Chapter 13

THE F2T UTILITY

The Fortran utility F2T (Frequency-to-Time-domain) is a post-processor to transform frequency-domain WAMIT output to time-domain impulse-response functions (IRFs). This program is intended to provide a utility which can be used for general purposes, based on standard WAMIT outputs. This program accepts as input all of the first-order (linear) outputs from WAMIT, including any combinations of Options 1-7 (added mass/damping, Haskind exciting forces, Diffraction exciting forces, RAO's, body pressures/velocities, field-point pressures/velocities). In principle there are no restrictions regarding the numbers of rigid-body modes, generalized modes, or bodies. The computed IRFs are saved in output files which are analogous to the input files for each option and use the same filename extensions.

The Fourier transforms from the frequency-domain to the time-domain are evaluated in F2T by Filon numerical integration. This method provides relatively accurate results for large values of the time variable t. A fundamental requirement is that the frequency-domain data must be evaluated by WAMIT for a large number N of uniformly-spaced frequencies ω_n where n=1,2,3,...,N. Special attention is necessary to ensure that the increment $\Delta\omega = \omega_{n+1} - \omega_n$ is sufficiently small (to preserve the accuracy of the numerical integration) and that the highest finite frequency ω_N is sufficiently large to span the physically-significant range of frequencies for the application (or from the mathematical standpoint, to ensure that the truncated Fourier integrals are reasonable approximations of the infinite integrals). In view of the need to include high frequencies in the WAMIT analysis it is usually advisable to use the irregular-frequency option (IRR=1), unless the body is submerged or its waterplane area is very small. The requirement of accuracy over a broad range of frequencies means that either a large number of low-order panels should be used, or alternatively that the higher-order method is used with appropriate control of the panel subdivision indices NU,NV or the global parameter PANEL_SIZE.

Reference [26] contains illustrative results from the use of F2T, including comparisons with the results from the time-domain panel program TiMIT.

13.1 DEFINITIONS OF RADIATION AND DIFFRACTION OUTPUTS

The outputs from WAMIT and F2T are considered to be of either the radiation or diffraction type, depending on whether they are caused by forced motions in calm water or by incident waves, respectively. The simplest physical distinction between these two types is in terms of the incident wave amplitude: if the response is proportional to the wave amplitude it is of the diffraction type, and vice versa.

The added-mass and damping coefficients (Option 1) are of the radiation type, whereas the exciting forces and RAO's (Options 2,3,4) are of the diffraction type. Except as noted in Section 13.5, the pressures and fluid velocities on the body (Option 5) and in the fluid (Options 6,7) are of the diffraction type, since these are defined in the WAMIT convention as total responses with the body free to respond (or fixed) in incident waves.

A fundamental distinction between the two types of outputs is in terms of their limits at infinite frequency or zero period. In this limit the radiation outputs are generally real and nonzero, corresponding to the added mass, pressure, and fluid velocity induced by forced motions of the body without wave effects on the free surface. Conversely, in the same limit there are no diffraction effects since the 'incident waves' have vanishingly small wavelength and cause no disturbance of either the body or the fluid.

When radiation IRFs are evaluated it is necessary to evaluate the corresponding frequency-domain coefficients for $\omega_0 = 0$ and $\omega_{N+1} = \infty$, using the special instructions in the WAMIT User Manual (Section 3.1, page 3-9 of the V6.1 User Manual). Thus, in V6.1, two WAMIT runs are required. V6.1 also restricts the $\omega_0 = 0$ and $\omega_{N+1} = \infty$ evaluations to Option 1, so that V6.1 cannot be used with F2T to analyse radiation type outputs in Options 5,6,7. WAMIT V6.2 removes this restriction, and will also permit the analysis of all frequency-domain outputs to be made in a single run. To simplify the instructions below, Version 6.2 or higher is assumed, and instructions are given for making only one WAMIT run. (Users of V6.1 should make two separate runs, one for finite wave periods and one for zero and infinity, and for the latter only Option 1 should be specified.)

13.2 ACQUIRING INPUT DATA FOR F2T WITH WAMIT

The frequency-domain input data for F2T is evaluated by WAMIT. The algorithms used to evaluate the Fourier transforms in F2T require that the input data is restricted to a uniformly-spaced set of frequencies $\omega_n = n\Delta\omega$, where (n=1,2,3,...,NPER), augmented by the limiting frequencies 0 and ∞. In the WAMIT run this is done most easily by setting the parameter IPERIO=2 in the configuration file (inputs are radian frequencies), and by using the option to write the data -NPER and ω_1, $\Delta\omega$ on the lines normally used to specify NPER and the array PER. The simplest procedure is to make one run, with $\omega_1 = -\Delta\omega$, so that both infinite and zero wave periods are included in the run. (Note in this case that NPER must include the total number of wave periods including zero and infinity.)

