootstrap current. See Section 4.1.1.3.2.2 of U.M. |
| ALPHA0 | (0) | : | Used only if NSURF=3 or 4. Defines plasma surface shape. See Section 3 of U.M. |
| AP | (10*0.) | : | Specification of pressure profile. See Section 4 in U.M. |
| APLACE | (10*0.) | : | Used only if NMESHA=1. See Section 5 of U.M. |
| AP2 | (10*0.) | : | Specification of pressure profile. See Section 4 in U.M. |
| ASPCT | (0.33333) | : | Inverse aspect ratio. Defines plasma surface shape. See Section 3 of U.M or [1] Section 3.2 or [2] Section 2.6.2. |
| AT | (10*0.) | : | Specification of toroidal magnetic flux TT', I* or $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$ profile. See Section 4 of U.M. |
| AT2 | (10*0.) | : | Specification of TT', I* or $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$ profile. See Section 4 of U.M. |
| AT3 | (10*0.) | : | Specification of TT', I* or $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$ profile. See Section 4 of U.M. |
| AT4 | (10*0.) | : | Specification of TT', I* or $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$ profile. See Section 4 of U.M. |
| AWIDTH | (10*0.) | : | Used only if NMESHA=1. See Section 5 of U.M. |
| BEANS | (0) | : | Used only if NSURF=2,3 or 4. Defines plasma surface shape. See Section 3 of U.M. |
| BPLACE | (10*0.) | : | Used only if NMESHB=1 and NSTTP=2 or 3. See Section 5 of U.M. |
| BSFRAC | (0.5) | : | Used only if NBSOPT=1 and NBSTRP=1. Specification of the fraction of bootstrap current density. See Section 4.1.1.3.1 of U.M. |
| BWIDTH | (10*0.) | : | Used only if NMESHB=1 and NSTTP=2 or 3. More details in Section 5 of U.M. |
| CETA | (0) | : | Used only if NSURF=4. Defines plasma surface shape. See Section 3 of U.M or [2] Section 2.6.2. |

| | | | |
|---|---|---|---|
| CFBAL | (1.) | : | Coefficient used to limit the pressure profile:<br>**<u>If NBLOPT=1:</u>**<br>$p'(\psi)$ is limited in the second ballooning stability region so that: $\|p'(\psi)\| < \|q'(\psi) * CFBAL\|$<br>**<u>If NBSOPT=1:</u>**<br>$p'(\psi)$ is limited so that: $p'(\psi) > - CFBAL$ |
| CPLACE | (10*0.) | : | Used only if NMESHC = 1. See Section 5 of U.M. |
| CPRESS | (1.) | : | Coefficient used to rescale the pressure profile of the ballooning optimized equilibrium if it is kink unstable: $\|p'(\psi)_{new}\| = \|p'(\psi)_{old}\| * CPRESS$ |
| CQ0 | (0.75) | : | Used only if NSURF=1. Safety factor on magnetic axis used to specify Solovev equilibrium. See [1] Section 3.1 or [2] Section 2.6.1. |
| CSSPEC | (0.) | : | Used only if NCSCAL = 1 or 3. See Section 6 of U.M or [1] Appendix B or [2] Section 2.5. |
| CURRT | (0.5) | : | Total plasma current (in CHEASE normalization). See Section 6 of U.M or [1] Appendix B or [2] Section 2.5. |
| CWIDTH | (10*0.) | : | Used only if NMESHC = 1. See Section 5 of U.M. |
| DELTA | (0.) | : | Used only if NSURF=4. Defines plasma surface shape. See Section 3 of U.M or [1] Section 3.2 or [2] Section 2.6.2. |
| DPLACE | (10*0.) | : | Used only if NMESHD = 1. See Section 5 of U.M. |
| DWIDTH | (10*0.) | : | Used only if NMESHD = 1. See Section 5 of U.M. |
| ELLIPT | (1.) | : | Elongation of the plasma cross-section. See Section 3 of U.M or [1] Section 3.2 or [2] Section 2.6.2. |
| EPLACE | (10*0.) | : | Used only if NMESHE = 1. See Section 5 of U.M. |
| EPSLON | (1.e-10) | : | Precision required for the nonlinear equilibrium solution. If NSTTP=2 or 3, the precision required for the profiles is 100*EPSLON. See [1] Appendix A or [2] Section 2.2 and 2.4. |
| ETAEI | (1.5) | : | $\eta_i$ = d(log(T))/d(log(n)) used for the calculation of the bootstrap current density using Hirshman's definition. See Section 4.1.1.3 of U.M. |
| EWIDTH | (10*0.) | : | Used only if NMESHE = 1. See Section 5 of U.M. |
| GAMMA | (1.6666) | : | adiabatic coefficient (for stability only) |
| PANGLE | (0) | : | Used if NPROFZ = 1. See Section 4 of U.M. |

| | | | |
|---|---|---|---|
| PSISCL | (1.) | : | Scale factor used to reduce the size of the equilibrium domain for the stability calculation so that: $\psi_{new} = \psi_{min}$ (1. - PSISCL * $s^2$) with 0 < s < 1. The pressure profile is integrated so that $p(\psi_{surf}=0) = 0$. |
| QSPEC | (1.) | : | Used only if NCSCAL=1 or 3. See Section 6 of U.M or [1] Appendix B or [2] Section 2.5. |
| QPLACE | (10*0) | : | Used only if NMESHA=2. See Section 5 of U.M. |
| QWIDTH | (10*0) | : | Used only if NMESHA=2. See Section 5 of U.M. |
| RC | (1.) | : | Scaling factor for plasma boundary. Usually RC = 1 |
| REXT | (1.) | : | Defines vacuum radius for MARS and ERATO. For MARS, the distance from plasma surface to the conducting shell is (REXT-1) * $s_{vacuum}$. See [2] Appendix C.2. |
| RNU | (0.) | : | Used only if NSURF=4. Defines plasma surface shape. See Section 3 of U.M. |
| RZION | (1.) | : | Ion charge used for the calculation of the bootstrap current density, Hirshman's definition. See Section 4.1.1.3 of U.M. |
| R0 | (1.) | : | Major axis of equilibrium mesh center. See [1] Section 2 or [2] Section 2.1. |
| R0W | (0.) | : | Major axis of mesh used for the vacuum discretization of MARS. See [2] Appendix C.2. |
| RZ0 | (0.) | : | Z-position of equilibrium mesh center. See [1] Section 2 or [2] Section 2.1. |
| RZ0W | (0.) | : | Z-position of mesh used for the vacuum discretization of MARS. See [2] Appendix C.2. |
| SCALNE | (0.) | : | Used only if NPROFZ = 1. Scaling factor which permits to vary the poloidal $\beta$ of the equilibrium when the current density is defined using the plasma temperature $T_e$ and the plasma density $n_e$. See Section 4 of U.M. |
| SGMA | (0.) | : | Used only if NSURF=3 or 4. Defines plasma surface shape. See Section 3 of U.M. |
| SOLPDA | (0.) | : | Used only if NMESHA = 1 or 2. See Section 5 of U.M. |
| SOLPDB | (0.) | : | Used only if NMESHB = 1. See Section 5 of U.M. |
| SOLPDC | (0.) | : | Used only if NMESHC = 1. See Section 5 of U.M. |
| SOLPDD | (0.) | : | Used only if NMESHD = 1. See Section 5 of U.M. |
| SOLPDE | (0.) | : | Used only if NMESHE = 1. See Section 5 of U.M. |

TRIANG (0.) : Used only if NSURF=2,3 or 4. Defines plasma surface shape. See Section 3 of U.M or [1] Section 3.2 or [2] Section 2.6.2.

TRIPLT (0.) : Used only if NSURF=3. Defines plasma surface shape. See Section 3 of U.M.

MSMAX (10) : Number of poloidal Fourier modes used by the stability code MARS. See [1] Appendix C.2 or [2] Appendix C.2.

NANAL (0) : Used only if NSURF = 1.
NANAL = 0 → numeric Solovev solution.
NANAL = 1 → analytic Solovev solution on equilibrium gridpoints.

NBAL (1) : NBAL = 0 → no ballooning, Mercier and resistive interchange stability tests.
NBAL = 1 → ballooning, Mercier and resistive interchange stability are tested.
See [1] Appendix C or [2] Section 3.7

NBLC0 (1) : Number of $\chi_0$ integration constants used for the computation of the ballooning energy integral. If NSYM=1, the $\chi_0$'s are uniformly distributed between 0 and $\pi$. If NSYM=0, they are uniformly distributed between 0 and $2\pi$. See [1] Appendix C and [2] Section 3.7.

NBLOPT (0) : NBLOPT= 0 → $p'(\psi)$ is specified.
NBLOPT= 1 → Ballooning optimized equilibrium is computed.
See Section 4.1.1.2 of U.M.

NBSFUN (1) : Used only if NBSTRP=2. Selects the type of functional form used to compute the bootstrap current density so that $j_{b.s.} = F(s) * j_{parallel}$.
NBSFUN= 1 → F(s) is a polynomial of degree NSOUR.
NBSFUN= 2 → F(s) is given in 3 Sections.
NBSFUN= 3 → F(s) is given by the Princeton profile specification.
See Section 4.1.1.3.2 of U.M.

