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INTERNAL DOCUMENT 131

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SELECTED DIRECTIONAL WAVE SPECTRA
FOR USE IN THE ASSESSMENT OF
WAVE ENERGY CONVERTOR PERFORMANCE

Internal Document 131

J A CRABB

NATURAL ENVIRONMENT RESEARCH COUNCIL
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INTRODUCTION

In response to requests for a small number of directional wave spectra to be offered for use in device tank test programmes, an attempt has been made to select a smaller subset from the 399 South Uist synthesized directional spectra. (WESC (79) DA90, WESC (80) DA 111).

To this end, five parameters summarizing the main properties of each of the 399 were calculated. It was found that the individual parameters covered a wide range of values and combined in individual spectra to produce a wide diversity of spectral types. It has consequently proved impossible to derive a significantly smaller set which adequately covers the range of each of the five parameters in realistics combination with each of the other four.

Since this direct attempt to reproduce the statistics of the set of 399 in a more manageable form was not successful two further approaches, which represent compromises on the original intention, were pursued. These have resulted in two overlapping subsets of approximately 40 spectra each.

THE DESCRIPTIVE PARAMETERS

The parameters by which each spectrum is described were chosen for their simplicity and ease of interpretation, they are described below:

Energy Period (TE) — Defined as the ratio M_{-1}/Mo, where M_n is the nth moment of the one dimensional variance spectrum E(f)

$$M_n = \int_{f_1}^{f_2} f^n . \; E(f) . \; df$$

$$f_1 = 0.0444 \text{ Hz}, \quad f_2 = 0.6401 \text{ Hz}$$

Power (P) — total intergrated power between f_1 and f_2 calculated according to the full (depth corrected) expression.

Frequency Width (FW)	the frequency interval within which 80% of the power is found; ie excludes the two 10% portions of the power at the highest and lowest frequencies
Direction Width (DW)	the angular interval within which 80% of the power in the 80% frequency interval is found; ie excludes the two 10% portions of the power found in the angular intervals immediately North and South of due East (90°).
Peak Direction (DP)	the direction associated with the most powerful spectral component.

CLASSIFICATION OF SPECTRA-GENERAL

Values of each of the five parameters were calculated for each spectrum and the spectra were sorted into classes according to the values of the three parameters DW, TE and FW. Within each of these classes the spectra were subdivided into classes of power. The spectra were not further subdivided by DP.

At this point it was apparent that the range of spectral types was too great to be adequately represented in a subset of some 40 spectra. Even by effectively excluding one of the parameters (DP) and using moderately broad class widths for the remainder, some 165 occupied classes resulted requiring a minimum of one spectrum to represent each.

The only practical way round this difficulty appeared to lie in setting a number of limited objectives and attempting to select spectra to satisfy these separately. The objectives defined were:

1. To produce a set of approximately 40 spectra covering as wide a range as possible of the three parameters DW, TE and FW,whilst deliberately restricting the ranges of P and DP as described later.

2. To produce a set of approximately 40 spectra covering as wide a range as possible of the four parameters DW, TE, FW and P associated with those spectra which contribute the bulk of the energy arriving at South Uist (DP again restricted).

The process whereby these spectra were selected is detailed in the following section and further amplified in the appendix.

It is hoped that the first set will allow device performance figures already established as functions of the non-directional parameters Hs and TE to be extended to encompass a realistic range of spectral 'shapes' in both frequency and direction, and that the second set will allow a direct estimate of the annual productivity of each device to be made.

It has proved possible, by making the necessary compromises, to arrange a substantial overlap between the two sets, enabling both objectives to be realized with a total of 63 spectra.

CLASSIFICATION OF SPECTRA-DETAILED

SET 1

The 399 spectra were sorted according to the values of the three chosen parameters into the following classes:

DW - four classes

CLASS NO	1	2	3	4
DEGREES	30	60	90	>120

FW - four classes

CLASS NO	1	2	3	4
Hz	<0.0294	0.0295 - 0.0587	0.0588 - 0.0881	>0.0882

TE - five classes

CLASS NO	1	2	3	4	5
SECS	<6.00	6.01 - 8.00	8.01 - 10.00	10.01 - 12.00	>12.01

For each range of DW all those spectra jointly occupying a given class of FW and TE were listed along with the values of P and DP associated with each. The spectra so listed are the occupants of one cell of a frequency histogram in the three dimensions DW, FW and TE. The average power of all the spectra in each occupied cell was calculated. One spectrum was then selected to represent each cell, subject to the additional constraints that

1. it should have a DP values of either 240° or 270° (75% of all the spectra fall in this range)

2. it should have a power close to the mean power for the cell.

A total of 38 spectra resulted from this procedure. The weight to be attached to each is determined by the population of the cell which it represents.

The three dimensional histogram is set out in Table 1. This presentation is expanded in Table 2, where the occupants of each of the 38 classes are listed by serial number with the values of each of the five parameters. The classes are numbered in the order in which they are encountered, reading left to right and down the page, in Table 1. The spectra selected for both Set 1 and Set 2 are underlined.