The input files used for the tests of the ISSC TLP can be regarded as an example. These files are listed in Appendix A14a. They are essentially the same as for TEST14, with the exception of IPERIO=2 in TEST14.CFG, and the specification of the input frequencies.

When the input files to F2T are read, the data is sorted so that the frequencies are listed in ascending order, regardless of their order in the WAMIT output files. Thus the order of the periods (-1.0, 0.0) is irrelevant, and it is possible to patch together two or more separate sets of output files from WAMIT, e.g. one with a coarse set of wave frequencies and the other with intermediate frequencies, to provide a finer set, without concern regarding their order.

13.3 HOW TO USE F2T

The program F2T can be executed after the appropriate WAMIT output files are available. The user must specify the filenames of these files and a small number of input parameters, either interactively in response to appropriate runtime prompts or by preparing the special input file `inputs.f2t`. The following example of this special input file corresponds to the TEST14a test run described above:

```
header line for inputs.f2t control file, TLP example
TEST14a
0 0 1 (IRAD IDIFF NUMHDR)
0 0 0 (INUMOPT5 INUMOPT6 INUMOPT7)
0.2 100 (DT NT time step and number of time steps)
0 (IOUTFCFS, output both cosine and sine transforms)
43.125 9.80665 ULEN GRAV
```

These inputs are described for each line as follows:

Line 1 is an ASCII header dimensioned CHARACTER*72 as in most WAMIT input files. This line should be used to insert a brief description of the file.

Line 2 is a list of the filenames (not the extensions) of the primary and secondary WAMIT output files. F2T attempts to open all numeric output files with the same filenames, and includes all of these files in the analysis. Thus the determination of which options to be included depends on the available WAMIT output files. In this example where the TEST14.FRC control file was used as in the standard WAMIT test runs, Options 1,2,3,4 will be included in the F2T analysis. If all of the input data is included in the primary file it is not necessary to list other filenames. Additional secondary files can also be included, up to a maximum limit of 256 ASCII characters for the complete line. At least one blank space must be used to separate each filename.

Lines 3 and 4 contain the six WAMIT control parameters identified by the comments in parenthesis. These parameters must have the same values as in the WAMIT runs. (No distinction is made between IRAD,IDIFF=0 or 1, and the only important value to specify correctly is -1. For any input values of IRAD,IDIFF other than -1 the results are the same as for 0 or 1.) NUMHDR, which is optional in WAMIT with the default value 0, must be specified heree with the value 0 (no headers) or 1 (one line of headers) to indicate the presence or absence of a header line in the WAMIT numeric output files. INUMOPT5, the optional configuration parameter introduced in WAMIT Version 6.1 to permit outputting separate components of the body pressure and velocity, and also INUMOPT6, INUMOPT7 introduced in Version 6.2 must be specified here with the value 0 (default in WAMIT) or the separate-components values 1.

Line 5 contains the time step and number of time steps for the computation and tabulation of the time-domain response functions. The radiation IRF'S are computed and tabulated for t=0 and for NT positive times DT, 2DT, 3DT, ..., NT∗DT. The diffraction IRFs are evaluated for both positive and negative times, starting with −NT∗DT and ending with +NT∗DT.

Line 6 contains the optional parameter IOUTFCFS, with the following options for its value:

IOUTFCFS=1: output only the cosine transform of radiation irf's

IOUTFCFS=2: output only the sine transform of radiation irf's

IOUTFCFS=0 (or any other integer except 1 or 2): output both cosine and sine transforms

(These transforms are redundant, as explained below.) The default value IOUTFCS=0 is used if line 6 is missing from the file. Thus the use of this parameter is optional.

Line 7 contains the optional parameters ULEN and GRAV, which are the same characteristic length scale and gravitational acceleration parameters as input in the GDF file. These parameters are only required when Options 5, 6, or 7 are included, and when the radiation outputs are specified, as explained in Section 13.5 below. In all other circumstances the parameters ULEN and GRAV can be omitted from `inputs.f2t`. **When ULEN and GRAV are included in `inputs.f2t` it is essential to also include IOUTFCS on line 6.**

The use of the special file `inputs.f2t` is optional. If this file does not exist, or if the first five lines cannot be read with the appropriate data, the user is prompted to specify all of the above inputs interactively. The special file can also be used in a partial form with some but not all of the above lines, but the lines included must be in the same order as above. This permits the user to interactively input different values of the time step and number, simply by omitting Line 5 from the special file.

The numeric data in the special file is read with free format READ statements, separately for each line. Any additional text on the same lines is ignored, so that comments may be inserted as in the example above. The filenames on Line 2 are read as ASCII text of unknown length (maximum of 256 characters, all on one line) and no additional comments may be included on this line.