NBSOPT (0) : NBSOPT= 0 → $p'(\psi)$ is specified.
NBSOPT= 1 → $p'(\psi)$ is obtained using the bootstrap current density.
See Section 4.1.1.3 of U.M.

NBSTRP (1) : Used only if NBSOPT=1.
NBSTRP= 1 → $j_{b.s.} = BSFRAC * j_{parallel.}$
NBSTRP= 2 → $j_{b.s.} = F(s) * j_{parallel.}$
See Section 4.1.1.3 of U.M.

NCHI (100): Number of poloidal stability intervals. See [1] Section 4.1 or [2] Section 3.2.

NCSCAL (2) : NCSCAL= 1 → the equilibrium is rescaled so that $q(s_{spec}) = q_{spec.}$
NCSCAL= 2 → the equilibrium is rescaled so that the total current is equal to I = CURRT.
NCSCAL= 3 → the equilibrium is rescaled such that the $q(\rho_{spec}) = q_{spec.}$
NCSCAL= 4 → the equilibrium is not rescaled.
See Section 6 of U.M or [1] Appendix B or [2] Section 2.5.

NDIFPS (1) : NDIFPS = 0 → no automatic packing in s.
NDIFPS = 1 → Automatic packing of the radial stability mesh s. See Section 5 of U.M.

NDIFT (1) : NDIFT = 0 → no automatic packing in $\theta$.
NDIFT = 1 → Automatic packing of the angular equilibrium mesh $\theta$. See Section 5 of U.M.
NDIFT = 2 → Automatic packing of the angular equilibrium mesh $\theta$. See Section 5 of U.M.

NEGP (-1) : Power of R in the definition of the flux coordinate Jacobian $J = C(\psi)\, R^{(NER)}\, |\nabla\psi|^{(NEGP)}$ used by ERATO, MARS, LION and in the ballooning stability calculation. See [1] Section 4.1 or [2] Section 3.2.

NER (1) : Power of $|\nabla\psi|$ in the definition of the flux coordinate Jacobian $J = C(\psi)\, R^{(NER)}\, |\nabla\psi|^{(NEGP)}$ used by ERATO, MARS, LION and in the ballooning stability calculation. See [1] Section 4.1 or [2] Section 3.2.

NFUNC (1) : Selects the type of functional form used to define TT', $I^*$ or $\langle \mathbf{J}.\mathbf{B}\rangle/\langle \mathbf{B}.\nabla\phi\rangle$:
NFUNC = 1 → Polynomial of degree NSOUR.
NFUNC = 2 → Polynomial in 3 Sections.
NFUNC = 3 → Princeton specification.
NFUNC = 4 → Specification by a set of points.
See Section 4.1.2 of U.M.

NIDEAL (0) : NIDEAL = 0 → Mapping for MARS. See [1] Appendix C.2 or [2] Appendix C.2.
NIDEAL = 1 → Mapping for ERATO. See [1] Appendix C.1 or [2] Appendix C.1.
NIDEAL = 2 → Mapping for LION. See [1] Appendix C.1 or [2] Appendix C.1.
NIDEAL = 3 → Mapping for NOVA-W and PEST 3.4. See [2] Appendix C.3.
NIDEAL = 4 → Mapping for PENN.

NINMAP (20) : Used only if NSTTP ≠ 1. Maximum number of iterations over the mapping when I* or $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$ are specified. See [2] Section 2.4.

NINSCA (50) : Maximum Picard iterations. Not used if NSURF=1 (Solovev case). See [1] Appendix A or [2] Section 2.2.

NIPR (1) : Used only if NSTTP = 2. See Section 4 of U.M.

NISO (100): Used only if NSTTP≠1. Number of radial intervals use to define I*or $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$. **NISO≤NPSI**. See [2] Section 2.4

NMESHA (0) : NMESHA= 0 → No packing of radial stability s-mesh
NMESHA= 1 → "Manual" packing of radial stability s-mesh.
NMESHA= 2 → Automatic packing of radial stability s-mesh on rational-q surfaces
See Section 5 of U.M.

NMESHB (0) : NMESHB= 0 → No packing of radial s-mesh used for specification of I* or $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$.
NMESHB= 1 → "Manual" packing of radial s-mesh used for specification of I* or $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$.
See Section 5 of U.M.

NMESHC (0) : NMESHC= 0 → No packing of radial equilibrium $\sigma$-mesh
NMESHC= 1 → "Manual" packing of radial equilibrium $\sigma$-mesh. See Section 5 of U.M.

NMESHD (0) : NMESHD= 0 → No packing of angular equilibrium $\theta$-mesh
NMESHD= 1 → "Manual" packing of angular equilibrium $\theta$-mesh. See Section 5 of U.M.

NMESHE (0) : NMESHE= 0 → No packing of angular stability $\chi$-mesh
NMESHE= 1 → "Manual" packing of angular stability $\chi$-mesh. See Section 5 of U.M.

NMGAUS (4) : Number of Gaussian integration points used for the integration of line integrals along constant poloidal flux surfaces. See [1] Section 4.1 or [2] Section 3.3.

NOPT (0) : NOPT = 0 → Equilibrium is computed and written into file NOUT.
NOPT = 1 → Equilibrium is read from file NIN.

NPLOT (0) : NPLOT = 0 → No plot quantities are computed.
NPLOT = 1 → Plot quantities are computed and stored into file NUPLO.

NPOIDA (0) : Number of Lorentzians used for the radial stability s-mesh packing. See Section 5 of U.M.

NPOIDB (0) : Number of Lorentzians used for the packing of the radial s-mesh used for specification of I* or $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$. See Section 5 of U.M.

NPOIDC (0) : Number of Lorentzians used for the radial equilibrium $\sigma$-mesh packing. See Section 5 of U.M.

NPOIDD (0) : Number of Lorentzians used for the angular equilibrium $\theta$-mesh packing. See Section 5 of U.M.

NPOIDE (0) : Number of Lorentzians used for the angular stability $\chi$-mesh packing. See Section 5 of U.M.

NPOIDQ (0) : Used only if NMESHA=2. Number of rational-q surfaces where the radial stability s-mesh is packed.
See Section 5.2.1 of U.M.

NPP (0) : Used only if NPPFUN=2 (see Section 4.1.1.1.2 of U.M ) or NBSFUN=2 (see Section 4.1.3.2.2 of U.M ).

NPPFUN (1) : Selects the type of functional form used to define p'.
NPPFUN = 1 → Polynomial of degree NSOUR.
NPPFUN = 2 → Polynomial in 3 Sections.
NPPFUN = 3 → Princeton profile specification.
NPPFUN = 4 → Specification by a set of points.
See Section 4.1.1.1 of U.M.

NPPR (30) : Number of intervals used to define the pressure profile during the ballooning optimization.

NPROFZ (0) : NPROFZ = 0 → Toroidal current density defined as function of $\psi/\psi_{min}$.
NPROFZ = 1 → Toroidal current density defined by the plasma temperature profile $T_e$ and the plasma density profile $n_e$ given as polynomials. See Section 4 of U.M.

NPROPT (0) : Used only if NSURF=6 or NFUNC=4 or NPPFUN=4. See Section 8.3 of U.M.

NPROPT= 1 → GG', p' and the coordinates of the plasma boundary are saved into file EXPEQ.

NPROPT= 2 → I*, p' and the coordinates of the plasma boundary are saved into file EXPEQ.

NPROPT= 3 → $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$, p' and the coordinates of the plasma boundary are saved into file EXPEQ.

NPRPSI (0) : NPRPSI = 0 → No $\psi$, $\psi_\sigma$, $\psi_\theta$ and $\psi_{\sigma\theta}$ values are printed.

NPRPSI = 1 → $\psi$, $\psi_\sigma$, $\psi_\theta$ and $\psi_{\sigma\theta}$ values on equilibrium gridpoints are printed.

NPSI (100): Number of radial s-intervals used for the stability calculation. See [1] Section 4.1 or [2] Section 3.2.

NRFP (0) : NRFP = 0 → Tokamak equilibrium.

NRFP = 1 → Reversed field pinch equilibrium.

NRSCAL (0) : NRSCAL= 0 → No scaling of distances.

NRSCAL= 1 → Stability quantities are scaled such that $R_m = 1$ ($R_m$ is the major radius of the magnetic axis). If **NIDEAL=1**, NRSCAL=1 is compulsatory.

NS (40) : Number of radial $\sigma$-intervals used for the equilibrium discretization. See [1] Section 2 or [2] Section 2.1.

NSGAUS (4) : Number of Gaussian integration points used for the integration of the equilibrium problem in the radial $\sigma$-direction. See [1] Appendix A or [2] Section 2.2.

NSMOOTH(1) : Bicubic spline smoothing of the bicubic Hermite solution.

NSMOOTH = 0 → Bicubic Hermite solution.

NSMOOTH = 1 → Bicubic spline solution.

See [2] Appendix D.

NSOUR (0) : Used only if NSURF≠1 and (NFUNC=1 or NPPFUN=1 or NBSFUN=1). Degree of the polynomial used to specify the p', TT', $I^*$ or/and $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$ profile. See Section 4 of U.M.