The spectra of Set 1 are listed separately by serial number in Table 3 along with their relative weights.

SET 2

Each cell of the DW, TE, FW histogram was further subdivided into classes of power 10 kW/m wide; as previously mentioned this resulted in a total of 165 occupied classes. This number was reduced to 107 by regrouping the classes as follows:

Power - nine classes

CLASS NO	1	2	3	4	5	6	7	8	9
kW/m	<10	10-30	30-50	50-70	70-90	90-110	110-200	200-300	>300

A further reduction was effected by restricting consideration to those conditions under which the majority of the total annual energy is transported to the site. The distribution of total energy with Hs and TE, Figure 1, marked with approximate power contours, was inspected and those sea states which contribute relatively little to the total energy were identified and excluded.

The following categories of sea state are consequently not represented in Set 2 (the percentage of the total annual energy thereby excluded is marked against each category).

Excluded classes are those with:

Power	<	10 kW/m	(excludes 2.4% of total energy)
Power	>	300 kW/m	(" 8.5% " " ")
TE	<	7 seconds	(" 0.7% " " ")
TE	>	12.5 seconds	(" 0.8% " " ")

as well as spectra with unusual combinations of P, FW, DW and TE (ie classes in the four dimensional histogram occupied by one spectrum only). A further 11.1% of the total energy was associated with such spectra.

By this means it was possible to reduce the number of occupied classes to 46. The spectrum selected to represent each had a power as close as possible to the mean power of the class and a DP value of either 240° or 270°. The 46 spectra selected represent 267 of the original 399 synthesized spectra and, as shown above, these spectra account for 76.5% of the total energy in the set and thus, by projection, of the total energy arriving at the site. When each of the 46 spectra is weighed according to the number in the class which it represents, the set has an average power of 55.2 kW/m.

It is envisaged that the use of this set will allow the annual productivity of a device to be estimated. The weighted average power output of a device run against this set expressed as a fraction of the 55.2 kW/m available, is a direct estimate of the device efficiency over this range of conditions and thus determines what portion of the 76.5%

of the total annual energy represented may be retrieved. The ability of the device to capture power in those conditions excluded from the set and which account for the remaining 23.5% of the annual energy must be estimated separately. This may be effected by considering the device performance as established against Sets 1 and 2 in conjunction with the statistics of the excluded sea states presented in Table 4.

The spectra of Set 2 are listed by serial number and relative weight in Table 5.

CONCLUSION

The starting point for the present work was the set of 399 directional wave spectra which are themselves estimates of the probable directional wave conditions at South Uist. It was originally intended that these spectra would serve in the early stages of the Wave Energy Programme in view of the lack of any other more reliable data. It had been expected that they would, sooner rather than later, be superseded by measured directional data. There is still no immediate prospect of this occurring and it appears probable that a crucial evaluation of individual devices will be undertaken on the basis of the spectra described here. There must be reservations about proceding on this basis.

Given, however, that there is no other reasonable way forward it is encouraging to note that in those respects where it has been possible to test the representative nature of the 399, no serious shortcoming has come to light (WESC (80) DA101)(WESC (80) DA105). Furthermore, although the 399 were seen as a temporary expedient, no concious compromise on precision was made in the method of their synthesis.

Definite compromises have however been made in the attempts, described here, to further condense the information which they contain. The results presented here have been produced in response to strong pressures arising solely out of practical considerations, and their presentation does not imply that the estimated range of wave conditions at South Uist is sufficiently narrow that it can be adequately represented by a few 'typical' spectra.

Whilst the spectra listed here have been selected by reasonable and well-defined criteria, and as such cover a fairly wide range of conditions against which it is reasonable to check device performance - particularly for comparative purposes - no attempt has been made to cover those conditions which might result in extreme responses from particular devices. The systematic investigation of device performance in 'extreme' conditions must be outside this test set, and it should be borne in mind that the 399 themselves cannot cover the whole range of wave conditions likely at South Uist.

APPENDIX

The 399 spectra of the selected set are taken to be representative of the 2920 spectra which might be recorded in an average year. Each spectrum of the selected set therefore represents approximately 7 spectra in the hypothetical whole year set or, alternatively, each spectrum is representative of conditions which would be experienced for $^{1}/399$ of the year, ie 21.95 hours.

The distribution of the selected set properties is thus a coarser representation of the supposed annual distribution.

If the ith spectrum has a power Pi, then the average power of the selected set is,

$$\bar{P}_{399} = \frac{\sum_{i=1}^{399} P_i}{399} \qquad (1)$$

The result of this calculation is 47.8 kW/m and this is taken to be the mean power which would be measured over the average year.

