Chapter 14

MEAN DRIFT FORCES USING CONTROL SURFACES

Starting with V6.3, option .9c is included in WAMIT to evaluate the mean drift forces (and moments). In this option, the mean drift forces are evaluated from the momentum flux through a control surface surrounding the body. If IOPTN(9)>0 in the Force Control File, and ICTRSURF>0 in the Configuration File, the drift forces are evaluated both from the pressure-integration method (with output in the .9 numeric output file) and from the control-surface momentum-flux method (with output in the .9c file). When NBODY> 1, a control surface surrounding each body is required, and the drift force acting on each body is evaluated separately as in Option 9.

The advantages of using the control surface are i) all six components of the mean drift forces and moments, on a single body or on each body in the multiple body interaction, are evaluated as in the pressure integration, and ii) the computational results are more accurate than the pressure integration method when the body surface is not smooth, especially for bodies with sharp corners. The disadvantages are i) the user must specify the control surface as an additional input, and ii) the evaluation of the momentum flux at a sufficiently large number of field points on the control surfaces increases the run time of the FORCE module. This option is recommended when the accuracy of the mean forces and moments evaluated by pressure integration is uncertain, due to slow or lack of convergence with respect to the discretization of the body.

■ Starting with V6.4 it is possible to use two separate control surface files to represent the inner free surface and the remaining outer portion of the control surface. This procedure is described in Section 14.4 and illustrated in TEST13.

■ Starting with V6.4 it is also possible to define the control surface automatically. This procedure is described in Section 14.5 and illustrated in several test runs.

The drift forces and moments using a control surface are evaluated by one of two alternatives, depending on the integer parameter ICTRSURF in the configuration file. When ICTRSURF=1, Alternative 1 is used, based on equations (12.57) and (12.58) When ICTRSURF=2, Alternative 2 is used, based on equations (12.59) and (12.60). These two

alternatives are analytically equivalent. Alternative 1 is derived by transfer of the integral on the waterline (WL) in Alternative 2 to the line integral along the intersection of the free surface and the control surface (CL). Alternative 1 is generally more accurate for the horizontal forces and yaw moment, because it does not include a waterline integral. However, Alternative 2 must be used when CL is very close to the body. This is because the evaluation of the momemtum flux (pressure and/or velocity) very close to the body is either inaccurate or not possible. An example for which the Alternative 2 may be required is when the gap between two adjacent bodies is very small. The evaluations of the vertical drift force and horizontal components of the drift moment are identical in these two alternative methods.

To evaluate the mean drift forces and moments using this option, i) the parameter **ICTRSURF** must be specified in the CFG file, as explained in Section 3.7, and ii) the **CSF**(Control Surface File) defining the geometry of the control surface must be prepared. The CSF file must have the same filename as the corresponding geometric data file for the body, with the extension .csf, *i.e. gdf*.csf.

The control surface must be a closed surface surrounding the body in the fluid. In general, for a floating body which intersects the free surface, the control surface must start from the body's waterline, either extending outward on the free surface or downward away from the waterline into the fluid. Simple examples include a hemisphere or circular cylinder with sufficiently large dimensions so that the body is entirely within the interior of this surface, together with the intermediate portion of the free surface between the outer control surface and the body waterline. For multiple bodies, the control surface for each body should not include or intersect with other bodies, but it can intersect with other control surfaces.

In principle, the position and shape of the control surface are arbitrary. From a practical standpoint, the control surface should be sufficiently far from the body to ensure robust evaluation of the field velocity and pressure, but not so far as to require a very large number of field point evaluations. Simple geometrical description of the control surface is usually desirable.

If the Alternative 1 method is used, there is no contribution to the horizontal drift force and vertical drift moment from any part of the control surface that is in the plane of the free surface ($z = 0$). Thus, if these are the only required components of the drift forces, the control surface can be completely separated from the body surface without the need to include the intermediate portion of the free surface. This simplifies the definition of the control surface, especially for bodies with complicated geometry of the waterline. In addition, the numerical errors are generally smaller for field points that are not too close to the body surface.

■ If thin submerged elements are represented by dipole panels or patches, the mean drift force and moment cannot be evaluated by direct pressure integration on the body. The alternative method using a control surface is valid in this case, with some exceptions. If the dipole elements are entirely below the free surface, both Alternatives 1 and 2 can be used. If the dipole elements intersect the free surface, as in the case of the spar with helical strakes shown in Appendix A, Alternative 1 must be used and only the horizontal drift

force and vertical drift moment can be evaluated correctly.

∎ The drift force and moment evaluated using a control surface are defined in terms of the body coordinates, as in the case of direct pressure integration.