NSTTP (1) : NSTTP=1 → TT' is specified. See [1] Section 3.2 or [2] Section 2.6.2.

NSTTP=2 → I* is specified. See [2] Section 2.4 and 2.6.2

NSTTP=3 → $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$ is specified. See [2] Section 2.4

Further information in Section 4.1.2 of U.M.

NSURF (1) : NSURF = 1 → Solovev plasma cross-section. See [1] Section 3.1 or [2] Section 2.6.1.
NSURF = 2 → Symmetric plasma cross-section. See [1] Section 3.2 or [2] Section 2.6.2.
NSURF = 3 → Racetrack like plasma cross-section.
NSURF = 4 → Asymmetric plasma cross-section.
NSURF = 5 → Octopole plasma cross-section.
NSURF = 6 → Plasma boundary given by a set of (R,Z) coordinates.
For more information, see Section 3 of U.M.

NSYM (1) : NSYM = 0 → Asymmetric version of ERATO is used.
NSYM = 1 → Symmetric version of ERATO is used.

NT (40) : Number of angular $\theta$-intervals used for the equilibrium discretization. See [1] Section 2 or [2] Section 2.1.

NTCASE(0) : NTCASE= 0 → All Namelist variables are specified by the user or the default settings.
NTCASE= 1 → Solovev test case.
NTCASE= 2 → Symmetric test case (JET cross-section) with polynomial p' and TT' profiles.
NTCASE= 3 → Symmetric test case (NET cross-section) with p' and I* specification.

NTGAUS (4) : Number of Gaussian integration points used for the integration of the equilibrium problem in the angular $\theta$-direction. See [1] Appendix A or [2] Section 2.2.

NTNOVA (64) : Number of angular $\theta$-intervals used in NOVA-W or the PEST 3.4 stability calculation. **Must be less or equal to NPCHI**. See [2] Appendix C.3.

NTEST (0) : Used only if NSURF = 1 and NANAL = 0.
NTEST = 0 → No comparison is done with the analytic Solovev solution.
NTEST = 1 → Numeric Solvev solution is compared with the analytic solution.

NTMF0 (1) : NTMF0 = 0 → $T_{surf}=1$ after rescaling of the equilibrium.
NTMF0 = 1 → $T_0=1$ after rescaling of the equilibrium
See Section 6 of U.M or [1] Appendix B or [2] Section 2.5.

NTURN (10) : Number of $2\pi$ intervals used for the integration of the ballooning integral. See [1] Appendix C or [2] Section 3.7.

NV (20) : Number of radial s-intervals used for the vacuum discretization of MARS. See [2] Appendix C.2.

NVEXP (0) : NVEXP = 0 → Equidistant radial vacuum mesh for MARS.

NVEXP = 1 → Exponential packed radial vacuum mesh for MARS so that the s-mesh density is constant on the plasma vacuum interface.

## 3. Specification of the plasma surface

**3.1 NSURF = 1:** Solovev equilibrium.

$$R = R_S \sqrt{1 + 2\,\varepsilon_S \cos(\theta)}$$

$$Z = \frac{R_S\,\varepsilon_S\,E\,\sin(\theta)}{\sqrt{1 + 2\,\varepsilon_S \cos(\theta)}}$$

The corresponding Namelist variables are

$R_S$ <------> RC
E <------> ELLIPT
$\varepsilon_S$ <------> ASPCT

**3.2.NSURF = 2:** Symmetric equilibrium.

$$R = R_S + R_S\varepsilon_S\cos(\theta + \delta\sin(\theta) - \zeta\sin(2\theta))\,(1 + b\cos(\theta))$$

$$Z = R_S\varepsilon_S\,E\,\sin(\theta + \sigma\sin(2\theta))$$

The corresponding Namelist variables are

$R_S$ <------> RC
E <------> ELLIPT
$\delta$ <------> TRIANG
b <------> BEANS
$\zeta$ <------> CETA
$\sigma$ <------> SGMA

$\varepsilon_S$ is adjusted such that the inverse aspect ratio

$$\varepsilon = \frac{a}{R_S} = \frac{R_{max} - R_{min}}{R_{max} + R_{min}}$$

is equal to ASPCT. $R_{min}$ and $R_{max}$ are the minimum and the maximum value of R on the plasma boundary.

**3.3.NSURF = 3:** Symmetric equilibrium.

$$R = R_S + R_S\varepsilon_S \cos\left(f(\theta) + \delta \sin\left(f(\theta)\right)\right)\left(1 + b\cos(\theta)\right)\left(1 + t\cos\left(\frac{5\pi}{2}\sin(\theta)\right)\right)$$

$$Z = R_S\varepsilon_S\, E \sin(\theta)$$

where

$$f(\theta) = \pi\, \mathrm{int}\left(\frac{2\theta}{\pi}\right) + \left[\theta - \pi\, \mathrm{int}\left(\frac{2\theta}{\pi}\right)\right]\left\{e^{-\sigma\alpha_o} + \left[1 - e^{-\sigma\alpha_o}\right] e^{-\sigma\left|\mathrm{cotg}(\theta)\right|}\right\}$$

with $0 \le \theta \le \pi$. For $\pi < \theta < 2\pi$, the boundary is computed by symmetry. The corresponding Namelist variables are

| | | |
|---|---|---|
| $R_S$ | <------> | RC |
| E | <------> | ELLIPT |
| $\delta$ | <------> | TRIANG |
| b | <------> | BEANS |
| t | <------> | TRIPLT |
| $\sigma$ | <------> | SGMA |
| $\alpha_o$ | <------> | ALPHA0 |

$\varepsilon_S$ is adjusted such that the inverse aspect ratio

$$\varepsilon = \frac{a}{R_S} = \frac{R_{max} - R_{min}}{R_{max} + R_{min}}$$

is equal to ASPCT. $R_{min}$ and $R_{max}$ are the minimum and the maximum value of R on the plasma boundary.

Remark : If t = 0 and $\sigma$ = 0, NSURF=3 is identical to NSURF=2, only the computation time is longer.

**3.4.NSURF = 4:** Asymmetric equilibrium.

$$R = R_S + R_S\varepsilon_S f(\theta)\cos(\theta + \delta\sin(\theta))(1 + b\cos(\theta))$$

$$Z = R_S\varepsilon_S E f(\theta)\sin(\theta)$$

where

$$f(\alpha) = 1 + \frac{\sigma}{1 + \frac{\left[\sin^2\left(\frac{\alpha - \alpha_o}{2}\right) + \zeta\right]^\nu}{\Delta}}$$

with $0 \leq \alpha < 2\pi$.
The corresponding Namelist variables are

| | | |
|---|---|---|
| $R_S$ | <------> | RC |
| E | <------> | ELLIPT |
| $\delta$ | <------> | TRIANG |
| b | <------> | BEANS |
| $\nu$ | <------> | RNU |
| $\zeta$ | <------> | CETA |
| $\Delta$ | <------> | DELTA |
| $\sigma$ | <------> | SGMA |
| $\alpha_o$ | <------> | ALPHA0 |

$\varepsilon_S$ is adjusted such that the inverse aspect ratio

$$\varepsilon = \frac{a}{R_S} = \frac{R_{max} - R_{min}}{R_{max} + R_{min}}$$

is equal to ASPCT. $R_{min}$ and $R_{max}$ are the minimum and the maximum value of R on the plasma boundary.

**3.5.NSURF = 5:** Octopole equilibrium.

$$R = R_S + R_S\varepsilon_S f(\theta)\cos(\theta)$$
$$Z = R_S\varepsilon_S f(\theta)\sin(\theta)$$

where

$$f(\alpha) = \frac{1}{[1 - \sigma\{\cos[4(\alpha - \alpha_o)] - 1\}]^{\Delta}}$$

with $0 \leq \alpha < 2\pi$. The corresponding Namelist variables are

| | | |
|---|---|---|
| $R_S$ | <------> | RC |
| $\Delta$ | <------> | DELTA |
| $\sigma$ | <------> | SGMA |
| $\alpha_o$ | <------> | ALPHA0 |

$\varepsilon_S$ is adjusted such that the inverse aspect ratio

$$\varepsilon = \frac{a}{R_S} = \frac{R_{max} - R_{min}}{R_{max} + R_{min}}$$

is equal to ASPCT. $R_{min}$ and $R_{max}$ are the minimum and the maximum value of R on the plasma boundary.

**3.6.NSURF = 6:** Equilibrium boundary given by a set of (R;Z) coordinates.

The equilibrium boundary is read on a file called EXPEQ in the following format:

```
        write(NO,1000)  NBPS
        write(NO,1001) (RBOUND(K),ZBOUND(K),K=1,NBPS)
1000    format(I5)
1001    format(2E18.8)
```

NBPS is the number of (R,Z) points used for the reconstruction of the plasma boundary. CHEASE obtains all boundary information by cubic spline interpolations. For more information about the file EXPEQ, see Section 8.3 of U.M.

## 4.Profile Specification :

10 parameters provide the whole profile specification : NFUNC, NSTTP, NIPR, NPPFUN, NPP, NBSFUN, NBSTRP, NBLOPT, NBSOPT and NPROFZ.