The total energy arriving at the site per metre of wavefront is therefore estimated as

$$E_A = 47.8 \times 365 \times 24$$

$$= 418{,}728 \text{ kWh/m} \qquad (2)$$

Now consider the selection of a smaller number of spectra (Set 2) for the purpose of estimating device productivity. As explained in the text a number of spectra were excluded at the outset leaving 267 which then represent the range of conditions supposed to occur for $^{267}/399$ of the year. The average power of this set

$$\bar{P}_{267} = \frac{\sum_{i=1}^{267} P_i}{267} \qquad (3)$$

was 54.5 kW/m. The total energy in one year associated with such conditions is then

$$Ep = 54.5 \times \frac{267}{399} \times 365 \times 24$$

$$= 319{,}476 \text{ kWh/m} \qquad (4)$$

$$= 0.763 \times E_A \qquad (5)$$

As previously described the 267 spectra were divided into classes according to the values of DW, TE, FW and P associated with each. One spectrum was chosen to represent the n_j spectra in the jth class. The mean power of the spectra in the jth class is

$$\bar{P}_j = \frac{\sum_{i=1}^{n_j} P_{i,j}}{n_j} \qquad (6)$$

where $P_{i,j}$ is the power of the ith spectrum in the jth class. The chosen spectrum has a power, Pj, as close as possible to $\bar{P}_j$. A total of 46 classes were represented in this way.

The weighted average power of the set of 46 (Set 2) is

$$\bar{P}_2 = \frac{\sum_{j=1}^{46} P_j \times n_j}{\sum_{j=1}^{46} n_j} \simeq \frac{\sum_{j=1}^{46} \bar{P}_j \times n_j}{\sum_{j=1}^{46} n_j} \qquad (7)$$

using (6) and (3)

$$\bar{P}_2 \simeq \frac{\sum_{j=1}^{46} \sum_{i=1}^{n_j} P_{i,j}}{\sum_{j=1}^{46} n_j} = \frac{\sum_{i=1}^{267} P_i}{267} = 54.5 \text{ kW/m}$$

Thus the weighted average power of Set 2 (55.2 kW/m) is approximately equal to that of the set of 267 which they represent. Consequently they represent the same portion, Ep, of the total annual energy.

It is envisaged that the output power of a device in all 46 selected spectra will be determined. If the output power for the jth spectrum is Poj, the weighted average output power for the set is

$$\bar{P}_o = \frac{\sum_{j=1}^{46} P_{oj} \times n_j}{\sum_{j=1}^{46} n_j}$$

and the overall efficiency of the device in this range of conditions is

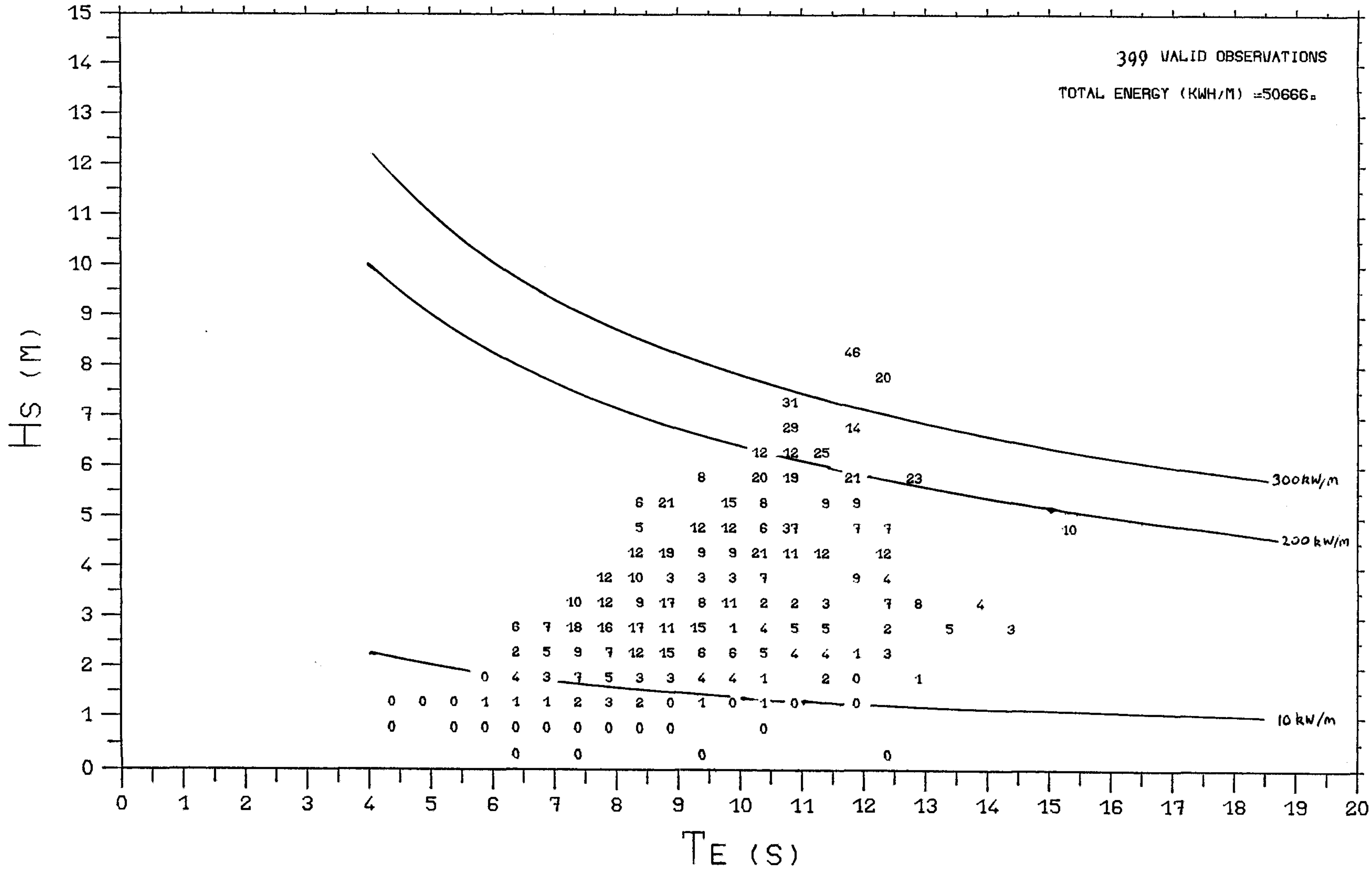
$$\varepsilon = \frac{\bar{P}o}{\bar{P}_2}$$