14.1 CONTROL SURFACE FILE (CSF)

The geometry of the control surface can be described in the same manner as the body geometry. Similar options exist to define the control surface, and different options can be used for the control surface and for the body. In the low-order method, specified by inputting the parameter ILOWHICSF=0 on line 2 of the CSF file, the control surface is described with quadrilateral panels in the same manner as is described for the body in Chapter 5. In the higher-order method, the parameter ILOWHICSF=1 on line 2 of the CSF file and the control surface is described in the same manner as is described for the body in Chapter 6, using any of the options available for higher-order representation of the body surface, including flat panels, B-splines, MS2 files and analytically using subroutines in GEOMXACT. The format of the CSF file is almost identical with the GDF file. The principal difference is on line 2, where the parameters ULEN and GRAV in the GDF file are replaced by ILOWHICSF. Also, when ILOWHICSF=1, the parameter PSZCSF is specified in the CSF file to control the accuracy of the numerical integration.

The control surface is defined in terms of the body coordinate system, and using the same unit of length. The normal vector is defined to point into the interior of the control surface (toward the fluid in the domain between the control surface and the body and toward the body). If part of the control surface coincides with the plane of the free surface, the normal on this surface is positive downwards.

The accuracy of the numerical integration of the momentum flux depends not only on the accuracy of the field quantities on the control surface, but also on the discretization of the control surface. If a low-order control surface is used, the integral of the momentum flux is calculated as the sum of the product of the flux at the centroid of each panel and the area of the panel. If a higher-order control surface is used, the control surface is subdivided into 'higher-order' panels. On each panel, the momentum flux is calculated based on third-order Gauss quadratures. The subdivision of each patch into panels is controlled by parameters NUC,NVC in the same way as the parameters NU,NV are used on the body surface (see Chapter 6).

The input files for the test runs 5, 13, and 22, shown in Appendix A, illustrate the different methods for defining the control surfaces, as noted below. As noted above, it is possible to use different values of ILOWHI and ILOWHICSF. In TEST05, which uses the low-order analysis for two bodies, the control surface around the cylinder is defined by low-order panels while the control surface around the spheroid is defined by the higher-order analytical method using a special subroutine in the GEOMXACT DLL file.

Since the description of the control surface in FORCE is completely separate from the solution in POTEN, arbitrary combinations of ILOWHI in POTEN and ILOWHICSF in FORCE can be used together. One or two planes of symmetry can be used to simplify

the definition of the control surface, even when the body is not symmetric with respect to the same plane(s). However the opposite is not true: if the body is defined with one or two planes of symmetry, the control surface must use the same plane(s) of symmetry. (The case NBODY>1 is an exception, since symmetric bodies are reflected and analyzed without any planes of symmetry; thus it is possible in this case to use a non-symmetric control surface with a symmetric body, but this is not likely to be useful.)

14.2   LOW-ORDER CONTROL SURFACE FILE

In the low-order method the control surface is represented by an ensemble of panels. The CSF file contains a description of this discretized surface in the same format as in the GDF file except that ULEN and GRAV are not specified in CSF.

The data in the CSF file can be input in the following form:

```
header
0 (ILOWHICSF)
ISXCSF ISYCSF
NPANCSF
X1(1) Y1(1) Z1(1) X2(1) Y2(1) Z2(1) X3(1) Y3(1) Z3(1) X4(1) Y4(1) Z4(1)
X1(2) Y1(2) Z1(2) X2(2) Y2(2) Z2(2) X3(2) Y3(2) Z3(2) X4(2) Y4(2) Z4(2)
.
.
.
.   .   . . . . . .   .   . . . . X4(NPANCSF) Y4(NPANCSF) Z4(NPANCSF)
```

'header' denotes a one-line ASCII header dimensioned CHARACTER∗72.

ISXCSF, **ISYCSF** are the geometry symmetry indices which have integer values 0 or 1. If ISXCSF and/or ISYCSF =1, $x = 0$ and/or $y = 0$ is a geometric plane of symmetry, and the input data are restricted to one quadrant or one half of the control surface. Conversely, if ISXCSF=0 and ISYCSF=0, the complete control surface must be represented by panels.

ISXCSF = 1: The $x = 0$ plane is a geometric plane of symmetry.
ISXCSF = 0: The $x = 0$ plane is not a geometric plane of symmetry.

ISYCSF = 1: The $y = 0$ plane is a geometric plane of symmetry.
ISYCSF = 0: The $y = 0$ plane is not a geometric plane of symmetry.

For all values of ISXCSF and ISYCSF, the (x, y) axes are understood to belong to the body system of the corresponding GDF file and the panel data are always referenced with respect to this system.