### 4.1 NPROFZ=0:
### 4.1.1.Pressure Profile:
### 4.1.1.1.NBLOPT=0 and NBSOPT=0:
### 4.1.1.1.1.NPPFUN=1:

p' is a polynomial

$$p'(\psi) = \frac{dp}{d\psi} = \sum_{i=0}^{N} p_i \left[\frac{\psi}{\psi_{min}}\right]^i$$

$\psi_{min}$ is the value of $\psi$ on the magnetic axis. The corresponding Namelist variables are

$p_i$ <------> AP(i), i=1,...,NSOUR
N <------> NSOUR ≤ 10

### 4.1.1.1.2.NPPFUN=2:

p' = dp/dψ is specified as a combination of 3 polynomial sections, as shown in Figure 1. The abscissas t in Figure 1 can be specified as:

$$t = 1 - \frac{\psi}{\psi_{min}} \qquad \text{if} \quad \mathbf{NPP} = 1$$

$$t = \sqrt{1 - \frac{\psi}{\psi_{min}}} \qquad \text{if} \quad \mathbf{NPP} = 2$$

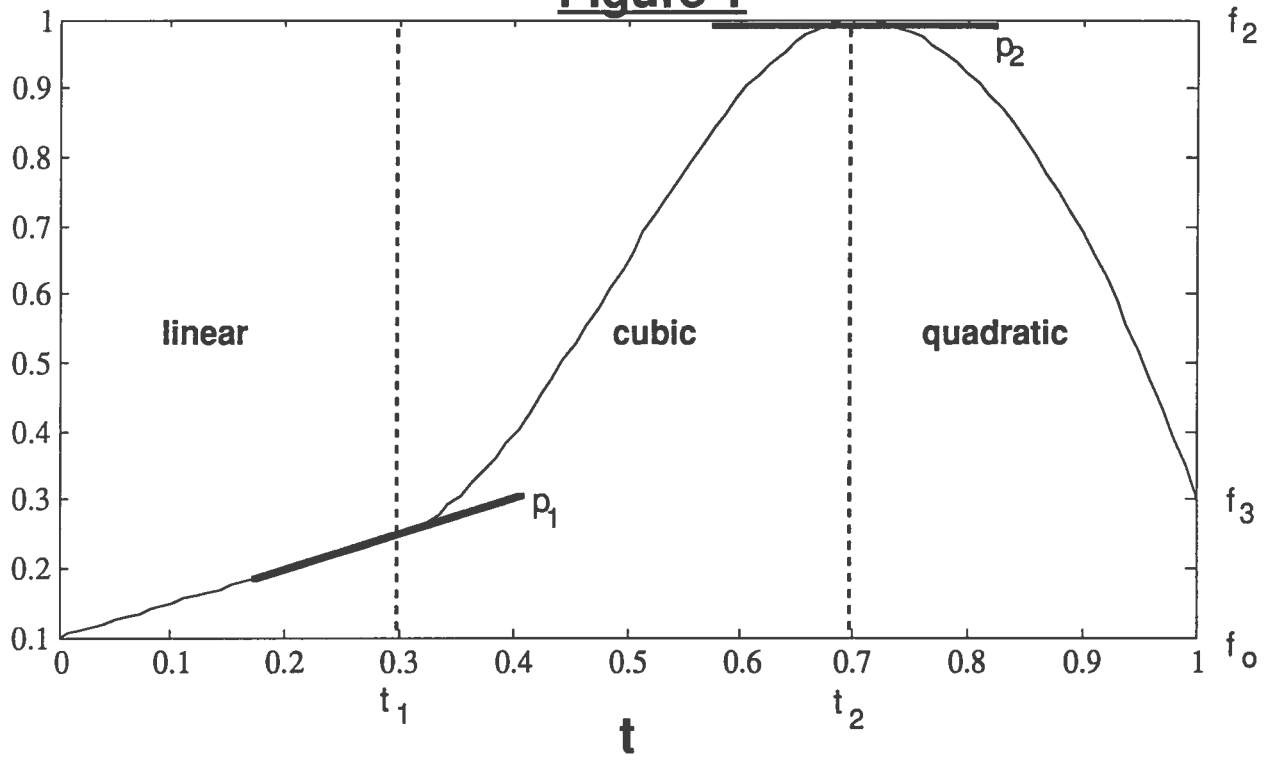
$\psi_{min}$ is the value of $\psi$ on the magnetic axis. The corresponding Namelist variables are

$t_1$ <------> AP(1)
$t_2$ <------> AP(2)
$f_2$ <------> AP(3)
$p_1$ <------> AP(4) **if NPP = 1**
$f_0$ <------> AP(5)
$f_3$ <------> AP(6)
$p_2$ <------> AP(7)

$t_1$ <------> AP2(1)
$t_2$ <------> AP2(2)
$f_2$ <------> AP2(3)
$p_1$ <------> AP2(4)
$f_o$ <------> AP2(5)
$f_3$ <------> AP2(6)
$p_2$ <------> AP2(7)

**if NPP = 2**

**Figure 1**




**4.1.1.1.3.NPPFUN = 3 :**

p' is given by

$$p'(\psi) = \frac{dp}{d\psi} = p_0\left[1 - t^{\beta}\right]^{\alpha}$$

where

$$t = 1 - \frac{\psi}{\psi_{min}}$$

$\psi_{min}$ is the value of $\psi$ on the magnetic axis. The corresponding Namelist variables are

$p_0$ <------> AP(1)

$\alpha$ <------> AP(2)

$\beta$ <------> AP(3)

#### 4.1.1.1.4. NPPFUN = 4 :

p' is given by a set of points which are read on file EXPEQ in the following format:

```
        read(NO,1000)          NPPF1,NSTTP
        read(NO,1001)          (FCSM(K),K=1,NPPF1)
        IF (NPPFUN .EQ. 4)     read(NO,1001) (RPPF(K),K=1,NPPF1)
        IF (NFUNC .EQ. 4)      read(NO,1001) (RFUN(K),K=1,NPPF1)
1000    format(I5)
1001    format(1E18.8)
```

If NSURF = 6, these data must be stored after the boundary coordinates in EXPEQ. NPPF1 is the number of s grid points where the profiles are given. The s values are stored in FCSM and the p' values in RPPF. Denpending on the value of NSTTP, the values corresponding to TT', I* or $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$ are read into RFUN. For more information about the file EXPEQ, see Section 8.3 of U.M.

#### 4.1.1.2 NBLOPT=1 :

The ballooning optimization of the pressure profile is performed. This option introduces a supplementary iteration over the equilibrium equation. At every iteration, the p' profile, defined on NPPR points, is readjusted so that the code converges to a marginal ballooning stable equilibrium. If values of p' are required at other locations than these NPPR points, they are obtained by cubic spline interpolations. The first guess of the p' profile is given as for NBLOPT=0, see Section 4.1.1.1 of U.M. The ballooning optimization is performed on the small equilibrium, the equilibrium with full mesh size is only computed after the convergence of the ballooning optimization.

#### 4.1.1.3 NBSOPT=1 :

The boostrap current density is specified. As for the ballooning optimization in Section 4.1.1.2 of U.M, this option introduces a supplementary iteration over the equilibrium equation. The first guess of the p' profile is given as for NBSOPT=0, see Section 4.1.1.1 of U.M. In the following,

$$j_{//}(\psi) = - T(\psi)\, p'(\psi) - T'(\psi) \langle B^2 \rangle$$

where

$$\langle \ldots \rangle = \frac{\oint_{\psi=const} \ldots J\, d\chi}{\oint_{\psi=const} J\, d\chi}$$

and the boostrap current is given by (S.P.Hirshman Phys. Fluids **31**, 3150 (1988)):

$$j_{B.S.}(\psi) = - L_{31} (A_1^e + (A_1^i + \alpha_i A_2^i)) - L_{32} A_2^e$$

where

$$L_{31} = j_o \, x \, [0.754 + 2.21 Z_i + Z_i^2 + x\,(0.348 + 1.243\, Z_i + Z_i^2)] \,/\, D(x)$$

$$L_{32} = - j_o \, x \, (0.884 + 2.074 Z_i \,) \,/\, D(x)$$

$$\alpha_i = -1.172 \,/\, (1 + 0.462\, x)$$

$$D(x) = 1.414\, Z_i + Z_i^2 + x\,(\, 0.754 + 2.657\, Z_i + 2\, Z_i^2) + x^2\,(0.348 + 1.243\, Z_i + Z_i^2)$$

and

$$x = \frac{1 - f_c}{f_c} \qquad f_c = \frac{3}{4}\langle B^2 \rangle \int_0^{B_{max}^{-1}} \frac{\lambda \, d\lambda}{\langle (1 - \lambda B)^{1/2} \rangle}$$

$$A_1^e = A_1^i = p'(\psi) \qquad A_2^e = A_2^i = \frac{\eta_i}{1 + \eta_i} p'(\psi)$$

$$j_o = \frac{T(\psi)}{2}$$

Two options are available for the specification of the boostrap current density:

**4.1.1.3.1 NBSTRP=1 :**

The total boostrap current is a fraction of total current:

$$p'_{k+1}(\psi) = C \frac{j_{B.S.}(\psi)}{j_{//}(\psi)} p'_k(\psi)$$

The p' profile has converged when $||p'_{k+1}(\psi) - p'_k(\psi)|| < \varepsilon$, where $\varepsilon$ is a prescribed small value. The corresponding Namelist variables are

| | | |
|---|---|---|
| C | <------> | BSFRAC |
| $Z_i$ | <------> | RZION |
| $\eta_i$ | <------> | ETAEI |

**4.1.1.3.2 NBSTRP=2 :**

The boostrap current density is given by:

$$p'_{k+1}(\psi) = F(\psi) \frac{j_{B.S.}(\psi)}{j_{//}(\psi)} p'_k(\psi)$$

where $F(\psi)$ is defined in Sections 4.1.1.3.2.1-3 of U.M.