The productivity of the device during the $^{267}/399$ of the year in which these conditions prevail is thus estimated to be

$$Eo = \varepsilon \times 0.763 \times E_A \quad kWh/m$$

This is one element of the final productivity figure. The productivity of a device under conditions excluded from the set needs to be determined separately and the resulting energy added to Eo. Approximately half of the excluded power has, however, been excluded on the grounds of being associated with very high or very low power sea states, and the rest of the excluded power is associated with a wide range of spectral types. It may thus, as a first approximation, be permissible to assume that the device efficiency under these conditions is substantially the same as that established for Set 2, and that the annual productivity is simply

$$E = \varepsilon \times E_A \quad kWh/m$$



DISTRIBUTION OF TOTAL MEASURED WAVE ENERGY
WITH HS AND TE (PPT)

SOUTH UIST SELECTED SET (399 SPECTRA)

Figure 1

DW CLASS 1

TE CLASS NUMBER \ FW CLASS NUMBER	1	2	3	4
1		3	1	
2	4	7	4	
3	15	8		
4	9			
5				

DW CLASS 2

TE CLASS NUMBER \ FW CLASS NUMBER	1	2	3	4
1		2	2	
2	28	41	5	
3	56	12	1	
4	30	2		
5	18			

DW CLASS 3

TE CLASS NUMBER \ FW CLASS NUMBER	1	2	3	4
1		2		2
2	12	15	2	
3	20	6		
4	18			
5	2			

DW CLASS 4

TE CLASS NUMBER \ FW CLASS NUMBER	1	2	3	4
1		1	1	2
2	5	26	4	
3	20	4		
4	8			
5	1			

Distribution of the 399 synthesized directional spectra with the three parameters DW, FW and TE.

Numbers tabulated are total number of spectra in each class.

TABLE 1

CLASS NO.	FW (Hz)	TE (secs)	DW (degs)	DMAX (degs)	POWER (kW/m)	SPEC NO.	CLASS AVGE POWER
	0.0586	5.8700	30.	270.	0.18480E 01	28.	
	0.0488	5.1600	30.	270.	0.20020E 01	29.	
1	0.0488	6.0200	30.	240.	0.99890E 01	143.	0.46130E 01
2	0.0684	5.5000	30.	240.	0.33020E 01	82.	0.33020E 01
	0.0293	7.9500	30.	270.	0.11920E 02	100.	
	0.0293	7.1600	30.	240.	0.12450E 02	122.	
	0.0293	7.3000	30.	330.	0.22050E 02	205.	
3	0.0293	8.0000	30.	240.	0.27210E 02	258.	0.18408E 02
	0.0488	7.7600	30.	270.	0.11190E 01	10.	
	0.0391	6.6300	30.	270.	0.18270E 01	13.	
	0.0391	7.2800	30.	270.	0.50600E 01	55.	
	0.0391	7.6100	30.	270.	0.81890E 01	63.	
	0.0586	6.7000	30.	240.	0.10980E 02	138.	
	0.0391	6.5600	30.	240.	0.11670E 02	139.	
4	0.0488	6.1400	30.	240.	0.10570E 02	142.	0.70593E 01
	0.0684	7.8700	30.	240.	0.13840E 01	6.	
	0.0684	7.0100	30.	240.	0.35240E 01	14.	
	0.0684	6.8700	30.	240.	0.21430E 01	16.	
5	0.0781	6.0500	30.	240.	0.59960E 01	66.	0.32617E 01
	0.0293	9.6000	30.	270.	0.59710E 01	57.	
	0.0195	9.7800	30.	270.	0.16870E 02	91.	
	0.0293	9.0600	30.	270.	0.12600E 02	99.	
	0.0195	8.2500	30.	270.	0.19160E 02	177.	
	0.0293	8.5000	30.	330.	0.25710E 02	175.	
	0.0293	8.3900	30.	240.	0.23630E 02	184.	
	0.0293	9.4100	30.	240.	0.21410E 02	195.	
	0.0293	8.8500	30.	270.	0.36640E 02	228.	
	0.0195	9.2200	30.	270.	0.36160E 02	229.	
	0.0293	8.8700	30.	240.	0.48920E 02	304.	
	0.0195	9.6400	30.	240.	0.65040E 02	297.	
	0.0195	8.6700	30.	270.	0.85150E 02	353.	
	0.0293	9.3000	30.	330.	0.10980E 03	365.	
	0.0195	9.7100	30.	240.	0.11340E 03	366.	
6	0.0293	9.8300	30.	240.	0.13400E 03	368.	0.50297E 02
	0.0391	9.5900	30.	240.	0.17040E 02	109.	
	0.0488	8.3000	30.	330.	0.17460E 02	115.	
	0.0391	8.5900	30.	270.	0.25920E 02	161.	
	0.0391	8.6300	30.	240.	0.23390E 02	168.	
	0.0391	8.0500	30.	270.	0.26330E 02	185.	
	0.0391	8.9500	30.	330.	0.21020E 02	186.	
	0.0391	8.1600	30.	270.	0.20640E 02	192.	
7	0.0391	9.1700	30.	330.	0.65650E 02	328.	0.27181E 02