NPANCSF is equal to the number of panels with coordinates defined in this file.

XI(J), YI(J), ZI(J) are the Cartesian coordinates (x, y, z) of I-th vertex of the J-th panel. The four vertices of a panel are specified in the anti-clockwise direction when the panel is viewed from outside of the control surface, as in the case of the body surface illustrated in Figure 5.1.

Further description of the data in the CSF file can be found in Section 5.1, which describes the low-order GDF file.

14.3 HIGHER-ORDER CONTROL SURFACE FILE

In the higher-order method the first part of the CSF file is as follows:

```
header
1 (ILOWHICSF)
ISXCSF   ISYCSF
NPATCSF   ICDEF   PSZCSF
```

Subsequent data may be included in the CSF file after these four lines, depending on the manner in which the geometry of the control surface is represented, in the same manner as for the GDF file (See Sections 6.5-6.8.)

header, **ISXCSF** and **ISYCSF** are the same as those in the CSF file for ILOWHI=0 above.

NPATCSF is equal to the number of patches used to describe the control surface. If one or two planes of symmetry are specified, NPATCSF is the number of patches required to discretize a half or one quadrant of the whole of the control surface, respectively.

ICDEF is an integer parameter which is used to specify the manner in which the geometry of the control surface is defined. Four specific cases are relevant, corresponding respectively to the representations explained in Sections 6.5, 6.6, 6.7 and 6.8:

ICDEF = 0: The geometry of each patch is a flat quadrilateral, with vertices listed in the CSF file (cf. Section 6.5).

ICDEF = 1: The geometry of each patch is represented by B-splines, with the corresponding data in the CSF file (cf. Section 6.6).

ICDEF = 2: The geometry is defined by inputs from a MultiSurf .ms2 file (cf. Section 6.7).

ICDEF < 0 or > 2: The geometry of each patch is represented explicitly by a subroutine in the library GEOMXACT, with optional data in the CSF file (cf. Section 6.8).

In the last case (ICDEF < 0 or > 2), the parameter ICDEF is used in the same manner as IGDEF, to select the appropriate subroutine. Any of the existing subroutines which are normally used to define body geometry can be used to define the control surface, for example specifying ICDEF=-1 defines the control surface as a circular cylinder with specified radius and draft. It is important to use different subroutines for the body geometry and control surface, with ICDEF≠IGDEF. (The reason for this restriction is that, when parameters are input by the same subroutine from the GDF file and CSF file, these parameters may be overwritten. If it is desired to use the same subroutine for both geometries, a duplicate copy of the subroutine with a different name and assigned value of IGDEF should be added to GEOMXACT.)

PSZCSF is a parameter which controls the accuracy of the numerical integration over the control surface, in the same manner that PANEL_SIZE is used on the body (cf. Chapter 6). Thus the control surface is subdivided into elements with the approximate length scale of each element equal to PSZCSF. If the parameter PSZCSF is negative, the subdivision of the control surface is determined by the parameters NU,NV in the file *gdf*.CSP, in an analogous manner to the use of the same parameters in the spline control file *gdf*.SPL (Section 6.11). TEST22 is an example where the latter procedure is used.

14.4   COMBINING TWO CONTROL SURFACE FILES

In some cases it is convenient to use separate CSF files to represent the 'inner' part on the free surface and the 'outer' part which forms the remainder of the closed control surface below the free surface. For example, a low-order surface is generally used when the body surface is defined by low-order panels, in order to provide a good fit at the waterline. On the other hand, a higher-order outer surface has the advantage of more efficient integration using Gauss quadratures, to reduce the computational time. Thus, in this situation, it may be advantageous to use ILOWHICSF=0 for the inner free surface and ILOWHICSF=1 for the outer part of the control surface.

Starting with Version 6.4, it is possible to use two separate CSF files which have the formats and data described in Sections 14.2 and 14.3. In this case the file *gdf*.csf is input in the following form:

```
header
2          ILOWHICSF
fname1.csf
fname2.csf
```

Here `fname1` and `fname2` are the filenames of the two separate CSF files. Note that the special value ILOWHICSF=2 is used for this purpose. No other data should be included in this file. The two separate CSF files are as described in Sections 14.2 and 14.3, except that one file should represent only the inner free surface, and the other should represent

only the outer surface. Both surfaces should meet on the common outer waterline. The order of the two files is arbitrary, e.g. `fname1` and `fname2` can correspond to the inner and outer surfaces, or vice versa.