The corresponding Namelist variables are

$Z_i$ <------> RZION

$\eta_i$ <------> ETAEI

**4.1.1.3.2.1 NBSFUN = 1 :**

$F(\psi)$ is a polynomial

$$F(\psi) = \sum_{i=0}^{N} f_i \left[\frac{\psi}{\psi_{min}}\right]^i$$

$\psi_{min}$ is the value of $\psi$ on the magnetic axis. The corresponding Namelist variables are

$f_i$ <------> AFBS(i), i=1,...,NSOUR

N <------> NSOUR ≤ 10

**4.1.1.3.2.2 NBSFUN = 2:**

$F(\psi)$ is specified as a combination of 3 polynomial sections, as shown in Figure 1. The abscissas t in Figure 1 can be specified as:

$$t = 1 - \frac{\psi}{\psi_{min}} \qquad \text{if } \mathbf{NPP} = 1$$

$$t = \sqrt{1 - \frac{\psi}{\psi_{min}}} \qquad \text{if } \mathbf{NPP} = 2$$

$\psi_{min}$ is the value of $\psi$ on the magnetic axis. The corresponding Namelist variables are

$t_1$ <------> AFBS(1)

$t_2$ <------> AFBS(2)

$f_2$ <------> AFBS(3)

$p_1$ <------> AFBS(4) **if NPP = 1**

$f_o$ <------> AFBS(5)

$f_3$ <------> AFBS(6)

$p_2$ <------> AFBS(7)

$t_1$ <------> AFBS2(1)
$t_2$ <------> AFBS2(2)
$f_2$ <------> AFBS2(3)
$p_1$ <------> AFBS2(4) **if NPP = 2**
$f_o$ <------> AFBS2(5)
$f_3$ <------> AFBS2(6)
$p_2$ <------> AFBS2(7)

**4.1.1.1.3.NBSFUN=3 :**

$F(\psi)$ is given by

$$F(\psi) = f_0\left[1 - t^{\beta}\right]^{\alpha}$$

where

$$t = 1 - \frac{\psi}{\psi_{min}}$$

$\psi_{min}$ is the value of $\psi$ on the magnetic axis. The corresponding Namelist variables are

$f_o$ <------> AFBS(1)
$\alpha$ <------> AFBS(2)
$\beta$ <------> AFBS(3)

**4.1.2. TT', I* and <J.B>/<B.∇φ> profiles:**

**4.1.2.1.NFUNC=1:**

**4.1.2.1.1.NRFP=0:**

TT', $I^*$ or **<J.B>/<B.∇φ>** , symbolized by F, is a polynomial

$$F(\psi) = \sum_{i=0}^{N} t_i \left[\frac{\psi}{\psi_{min}}\right]^i$$

If **NSTTP = 1** -----> F = **TT'**
If **NSTTP = 2** -----> F = **$I^*$**
If **NSTTP = 3** -----> F = **<J.B>/<B.∇φ>**

$\psi_{min}$ is the value of $\psi$ on the magnetic axis. The corresponding Namelist variables are

$t_i$ <------> AT(i), i=1,...,NSOUR
N <------> NSOUR ≤ 10

**4.1.2.1.2.NRFP=1 : (does not work with new version of CHEASE!)**

T is given according to

$$T = T_3 - t\,T_1\left[1 - \frac{1}{(T_2+1)}\,t^{T_2}\right]$$

where

$$t = 1 - \frac{\psi}{\psi_{min}}$$

This formula is derived from the cylindrical approximation :

$$T = T(0) - \int \mu\, d\psi$$

with $\mu$ given by

$$\mu = T_1\left[1 - t^{T_2}\right]$$

and T(0) = $T_3$. The corresponding Namelist variables are :

$T_i$ <------> AT(i), i=1,...,3

**Remark :** The RFP equilibria can be computed only with prescribed total current. Therefore, the value of T(0) changes during the computation of the equilibrium because the solution is rescaled.

**4.1.2.2.NFUNC=2 :**

In this case, TT', $I^*$ or $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$ is specified as a combination of 3 polynomial sections, as shown in Figure 2.

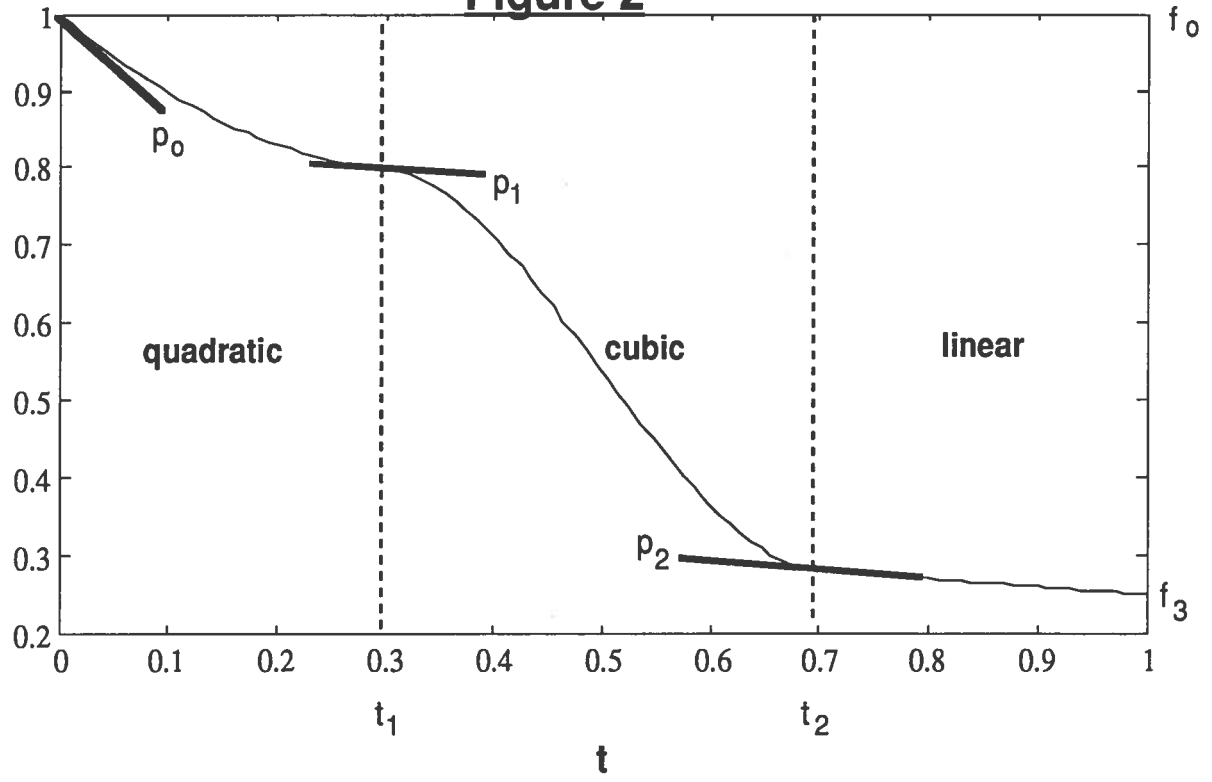
| | | |
|---|---|---|
| If **NSTTP = 1** | -----> | **TT'** is a polynomial in 3 Sections. |
| If **NSTTP = 2** | -----> | $\mathbf{I^*}$ is a polynomial in 3 Sections. |
| If **NSTTP = 3** | -----> | $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$ is a polynomial in 3 Sections. |

$I^*$ is defined by

$$I^*(t) = \frac{\oint_{\psi=\text{const}} \frac{j_\phi}{R} J \, d\chi}{\oint_{\psi=\text{const}} \frac{1}{R} J \, d\chi}$$

where $j_\phi$ is the toroidal current density.