Table 2

CLASS NO.	FW (Hz)	TE (secs)	DW (degs)	DMAX (degs)	POWER (kW/m)	SPEC NO.	CLASS AVGE POWER
	0.0098	11.6800	30.	270.	0.14830E 02	94.	
	0.0195	10.1300	30.	270.	0.15770E 02	112.	
	0.0195	11.3900	30.	270.	0.21400E 02	102.	
	0.0195	10.6800	30.	240.	0.53380E 02	221.	
	0.0195	10.1600	30.	240.	0.72380E 02	325.	
	0.0195	10.3800	30.	240.	0.10750E 03	344.	
	0.0195	10.9500	30.	270.	0.15390E 03	360.	
	0.0195	11.5500	30.	270.	0.19940E 03	370.	
8	0.0293	11.6800	30.	270.	0.22790E 03	384.	0.96273E 02
	0.0391	5.9400	60.	270.	0.37050E 01	71.	
9	0.0586	5.8900	60.	270.	0.95010E 01	137.	0.66030E 01
	0.0879	5.3000	60.	270.	0.32840E 01	81.	
10	0.0684	6.0100	60.	270.	0.91880E 01	146.	0.62360E 01
	0.0195	7.7100	60.	270.	0.37480E 01	23.	
	0.0293	7.4800	60.	210.	0.72590E 01	64.	
	0.0293	7.1100	60.	270.	0.43750E 01	73.	
	0.0293	7.1400	60.	270.	0.51870E 01	78.	
	0.0293	7.7600	60.	270.	0.12320E 02	101.	
	0.0293	7.3600	60.	330.	0.12160E 02	117.	
	0.0293	7.6100	60.	210.	0.15170E 02	118.	
	0.0293	7.6900	60.	270.	0.12080E 02	123.	
	0.0293	7.0500	60.	240.	0.12940E 02	128.	
	0.0195	7.8400	60.	270.	0.10360E 02	130.	
	0.0293	7.0200	60.	210.	0.10920E 02	135.	
	0.0195	7.1400	60.	270.	0.12610E 02	141.	
	0.0293	7.5400	60.	240.	0.16400E 02	178.	
	0.0293	7.8500	60.	300.	0.16830E 02	183.	
	0.0293	6.8900	60.	300.	0.19600E 02	202.	
	0.0195	7.4000	60.	240.	0.19250E 02	203.	
	0.0293	6.9600	60.	0.	0.15460E 02	207.	
	0.0293	7.1100	60.	270.	0.18080E 02	210.	
	0.0293	7.5800	60.	240.	0.21110E 02	191.	
	0.0293	7.6500	60.	330.	0.27940E 02	252.	
	0.0293	7.3500	60.	240.	0.28660E 02	269.	
	0.0293	7.1400	60.	240.	0.24360E 02	276.	
	0.0293	7.1500	60.	240.	0.24070E 02	281.	
	0.0293	6.4700	60.	240.	0.28210E 02	282.	
	0.0293	7.5700	60.	240.	0.34540E 02	247.	
	0.0293	8.0100	60.	240.	0.32820E 02	248.	
	0.0293	7.9300	60.	240.	0.33090E 02	254.	
11	0.0293	8.0200	60.	270.	0.34420E 02	267.	0.18356E 02

Table 2 (cont.)