13.4 OUTPUT FILES

The output files from F2T are in two complementary formats with duplication of the output data in the two formats. The filename assigned to all of the output files is *primary*, with different extensions. The first set of output files have appended filenames including _IR followed by the same extensions as the WAMIT output files. The second set have the appended filenames including _JR. The first set follow the same format as the WAMIT numeric output files of the same number, except that the period is replaced by the time step and the WAMIT force coefficients are replaced by their Fourier cosine and sine transforms. Different modes and mode combinations are listed on separate lines with the identifying mode indices, just as in the numeric output files of WAMIT.

To facilitate plotting and separation of the different modes and wave angles (BETA), all of the Fourier cosine/sine transforms are listed on one line in the output files denoted by _JR, in the same order of mode combinations but without explicit mode indices. The cosine/sine transforms are listed as pairs, unless one or the other is ommitted by setting IOUTFCFS equal to 1 or 2 as explained in the following paragraph. Column one of the _JR file contains the value of time t.

Either the cosine transforms of the added mass or the sine transforms of the damping can be used to evaluate the radiation IRFs (cf. equations 3 and 4 below). These two sets of data can be checked to verify their accuracy and consistency, in much the same way that the Haskind and Diffraction exciting forces or cross-coupling coefficients are compared. Alternatively, to achieve more compact output files, one of these transforms can be omitted using the parameter IOUTFCFS.

One more output file is produced with the extension .KR1, containing the impulse-response functions K_{ij} which are evaluated in TiMIT. These alternative IRF's are evaluated in F2T by numerical differentiation of the IRF's L_{ij} which are defined below.

The diffraction files _JR are different from the radiation files in two respects, to facilitate their use. First, the time steps begin with −NT∗DT, and end with +NT∗DT. Secondly, the cosine and sine transforms are combined (adding for $t < 0$ and subtracting for $t > 0$) to give the actual IRFs for the corresponding exciting forces and RAOs (cf. equation 8 below).

For practical purposes the .JRn files will be most useful, and the .IRn files may be useful only to clarify the identity of the different columns in the .JRn files.

Some experience and/or trial computations will be needed to determine appropriate values of the input frequencies and time steps. The dimensions of these parameters correspond to GRAV in the WAMIT run.

13.5 OPTIONS 5,6,7

The F2T utility has been developed primarily for use with Options 1 to 4 (global forces and RAO's). Local pressures, velocities, and wave elevations have not been tested, and these may be difficult to transform accurately, due to limited or non-convergence of the Fourier transforms at high frequencies.

If IDIFF=−1 is specified in the WAMIT run, signifying that there are no incident waves, the outputs from Options 5,6,7 are the total responses from superposition of all specified radiation modes; in this case all of the available outputs are of the radiation type. In this case, if more than one mode is considered, the output is for nonzero finite frequencies only and is not suitable for transform to the time domain. If the configuration parameters INUMOPT5, INUMOPT6, INUMOPT7 = 1 in the WAMIT run, the corresponding Option 5,6,7 outputs are separated into radiation components for each mode of forced motion plus the diffraction component, as explained in Sections 4.9 and 4.12; in this case F2T analyses the radiation components and diffraction components separately, according to their types.

13.6 THEORY

The fundamental relations between the time- and frequency-domain express the added-mass coefficient A_{ij} and damping coefficient B_{ij} in terms of Fourier transforms of the impulse-response function $L_{ij}(t)$:

$$A_{ij}(\omega) - A_{ij}(\infty) = \int_0^\infty L_{ij}(t)\cos\omega t\,dt \tag{13.1}$$

$$B_{ij}(\omega) = \omega\int_0^\infty L_{ij}(t)\sin\omega t\,dt \tag{13.2}$$

The inverse-transforms of (13.1-2) give complementary relations for the impulse-response function:

$$L_{ij}(t) = \frac{2}{\pi}\int_0^\infty [A_{ij}(\omega) - A_{ij}(\infty)]\cos\omega t\,d\omega \tag{13.3}$$

$$L_{ij}(t) = \frac{2}{\pi}\int_0^\infty \frac{B_{ij}(\omega)}{\omega}\sin\omega t\,d\omega \tag{13.4}$$

Similar relations exist for the exciting forces and RAOs. Define one of these quantities by the complex function $X_i(\omega)$ The corresponding impulse-response function is real, denoted by $K_i(t)$. The appropriate physical ranges are $(0 \le \omega < \infty)$ and $(-\infty < t < \infty)$. Then the complex Fourier transform pairs are as follows:

$$X_i(\omega) = \int_{-\infty}^\infty K_i(t)\mathrm{e}^{-i\omega t}\,dt \tag{13.5}$$

and

$$2\pi K_i(t) = \int_{-\infty}^\infty X_i(\omega)\mathrm{e}^{i\omega t}\,d\omega \tag{13.6}$$