When two CSF files are used to represent one control surface, the symmetry indices ISXCSF and ISYCSF should be the same in both files. If ILOWHICSF=1 is used for one or both files, the parameter PSZCSF may be assigned independently in each file. If PSZCSF is negative, the optional .csp file should be used to assign the parameters NU,NV for the corresponding file. Note that the filename(s) of the .csp file(s) should be the same as `fname1` or `fname2`.

The output files described in Section 14.6 for visualization of the control surfaces and for low-order control surfaces correspond to the complete control surface, with the same filename as the gdf file. Thus these output files are the same as in the case where only one CSF file is used.

14.5 AUTOMATIC CONTROL SURFACES

For bodies with 'regular' waterlines it is possible to define the control surface automatically, during the run. The higher-order option ILOWHICSF=1 must be specified for the control surface, but either the low-order (ILOWHI=0) or higher-order (ILOWHI=1) options can be used for the body geometry and solution. When this procedure is used the outer part of the control surface is defined either as a circular cylinder of specified radius and depth, or by a quadrilateral 'box', usually rectangular, with specified waterline and depth. The intermediate free surface, between this outer boundary and the body waterline(s), is defined by first tracing the waterlines and then establishing appropriate patches to cover the area of the free surface between the waterlines and the outer boundary. This procedure can be used with multiple waterlines, as in the case of a TLP, semi-sub, or catamaran. However it may fail in some cases where the waterlines are irregular, and it is advisable to confirm the representation of the resulting control surface by plotting the data in the auxiliary file *gdf*_**csf.dat**.

Examples of 'irregular' waterlines where the automatic option may fail include: (1) locally concave waterlines, (2) moonpools, (3) bodies with thin elements (dipole patches) which intersect the free surface (e.g. TEST21), and (4) bodies with horizontal patches or panels in the plane of the free surface.

In cases where only the horizontal components of the drift force and vertical component of the drift moment are required, the intermediate free surface can be omitted as explained below. The option to use two separate CSF files, described in Section 14.4 above, should not be used for automatic control surfaces.

When automatic representation of the control surface is requested, special values must be assigned to the parameters NPATCSF and ICDEF, as defined below, and the complete CSF file should be of the following format:

`header`

```
1 (ILOWHICSF)
ISXCSF  ISYCSF
NPATCSF  ICDEF  PSZCSF
RADIUS  DEPTH
NPART
NV(1)
X(1,1) Y(1,1)
X(1,2) Y(1,2)
.
.
.
X(1,NV1) Y(1,NV1)
NV(2)
X(2,1) Y(2,1)
X(2,2) Y(2,2)
.
.
.
X(2,NV2) Y(2,NV2)
NV(NPART)
X(NPART,1) Y(NPART,1)
X(NPART,2) Y(NPART,2)
.
.
.
X(NPART,NV1) Y(NPART,NV1)
```

The symmetry indices **ISXCSF** and **ISYCSF** must be the same as those in the GDF file for the same body. (If not, a warning message is issued and the CSF indices are replaced by the body indices.)

NPATCSF must be equal to zero or less than zero:

NPATCSF=0: the control surface is automatic and includes the intermediate free surface

NPATCSF<0 the control surface is automatic and the intermediate free surface is omitted

ICDEF must be equal to zero:

ICDEF=0: the control surface is automatic

RADIUS is the parameter which controls the radius of a circular outer surface, or specifies that the outer surface is quadrilateral:

RADIUS>0: the outer surface is a circular cylinder of this radius

RADIUS≤0: the boundary of the outer surface is quadrilateral with NV(1) vertices specified by the coordinates (X(1,n), Y(1,n)) (n=1,2,...,NV(1)).

DEPTH is the depth of the control surface. This must be a positive real number, greater

than the maximum depth (draft) of the body.

NPART is an integer which specifies the number of partition boundaries. Each partition boundary includes NV vertices, defined by the coordinates X,Y. Partition boundaries are required for two possible purposes, (a) to define the outer boundary of a quadrilateral control surface, and (b) to separate multiple waterlines. If the body has only one waterline and the outer boundary is circular, NPART=0. If the body has only one waterline and the outer boundary is a quadrilateral, NPART=1. When the outer boundary is a quadrilateral its vertices must be defined by the first partition, with NV(1) vertices, and other partition boundaries (if any) must be included after this in the file. Several examples of .csf files are included below to illustrate the use of partition boundaries. (Header lines are omitted for brevity.)