CLASS NO.	FW (Hz)	TE (secs)	DW (degs)	DMAX (degs)	POWER (kW/m)	SPEC NO.	CLASS AVGE POWER
	0. 0586	7. 7600	60.	270.	0. 27200E 01	15.	
	0. 0391	8. 0300	60.	300.	0. 66140E 01	35.	
	0. 0391	7. 6400	60.	240.	0. 61930E 01	40.	
	0. 0488	6. 8800	60.	210.	0. 42850E 01	46.	
	0. 0391	7. 2100	60.	210.	0. 67470E 01	48.	
	0. 0391	6. 9000	60.	270.	0. 58710E 01	54.	
	0. 0488	7. 7500	60.	240.	0. 84110E 01	56.	
	0. 0391	7. 5500	60.	270.	0. 58040E 01	58.	
	0. 0488	6. 7000	60.	240.	0. 70590E 01	68.	
	0. 0391	7. 9200	60.	270.	0. 68890E 01	69.	
	0. 0488	6. 5000	60.	270.	0. 86140E 01	145.	
	0. 0391	7. 9800	60.	240.	0. 16850E 02	110.	
	0. 0391	7. 9200	60.	270.	0. 15570E 02	111.	
	0. 0488	7. 4000	60.	240.	0. 13210E 02	114.	
	0. 0586	7. 2600	60.	270.	0. 14800E 02	126.	
	0. 0586	6. 3000	60.	270.	0. 12670E 02	129.	
	0. 0391	7. 0200	60.	240.	0. 11760E 02	136.	
	0. 0391	6. 9200	60.	240.	0. 13350E 02	140.	
	0. 0488	6. 7700	60.	240.	0. 10890E 02	144.	
	0. 0488	7. 6500	60.	240.	0. 17670E 02	194.	
	0. 0488	7. 4500	60.	240.	0. 17910E 02	199.	
	0. 0391	6. 6000	60.	180.	0. 17770E 02	209.	
	0. 0488	6. 8900	60.	270.	0. 15650E 02	213.	
	0. 0586	7. 2700	60.	270.	0. 20840E 02	201.	
	0. 0391	7. 7800	60.	240.	0. 21020E 02	206.	
	0. 0391	7. 2200	60.	270.	0. 22880E 02	208.	
	0. 0391	7. 3000	60.	330.	0. 25800E 02	257.	
	0. 0391	7. 4800	60.	270.	0. 29460E 02	259.	
	0. 0488	7. 7200	60.	270.	0. 29120E 02	260.	
	0. 0391	7. 1000	60.	240.	0. 24490E 02	261.	
	0. 0488	7. 4000	60.	270.	0. 27380E 02	275.	
	0. 0391	7. 1500	60.	270.	0. 26010E 02	283.	
	0. 0391	7. 6200	60.	240.	0. 30060E 02	263.	
	0. 0391	7. 6900	60.	270.	0. 30930E 02	265.	
	0. 0488	7. 3000	60.	300.	0. 36730E 02	320.	
	0. 0391	7. 8600	60.	240.	0. 49570E 02	311.	
	0. 0391	7. 6000	60.	240.	0. 48780E 02	312.	
	0. 0391	7. 7500	60.	300.	0. 48800E 02	314.	
	0. 0391	7. 6400	60.	330.	0. 45600E 02	315.	
	0. 0586	7. 1100	60.	270.	0. 40230E 02	319.	
12.	0. 0391	7. 7900	60.	240.	0. 61380E 02	330.	0. 21131E 02
	0. 0684	6. 4500	60.	270.	0. 61390E 00	4.	
	0. 0684	6. 0500	60.	270.	0. 11900E 02	147.	
	0. 0684	6. 6100	60.	300.	0. 15000E 02	214.	
	0. 0684	6. 9100	60.	270.	0. 29470E 02	277.	
13	0. 0879	6. 9700	60.	240.	0. 22860E 02	278.	0. 15969E 02

Table 2 (cont.)