Formally, since K_i is real, $X_i(-\omega) = X_i^*(\omega)$, and thus

$$2\pi K_i(t) = \int_0^\infty \left[X_i(\omega)\mathrm{e}^{i\omega t} + X_i^*(\omega)\mathrm{e}^{-i\omega t}\right]\,d\omega \tag{13.7}$$

or

$$K_i(t) = \frac{1}{\pi}\int_0^\infty [\mathrm{Re}(X_i)\cos\omega t - \mathrm{Im}(X_i)\sin\omega t]\,d\omega \tag{13.8}$$

The principal task is to evaluate (13.3), (13.4), and (13.8). This is done by truncating the infinite integrations at the largest value of the evaluated frequency, and using Filon quadratures to evaluate the resulting finite integrals. A truncation correction is derived below, and applied to (13.3).

Usually the most significant truncation error is associated with the transform of the added-mass (13.3). From partial integration of (13.1) it follows that

$$A_{ij}(\omega) - A_{ij}(\infty) = -\frac{1}{\omega}\int_0^\infty L'_{ij}(t)\sin\omega t\,dt \simeq -L'(0)\omega^{-2} \tag{13.9}$$

where the neglected integral is of order ω^{-3}. If (13.3) is truncated at a finite frequency $\omega_N = \Omega$, the truncation correction is

$$\Lambda_{ij}(t) = \frac{2}{\pi}\int_\Omega^\infty [A_{ij}(\omega) - A_{ij}(\infty)]\cos\omega t\,d\omega \tag{13.10}$$

This can be approximated, using (13.9), if Ω is sufficiently large:

$$\Lambda_{ij}(t) \simeq -\frac{2}{\pi}L'_{ij}(0)\int_\Omega^\infty \omega^{-2}\cos\omega t\,d\omega = -\frac{2}{\pi\Omega}L'_{ij}(0)\,[\cos\Omega t + \Omega t\,\mathrm{si}(\Omega t)] \tag{13.11}$$

Here we follow the notation of Abramowitz & Stegun (equation 5.2.26) for the sine integral

$$\int_z^\infty \frac{\sin t}{t}dt = -\mathrm{si}(z)$$

The constant $L'_{ij}(0)$ can be evaluated from the fact that $L_{ij}(0) = 0$, and thus

$$\Lambda_{ij}(0) = -\frac{2}{\pi}\int_0^\Omega [A_{ij}(\omega) - A_{ij}(\infty)]\;d\omega \simeq -\frac{2}{\pi\Omega}L'_{ij}(0) \tag{13.12}$$

Combining (13.11) and (13.12) gives the truncation correction in (13.10) in the form

$$\Lambda_{ij}(t) \simeq -\frac{2}{\pi}\,[\cos\Omega t + \Omega t\,\mathrm{si}(\Omega t)]\int_0^\Omega [A_{ij}(\omega) - A_{ij}(\infty)]\;d\omega \tag{13.13}$$

However this procedure suffers from the slow algebraic convergence of the last integral. An alternative procedure, which is adopted in F2T, is based instead on diffentiating (13.4) to give the relations

$$L'_{ij}(0) = \frac{2}{\pi}\int_0^\infty B_{ij}(\omega)\,d\omega \simeq \frac{2}{\pi}\int_0^\Omega B_{ij}(\omega)\,d\omega \tag{13.14}$$

$$\Lambda_{ij}(t) \simeq -\frac{4}{\pi^2\Omega}\,[\cos\Omega t + \Omega t\,\mathrm{si}(\Omega t)]\int_0^\Omega B_{ij}(\omega)\,d\omega \tag{13.15}$$

Equations (13.12) and (13.14) are complementary, but (13.14) is more robust since the integrand of (13.14) is positive-definite and converges to zero more rapidly than the integrand of (13.12).

13.7 DIMENSIONAL INPUT AND OUTPUT DATA

In the WAMIT output files all of the output data is nondimensional, except for the wave period. Definitions of the nondimensional outputs are given in Chapter 4. The wave period, usually defined in seconds, has the same dimension as $\sqrt{ULEN/GRAV}$, where the parameters ULEN and GRAV are input in the GDF file. Since the hydrodynamic force coefficients and other outputs from WAMIT are nondimensional, and the frequency ω has the dimension of inverse time, it follows that the impulse response functions defined by equations 13.3, 13.4 and 13.8 are all dimensional, with the dimension of inverse time. The additional impulse-response functions in the output file .KR1, defined as the time-derivatives of the IRF's L_{ij}, have the dimension of inverse time squared.

When nondimensional outputs are required from F2T this can be achieved most conveniently by setting ULEN=1.0 and GRAV=1.0 in the GDF inputs to the WAMIT run.