**Figure 2**



The abscissa t in Figure 2 can be specified as:

$$t = 1 - \frac{\psi}{\psi_{min}} \qquad \text{if} \quad \textbf{NIPR} = 1$$

$$t = \sqrt{1 - \frac{\psi}{\psi_{min}}} \qquad \text{if} \quad \textbf{NIPR} = 2$$

$$t = \left(1 - \frac{\psi}{\psi_{min}}\right)^{\frac{1}{4}} \qquad \text{if} \quad \textbf{NIPR} = 3$$

$\psi_{min}$ is the value of $\psi$ on the magnetic axis.
Moreover, if **NIPR = 4**, a Gaussian of the form

$$I^*(t) = h_g \exp\left[-\left(\frac{t - c_g}{w_g}\right)^2\right] \qquad \text{if } \textbf{NIPR} = 4$$

can be added, where

$$t = 1 - \frac{\psi}{\psi_{min}}$$

The corresponding Namelist variables are:

| | | | |
|---|---|---|---|
| $t_1$ | <------> | AT(1) | |
| $t_2$ | <------> | AT(2) | |
| $f_o$ | <------> | AT(3) | |
| $p_o$ | <------> | AT(4) | **if NIPR = 1** |
| $p_1$ | <------> | AT(5) | |
| $f_3$ | <------> | AT(6) | |
| $p_2$ | <------> | AT(7) | |

$\oplus$

| | | | |
|---|---|---|---|
| $t_1$ | <------> | AT2(1) | |
| $t_2$ | <------> | AT2(2) | |
| $f_o$ | <------> | AT2(3) | |
| $p_o$ | <------> | AT2(4) | **if NIPR = 2** |
| $p_1$ | <------> | AT2(5) | |
| $f_3$ | <------> | AT2(6) | |
| $p_2$ | <------> | AT2(7) | |

$\oplus$

$t_1$ <------> AT3(1)
$t_2$ <------> AT3(2)
$f_o$ <------> AT3(3)
$p_o$ <------> AT3(4) **if NIPR = 3**
$p_1$ <------> AT3(5)
$f_3$ <------> AT3(6)
$p_2$ <------> AT3(7)

$\oplus$

$c_g$ <------> AT4(1)
$w_g$ <------> AT4(2) **if NIPR = 4**
$h_g$ <------> AT4(3)

**4.1.2.3.NFUNC=3 :**

In this case, TT', $I^*$ or **<J.B>/<B.∇φ>**, symbolized by F, is specified as follows:

$$F = j_0 \left[1 - t^{\beta}\right]^{\alpha}$$

where

$$t = 1 - \frac{\psi}{\psi_{min}}$$

$\psi_{min}$ is the value of $\psi$ on the magnetic axis.

If **NSTTP = 1** -----> F = **TT'**.
If **NSTTP = 2** -----> F = $\mathbf{I^*}$.
If **NSTTP = 3** -----> F = **<J.B>/<B.∇φ>**.

The corresponding Namelist variables are

$j_o$ <------> AT(1)
$\alpha$ <------> AT(2)
$\beta$ <------> AT(3)

#### 4.1.2.4. NFUNC = 4 :

TT', $I^*$ or <**J.B**>/<**B.**$\nabla\phi$>, symbolized by F, is given by a set of points which are read on file EXPEQ in the following format:

```
        read(NO,1000)          NPPF1,NSTTP
        read(NO,1001)          (FCSM(K),K=1,NPPF1)
        IF (NPPFUN .EQ. 4)     read(NO,1001) (RPPF(K),K=1,NPPF1)
        IF (NFUNC .EQ. 4)      read(NO,1001) (RFUN(K),K=1,NPPF1)
1000    format(I5)
1001    format(1E18.8)
```

If NSURF = 6, these data must be stored after the boundary coordinates in EXPEQ. NPPF1 is the number of s grid points where the profiles are given. The s values are stored in FCSM and the p' values in RPPF. Denpending on the value of NSTTP, the values corresponding to TT', I* or <**J.B**>/<**B.**$\nabla\phi$> are read into RFUN. For more information about the file EXPEQ, see Section 8.3 of U.M.

### 4.2.NPROFZ=1 : (does not work !)

The pressure and the TT' profiles are specified using the density profile $n_e$ and the temperature profile $T_e$ of the plasma. $T_e$ and $n_e$ are defined as polynomials :

$$T_e(t) = \sum_{i=1}^{N} a_i t^i$$

$$n_e(t) = \lambda \sum_{i=1}^{N} b_i t^i$$

where $\lambda$ is a scaling factor which permits one to vary the poloidal $\beta$ of the plasma and

$$t = \frac{\rho}{\rho_s(\theta_o)}$$

The corresponding Namelist variables are

| | | |
|---|---|---|
| $\theta_o$ | <------> | PANGLE |
| N | <------> | NSOUR |
| $\lambda$ | <------> | SCALNE |
| $a_i$ | <------> | AT(i), i=1,...,NSOUR |
| $b_i$ | <------> | AP(i), i=1,...,NSOUR |

## 5.Mesh Packing:

### 5.1. "Manual" packing:

The equilibrium meshes ($\sigma$, $\theta$, and radial s mesh used for I* or $\langle \mathbf{J}.\mathbf{B} \rangle / \langle \mathbf{B}.\nabla\phi \rangle$ ) and the stability (s and $\chi$) meshes can be packed manually by using Lorentzians

$$f(x) = \frac{w_o}{w_o^2 + (x - x_o)^2}$$

where $x_o$ is the centre of the peak and $w_o$ its half-width at half height (see Figure 3). The packed mesh is

$$x_{packed} = p\,x + (1-p)\frac{\displaystyle\int_0^x \sum_{i=1}^{N} \frac{w_{o,i}}{w_{o,i}^2 + (x - x_{o,i})^2} dx}{\displaystyle\int_0^1 \sum_{i=1}^{N} \frac{w_{o,i}}{w_{o,i}^2 + (x - x_{o,i})^2} dx}$$

$$= p\,x + (1-p)\frac{\displaystyle\sum_{i=1}^{N} \mathrm{Atan}\left(\frac{x - x_{o,i}}{w_{o,i}}\right) + \mathrm{Atan}\left(\frac{x_{o,i}}{w_{o,i}}\right)}{\displaystyle\sum_{i=1}^{N} \mathrm{Atan}\left(\frac{1 - x_{o,i}}{w_{o,i}}\right) + \mathrm{Atan}\left(\frac{x_{o,i}}{w_{o,i}}\right)}$$

The corresponding Namelist variables are:

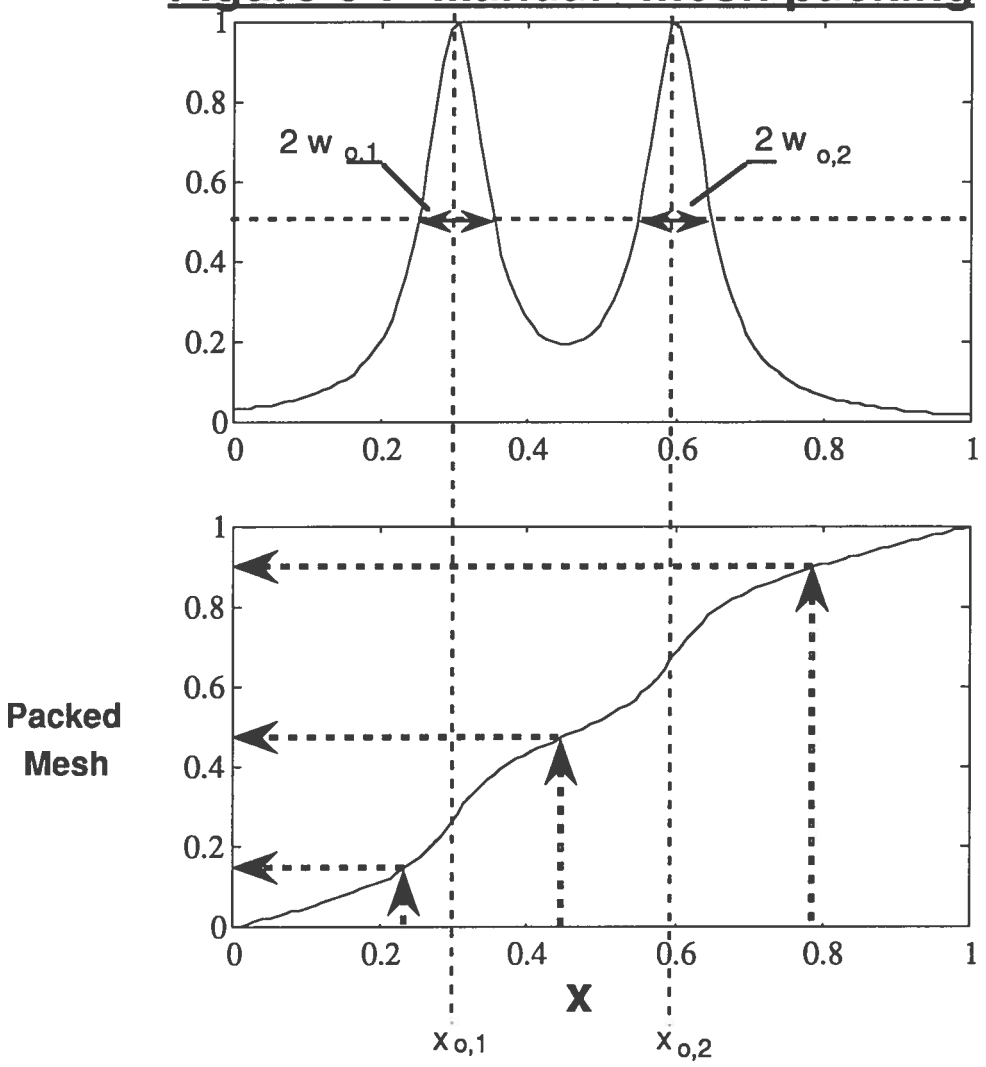
#### 5.1.1. Radial stability (s) mesh:

| | | |
|---|---|---|
| $x_{o,i}$ | <------> | APLACE(i), i=1,...,NPOIDA |
| $w_{o,i}$ | <------> | AWIDTH(i), i=1,...,NPOIDA |
| p | <------> | SOLPDA |
| N | <------> | NPOIDA ≤ **10** |

and

| | | |
|---|---|---|
| NMESHA | = 0 → | No packing on s mesh |
| NMESHA | = 1 → | s mesh packing is performed |