CLASS NO.	FW (Hz)	TE (secs)	DW (degs)	DMAX (degs)	POWER (kW/m)	SPEC NO.	CLASS AVGE POWER
	0.0195	8.6900	60.	270.	0.41510E 01	8.	
	0.0195	8.4300	60.	270.	0.32170E 01	19.	
	0.0293	8.8500	60.	270.	0.55490E 01	34.	
	0.0293	8.4500	60.	270.	0.70040E 01	36.	
	0.0098	9.0400	60.	270.	0.50460E 01	38.	
	0.0195	8.1500	60.	300.	0.87650E 01	39.	
	0.0293	8.8300	60.	240.	0.67930E 01	52.	
	0.0293	8.6200	60.	240.	0.60130E 01	61.	
	0.0293	8.0500	60.	240.	0.93720E 01	62.	
	0.0293	9.8300	60.	270.	0.18940E 02	90.	
	0.0195	8.5800	60.	270.	0.14500E 02	98.	
	0.0293	8.1600	60.	270.	0.11710E 02	104.	
	0.0195	9.0500	60.	270.	0.19470E 02	105.	
	0.0293	8.0600	60.	240.	0.14250E 02	113.	
	0.0293	9.4300	60.	270.	0.14230E 02	116.	
	0.0293	8.8600	60.	270.	0.14110E 02	120.	
	0.0195	8.4700	60.	330.	0.11970E 02	124.	
	0.0293	8.5200	60.	300.	0.19340E 02	174.	
	0.0195	9.9800	60.	270.	0.24940E 02	153.	
	0.0293	8.7900	60.	300.	0.28230E 02	155.	
	0.0195	9.2900	60.	270.	0.27400E 02	156.	
	0.0293	9.2100	60.	270.	0.25770E 02	157.	
	0.0293	8.8600	60.	240.	0.26150E 02	159.	
	0.0195	8.7800	60.	210.	0.24800E 02	163.	
	0.0293	8.5700	60.	270.	0.23610E 02	171.	
	0.0293	9.7400	60.	240.	0.28600E 02	187.	
	0.0195	8.2300	60.	210.	0.22350E 02	188.	
	0.0195	8.7700	60.	270.	0.25640E 02	189.	
	0.0293	9.5300	60.	240.	0.32230E 02	160.	
	0.0293	9.4200	60.	270.	0.30100E 02	162.	
	0.0195	10.0000	60.	270.	0.34410E 02	198.	
	0.0293	9.6000	60.	240.	0.33910E 02	225.	
	0.0195	9.3800	60.	270.	0.39120E 02	226.	
	0.0293	9.1300	60.	300.	0.36580E 02	231.	
	0.0293	8.4200	60.	240.	0.37230E 02	244.	
	0.0293	8.2400	60.	270.	0.30460E 02	245.	
	0.0293	8.3600	60.	300.	0.33700E 02	251.	
	0.0293	8.3300	60.	270.	0.32670E 02	264.	
	0.0195	9.4000	60.	270.	0.44880E 02	227.	
	0.0293	8.6200	60.	240.	0.40800E 02	237.	
	0.0293	8.5500	60.	270.	0.41400E 02	246.	
	0.0293	8.5700	60.	270.	0.42600E 02	298.	
	0.0293	8.6200	60.	270.	0.48820E 02	301.	
	0.0293	9.8200	60.	270.	0.50180E 02	288.	
	0.0293	9.8900	60.	270.	0.53580E 02	300.	
	0.0195	8.8300	60.	240.	0.51800E 02	302.	
	0.0293	8.4100	60.	270.	0.51990E 02	306.	
	0.0293	9.8900	60.	270.	0.60910E 02	292.	
	0.0293	9.3200	60.	240.	0.60060E 02	307.	
	0.0293	8.2800	60.	270.	0.62870E 02	331.	
	0.0195	9.9300	60.	300.	0.90430E 02	345.	
	0.0195	9.8600	60.	270.	0.96970E 02	346.	
	0.0195	9.2700	60.	300.	0.94440E 02	348.	
	0.0293	8.8200	60.	240.	0.91210E 02	349.	
	0.0293	9.0500	60.	240.	0.12420E 03	367.	
14	0.0293	8.7700	60.	240.	0.12950E 03	378.	0.36232E 02