Example 1: single waterline with circular outer boundary, as in TEST05c and TEST13c:

```
1            ILOWHICSF
1  1         ISX  ISY
0  0  1.     NPATCH  ICDEF  PSZCSF
1.2 2.2      RADIUS, DEPTH
0            NPART
```

Example 2: single waterline with quadrilateral outer boundary, as in TEST05s and TEST13s:

```
1              ILOWHICSF
1  1           ISX  ISY
0  0  0.5      NPATCH  ICDEF  PSZCSF
0.0   0.3      RADIUS, DEPTH
1              NPART
3              NV(1)
2.2  0.0
2.2  0.3
0.0  0.3      (X,Y coordinates of three vertices)
```

Note in Example 2 the partition boundary is specified only in quadrant one, since ISX=1 and ISY=1. The first vertex is on the $+x-$axis, the second vertex is above the first, and the third vertex is on the $+y-$axis to close the partition and surround the body waterline. The order of the vertices is such that they follow a counter-clockwise progression around the body with increasing polar angle relative to a point inside the body.

Example 3: four waterlines, one in each quadrant, with circular outer boundary, as in TEST07 and TEST14 (TLP with four columns):

```
 1   ILOWHICSF
 1  1          ISX  ISY
 0   0  10. NPATCH  ICDEF  PSZCSF
85.0  40.0    RADIUS, DEPTH
 1   NPART
 3   nv1
  0.0  50.0
  0.0  0.0
 30.0  0.0  (X,Y coordinates of vertices)
```

In this case the partition boundary is required to separate the waterline in quadrant one from the other three waterlines of the TLP. The partition boundary is down, along the $+y-$axis, and then to the right along the $+x-$axis. This example illustrates a useful feature that the outermost points do not need to intersect the outer boundary; the program extends or reduces the first and last segments automatically, to intersect the outer boundary (the inputs 50.0 and 30.0 could be replaced by any positive numbers).

Example 4: ten waterlines, two and a half in each quadrant, with rectangular outer boundary, as in TEST15 (semi-sub with a total of ten columns):

```
1              ILOWHICSF
1  1           ISX  ISY
0   0  10.  NPATCH  ICDEF   PSZCSF
0.0  40.0   RADIUS, DEPTH
 4   NPART
 3   NV(1)
 150.0   0.0
 150.0  60.0
   0.0  60.0   end of partition 1 (outer boundary of control surface)
 3   NV(2)
  0.0  0.0
 30.0  0.0
 30.0  50.0   end of partition 2 (encloses middle half-column)
 4   NV(3)
 30.0  50.0
 30.0  0.0
 90.0  0.0
 90.0  50.0   end of partition 3 (encloses second column)
 3   NV(4)
 90.0  50.0
 90.0  0.0
 150.0  0.0   end of partition 4 (encloses third column)
```

In this case the first partition boundary defines the outer rectangular boundary of the control surface, and the other three are required to separate the waterlines in quadrant one. Note that partition 2 starts at the origin in this case, without a segment along the $y-$axis, since only half of the middle column is in the first quadrant and the images of both the body and partition form a closed waterline and partition. As in Example 3 the outermost points do not need to intersect the outer boundary; the program extends or reduces the first and last segments automatically, to intersect the outer boundary (the inputs 50.0 are replaced by 60.0). For the last vertex (150, 0) the X-coordinate could be replaced by any value greater than 90.0. All four partitions obey the 'counter-clockwise rule' with respect to their domains. Also note that they completely define the interior free surface, without gaps or overlap. In this example, if only the horizontal drift forces and vertical drift moment were required, one could assign NPATCH=-1 and NPART=1, and omit all but the first partition.

Example 5: Monohull with one plane of symmetry, as in TEST22 (FPSO with internal tanks) using a rectangular outer control surface:

```
1              ILOWHICSF
1  1           ISX  ISY
0   0  2.      NPATCH  ICDEF  PSZCSF    (1st two indicate this is automatic)
 1   NPART
 4   nv0
 12.0   0.0
 12.0   3.0
-12.0   3.0
-12.0   0.0
```

In this case the outer rectangular boundary has four vertices, starting on the $+x$ axis and ending on the $-x$ axis.

14.6   OUTPUT

The mean forces and moments using a control surface are output in the OUT file and in the numeric output file optn.**9c**   (or *frc*.**9c**) in the same format as optn.9.

When IPLTDAT> 0 in the CFG file, the auxiliary file *gdf*_**csf.dat** is output. This can be used for visualization of the control surface, using TecPlot or other similar programs. As in the case of the corresponding data files for visualizing the body surface, there is only one output file when NBODY>1 with the filename associated to the first body.

When ILOWHICSF= 1 and ILOWGDF> 0 in the CFG file, the file *gdf*_**low.csf** is output. This contains the data of the control surface in the low-order form described in Section 14.2.

TEST05, TEST13 and TEST22 show examples of using the control surface in the evaluation of the mean forces and moments.