## Figure 3 : "Manual" mesh packing




### 5.1.2. s-mesh used for the definition of I* or <J.B>/<B.∇ϕ>:

$x_{o,i}$ <------> BPLACE(i), i=1,...,NPOIDB

$w_{o,i}$ <------> BWIDTH(i), i=1,...,NPOIDB

p <------> SOLPDB

N <------> NPOIDB ≤ **10**

and

NMESHB = 0 → No packing on I* or **<J.B>/<B.∇ϕ>** s-mesh

NMESHB = 1 → I* or **<J.B>/<B.∇ϕ>** s-mesh packing is performed

### 5.1.3. Radial equilibrium σ-mesh:

$x_{o,i}$ <------> CPLACE(i), i=1,...,NPOIDC

$w_{o,i}$ <------> CWIDTH(i), i=1,...,NPOIDC

p <------> SOLPDC

N <------> NPOIDC ≤ **10**

and

NMESHC = 0 → No packing on σ-mesh

NMESHC = 1 → σ-mesh packing is performed

### 5.1.4. Angular equilibrium θ-mesh:

$x_{o,i}$ <------> DPLACE(i), i=1,...,NPOIDD

$w_{o,i}$ <------> DWIDTH(i), i=1,...,NPOIDD

p <------> SOLPDD

N <------> NPOIDD ≤ **10**

and

NMESHD = 0 → No packing on θ-mesh

NMESHD = 1 → θ-mesh packing is performed

### 5.1.5. Angular stability χ-mesh:

$x_{o,i}$ <------> EPLACE(i), i=1,...,NPOIDE

$w_{o,i}$ <------> EWIDTH(i), i=1,...,NPOIDE

p <------> SOLPDE

N <------> NPOIDE ≤ **10**

and

NMESHE = 0 → No packing on χ-mesh

NMESHE = 1 → χ-mesh packing is performed

## 5.2. Automatic packing:

### 5.2.1. NMESHA=2: Packing on rational safety factor surfaces:

The method is the same as for the manual packing, but here the center of the Lorentzians are computed to fit with the rational safety factor surfaces. The corresponding Namelist variables are

$q_{o,i}$ <------> QPLACE(i), i=1,...,NPOIDQ
$w_{o,i}$ <------> QWIDTH(i), i=1,...,NPOIDQ
p <------> SOLPDA
N <------> NPOIDQ ≤ **10**

where N is the number of rational surfaces on which s is packed and $q_{o,i}$ the safety factor values on which s is packed. $w_{o,i}$ is the s-width of the Lorentzian i. p is the same weighting factor as before.

### 5.2.2. Densify radial stability mesh near plasma surface. NDIFPS=1:

This packing permits one to increase the density of the radial stability s-mesh close to the plasma surface. The s-mesh is computed in such a way that the generalized radius

$$\rho(s) = \sqrt{\frac{\int_{\psi-\psi_{min}}^{\psi}\int J\, d\chi\, d\psi}{\int\int J\, d\chi\, d\psi}}$$

is constant in every s-interval. This packing is performed if **NDIFPS = 1**.

**The different s-packing can be used simultaneously.**

### 5.2.3. Packing of angular equilibrium θ-mesh:

This packing permits to increase the density of the equilibrium θ-mesh in the region where plasma surface is elongated. Two options are available :

**1) NDIFT = 1 :** The θ-mesh is packed such that the flux area

$$A_i = \frac{1}{2}\int_{\theta_i}^{\theta_{i+1}} \rho_s^2(\theta)\, d\theta$$

is constant between to successive angular intervals on a constant σ-surface.

**2) NDIFT = 2 :** The θ-mesh is packed such that the arc length

$$A_i = \frac{1}{2}\int_{\theta_i}^{\theta_{i+1}} \rho_s(\theta)\, d\theta$$

is constant between to successive angular intervals on a constant σ-surface.

## 6.Equilibrium scaling laws

The equilibrium scaling rules are descibed in [1] Appendix B or [2] Section 2.5. First, the toroidal magnetic flux T is controlled by the Namelist variable NTMF0:

NTMF0 = 0→ $T_{surf} = 1$

NTMF0 = 1→ $T_o = 1$

Second, either the total current

$$I = \int_{\Omega} j_{\phi}\, d\Omega$$

or the safety factor

$$q(s_a) = \frac{T(s_a)}{2\pi} \int \frac{dl}{r|\nabla\psi|}$$

on some arbitrary radial flux coordinate $s_a$ can be specified:

**1) NCSCAL = 1 :** The safety factor is specified on $s_a$. The Namelist variables involved in this opreation are :

$s_a$ <------> CSSPEC

$q(s_a)$ <------> QSPEC

**2) NCSCAL = 2 :** The total current I is specified. The Namelist variable involved in this opreration is :

I <------> CURRT

**3) NCSCAL = 3 :** The safety factor is specified on $\rho_a$ where

$$\rho = \sqrt{\frac{V(\psi)}{V_{tot}}}$$

The Namelist variables involved in this opreation are :

$\rho_a$ <------> CSSPEC

$q(\rho_a)$ <------> QSPEC

**4) NCSCAL = 4 :** The equilibrium is not rescaled.

## 7.List of INCLUDE files :

### 7.1. Common blocks :

COMDIM.inc : PARAMETER's for array size definition.
COMBAL.inc : Ballooning quantities.
COMBLA.inc : Equilibrium matrix and RHS.
COMBND.inc : Plasma surface parameters.
COMCON.inc : Control parameter.
COMDAT.inc : Equilibrium Namelist.
COMERA.inc : Equilibrium quantities for ERATO.
COMESH.inc : Mesh quantities.
COMETA.inc : Equilibrium quantities for MARS.
COMINT.inc : Quantities on Gaussian quadrature points for equilibrium integration.
COMIOD.inc : Input/ouput control parameters.
COMISO.inc : Quantities on Gaussian quadrature points along iso-flux surfaces used for the computation of line integrals in the mappings.
COMLAB.inc : Labels of equilibrium.
COMMAP.inc : Values of line integrals computed in the mappings on the intersections of the equilibrium mesh with the constant flux surfaces.
COMNUM.inc : Size of arrays used for the computation.
COMPHY.inc : Physical quantities.
COMPLO.inc : Equilibrium plot quantities.
COMSOL.inc : Control quantities for the equilibrium solver.
COMSUR.inc : Constant flux surface quantities.
COMVAC.inc : Vacuum quantities for MARS.
COMVEV.inc : Quantities computed only for Solovev solutions.
NEWRUN.inc : ERATO Namelist.
PROCESS.inc : Free deck for IBM extended memory commands.

### 7.2.Statement functions decks:

BNDIND.inc : Perform band matrix numerotations.
CUCCCC.inc : Perform cubic Lagrange interpolations.
CUCDCD.inc : Perform cubic Hermite interpolations.
HERMIT.inc : Compute Hermite cubic basis functions.
QUAQDQ.inc : Perform quadratic interpolations using one derivative.
QUAQQQ.inc : Perform quadratic Lagrange interpolations.
SOLOV.inc : Compute analytic Solovev equilibrium.

## 8. List of input and output records :

### 8.1. Characteristics :

| File | Unit number | (default) | Format | Status |
|---|---|---|---|---|
| Namelist | 5 | 5 | Namelist | |
| Output | 6 | 6 | Formatted | Default |
| INP1 | INP1 | 46 | Unformatted | Default |
| JSOLVER | JSOLVER | 47 | Formatted | Default |
| NIN | NIN | 10 | Unformatted | Old |
| NOUT | NOUT | 11 | Unformatted | New |
| MEQ | MEQ | 4 | Unformatted | New |
| NDES | NDES | 16 | Unformatted | New for ERATO |
| | | | Formatted | New for MARS |
| NVAC | NVAC | 17 | Unformatted | New |
| NSAVE | NSAVE | 8 | Formatted | New |
| EQU01 | NO | 21 | Formatted | New |
| ETAVAC | NETVAC | 23 | Formatted | New |
| NUPLO | NUPLO | 33 | Formatted | New |
| EXPEQ | 48 | 48 | Formatted | Old |
| NPENN | NPENN | 49 | Unformatted | New |

An overview on these input/output operations in shown in Figure 6.

### 8.2. Content of I/O records

INP1 : Storage of equilibrium quantities for NOVA-W and PEST 3.4.
JSOLVER : Storage of equilibrium quantities for JSOLVER.
NIN : Used only if NOPT = 1. Read equilibrium.
NOUT : Storage of equilibrium
MEQ : Storage of EQ's for ERATO.
NDES : Storage of plot quantities required by ERATO and MARS.
NSAVE : Storage of equilibrium Namelist for ERATO.
NVAC : Storage of vacuum quantities for ERATO.
EQU01 : Storage of equilibrium quantities for MARS.
ETAVAC : Storage of vacuum quantities for MARS.
NUPLO : Storage of equilibrium plot quantities.
EXPEQ : Storage of equilibrium boundary and profiles given by experimental data.
NPEEN : Storage of equilibrium quantities for PENN.

## 8.3. Save an equilibrium with boundary and profiles given by points:

The data are saved into the file EXPEQ in the following format:

```
        write(NO,1000)  NBPS
        write(NO,1001) (RBOUND(K),ZBOUND(K),K=1,NBPS)
        write(NO,1000)  NPPF1,NPROPT
        write(NO,1002)  (FCSM(K),K=1,NPPF1)
        IF (NPPFUN .EQ. 4) write(NO,1002) (RPPF(K),K=1,NPPF1)
        IF (NFUNC .EQ. 4)   write(NO,1002) (RFUN(K),K=1,NPPF1)
1000    format(I5)
1001    format(2E18.8)
1002    format(1E18.8)
```

Depending on the value of NPROPT, TT', I* or <**J.B**>/<**B.**$\nabla\phi$> is save in RFUN.

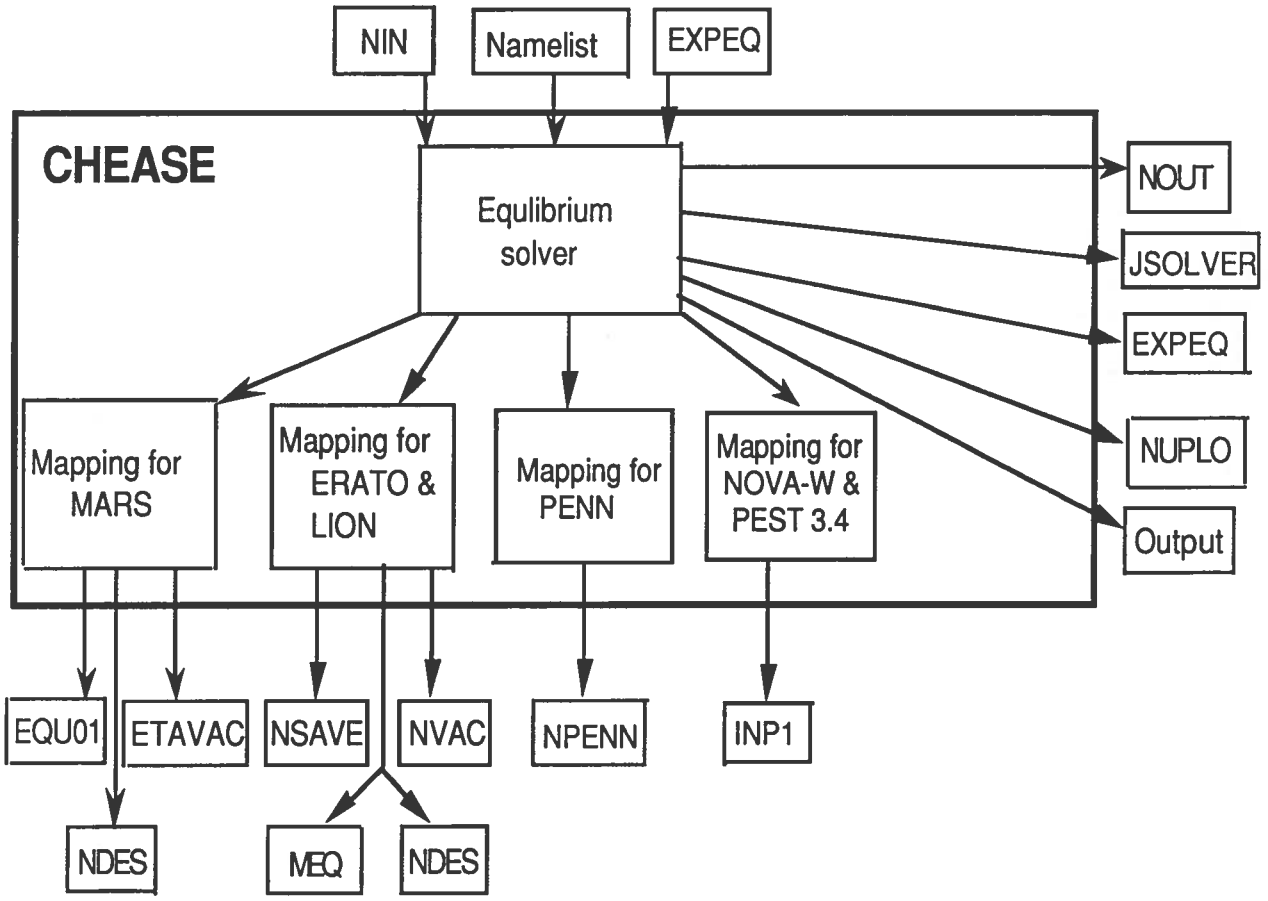
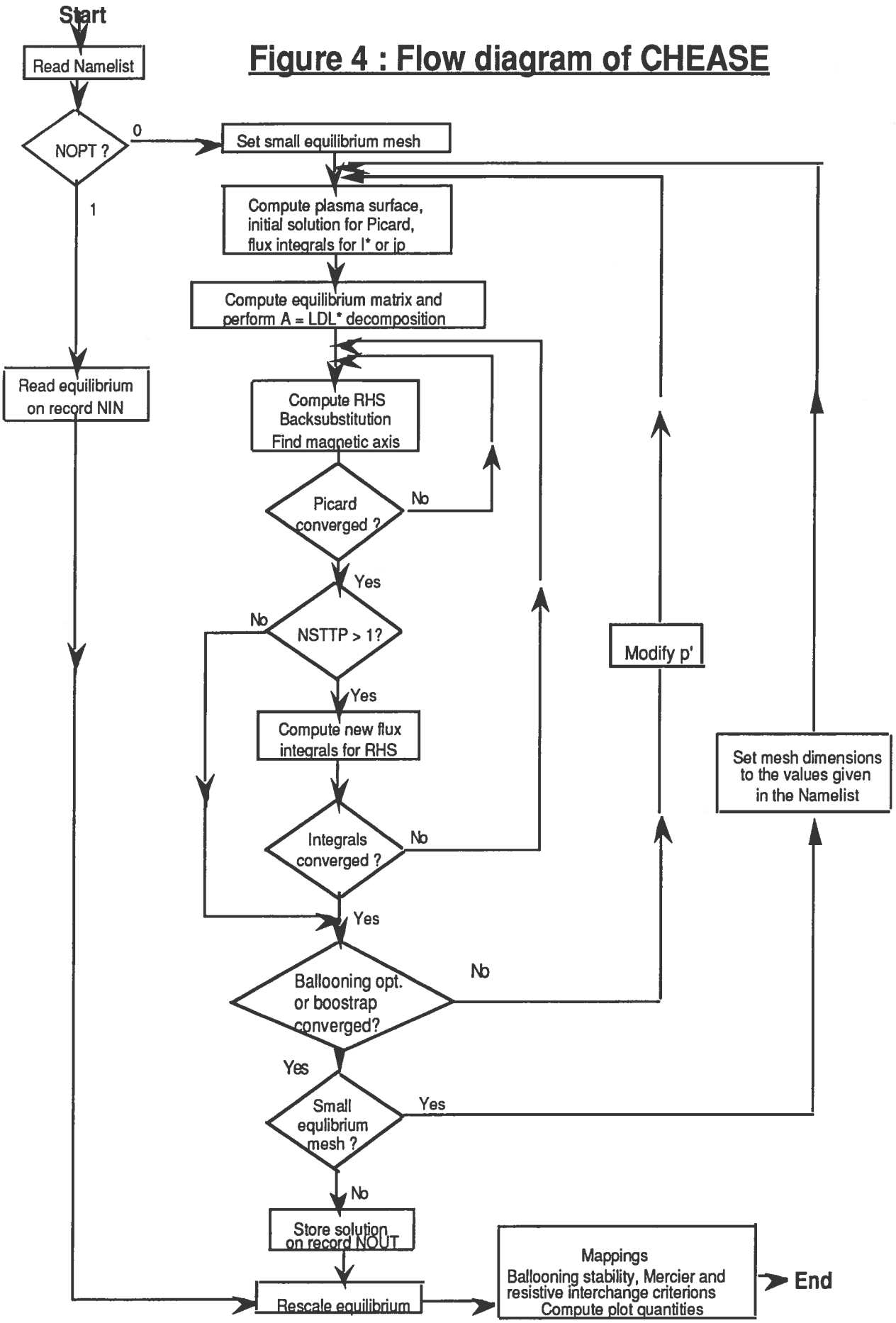



**Figure 6 : Input/output files**

# Figure 4 : Flow diagram of CHEASE



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