CLASS NO.	FW (Hz)	TE (secs)	DW (degs)	DMAX (degs)	POWER (kW/m)	SPEC NO.	CLASS AVGE POWER
	0. 0391	9. 4600	60.	270.	0. 55530E 00	2.	
	0. 0488	8. 1400	60.	240.	0. 72400E 01	33.	
	0. 0391	9. 0600	60.	240.	0. 96010E 01	42.	
	0. 0488	8. 2500	60.	240.	0. 60390E 01	72.	
	0. 0391	9. 9300	60.	270.	0. 13480E 02	93.	
	0. 0488	8. 6900	60.	270.	0. 12980E 02	103.	
	0. 0586	8. 0700	60.	240.	0. 14810E 02	108.	
	0. 0488	8. 4300	60.	240.	0. 29410E 02	240.	
	0. 0391	8. 4100	60.	270.	0. 37340E 02	249.	
	0. 0391	8. 4700	60.	240.	0. 31910E 02	250.	
	0. 0391	8. 4500	60.	240.	0. 41540E 02	243.	
15	0. 0391	8. 4600	60.	240.	0. 69000E 02	327.	0. 22825E 02
16	0. 0684	8. 0500	60.	240.	0. 39420E 01	7.	0. 39420E 01
	0. 0195	10. 2800	60.	270.	0. 12270E 02	31.	
	0. 0293	10. 2400	60.	210.	0. 11470E 02	45.	
	0. 0293	10. 1500	60.	210.	0. 22820E 02	106.	
	0. 0195	11. 3100	60.	270.	0. 27240E 02	150.	
	0. 0195	10. 2600	60.	240.	0. 24390E 02	154.	
	0. 0293	11. 0900	60.	210.	0. 26130E 02	164.	
	0. 0293	10. 6000	60.	270.	0. 26950E 02	172.	
	0. 0195	10. 7300	60.	270.	0. 27390E 02	197.	
	0. 0293	10. 2900	60.	270.	0. 32150E 02	165.	
	0. 0195	11. 4600	60.	270.	0. 31860E 02	167.	
	0. 0195	10. 1700	60.	270.	0. 39800E 02	223.	
	0. 0195	10. 1900	60.	210.	0. 38270E 02	236.	
	0. 0098	10. 8300	60.	270.	0. 44970E 02	222.	
	0. 0195	11. 2100	60.	270.	0. 54430E 02	220.	
	0. 0195	11. 1200	60.	240.	0. 50430E 02	232.	
	0. 0195	10. 8500	60.	240.	0. 57120E 02	303.	
	0. 0195	10. 2600	60.	270.	0. 51870E 02	309.	
	0. 0195	11. 0300	60.	270.	0. 76390E 02	289.	
	0. 0293	11. 8200	60.	270.	0. 85020E 02	321.	
	0. 0293	10. 3600	60.	240.	0. 80680E 02	324.	
	0. 0195	11. 9000	60.	270.	0. 95280E 02	322.	
	0. 0098	10. 0800	60.	240.	0. 93580E 02	341.	
	0. 0195	10. 0800	60.	300.	0. 96400E 02	342.	
	0. 0195	10. 5400	60.	240.	0. 10860E 03	339.	
	0. 0195	11. 1400	60.	270.	0. 11960E 03	338.	
	0. 0293	10. 1100	60.	240.	0. 11190E 03	340.	
	0. 0293	10. 7400	60.	300.	0. 11490E 03	343.	
	0. 0293	11. 7700	60.	270.	0. 19300E 03	371.	
	0. 0293	10. 3400	60.	240.	0. 19680E 03	386.	
17	0. 0293	10. 9400	60.	240.	0. 28060E 03	393.	0. 74410E 02
	0. 0391	10. 8900	60.	240.	0. 27540E 02	152.	
18	0. 0391	10. 8400	60.	270.	0. 13540E 03	364.	0. 81470E 02

Table 2 (cont.)

CLASS NO.	FW (Hz)	TE (secs)	DW (degs)	DMAX (degs)	POWER (kW/m)	SPEC NO.	CLASS AVGE POWER
	0.0098	12.4200	60.	270.	0.16610E 01	1.	
	0.0195	12.9800	60.	270.	0.28470E 02	87.	
	0.0195	12.4200	60.	270.	0.34680E 02	148.	
	0.0195	12.1900	60.	270.	0.40100E 02	149.	
	0.0195	13.0000	60.	270.	0.48430E 02	235.	
	0.0195	12.4700	60.	270.	0.46280E 02	242.	
	0.0195	14.0200	60.	270.	0.58970E 02	224.	
	0.0195	13.3200	60.	270.	0.66680E 02	219.	
	0.0098	12.5400	60.	270.	0.77060E 02	290.	
	0.0195	12.3700	60.	270.	0.70820E 02	295.	
	0.0195	12.3100	60.	270.	0.83690E 02	286.	
	0.0195	13.7500	60.	270.	0.86030E 02	287.	
	0.0195	12.6400	60.	270.	0.82950E 02	291.	
	0.0293	12.0900	60.	240.	0.91080E 02	323.	
	0.0195	12.4200	60.	240.	0.11530E 03	335.	
	0.0293	12.1200	60.	270.	0.13460E 03	336.	
	0.0195	12.4300	60.	300.	0.15280E 03	358.	
19	0.0098	15.3700	60.	240.	0.20320E 03	356.	0.79045E 02
	0.0586	5.5700	90.	210.	0.27000E 01	26.	
20	0.0488	5.9800	90.	300.	0.65310E 01	70.	0.46155E 01
	0.0977	4.4400	90.	210.	0.16000E 01	30.	
21	0.1172	4.4200	90.	210.	0.42590E 01	85.	0.29295E 01
	0.0195	6.3200	90.	210.	0.30970E 01	27.	
	0.0195	7.7000	90.	240.	0.70050E 01	37.	
	0.0293	7.7000	90.	240.	0.65020E 01	41.	
	0.0195	7.8800	90.	240.	0.66820E 01	44.	
	0.0293	7.1700	90.	240.	0.47640E 01	60.	
	0.0293	7.0700	90.	270.	0.87860E 01	121.	
	0.0293	7.6400	90.	270.	0.13300E 02	127.	
	0.0293	7.9800	90.	240.	0.17900E 02	180.	
	0.0293	6.9300	90.	300.	0.18620E 02	211.	
	0.0293	6.2100	90.	210.	0.16090E 02	215.	
	0.0293	7.9600	90.	330.	0.26290E 02	181.	
22	0.0195	8.0300	90.	300.	0.22100E 02	182.	0.12595E 02
	0.0488	7.0000	90.	240.	0.12820E 01	22.	
	0.0391	6.6200	90.	300.	0.15610E 01	24.	
	0.0488	7.1100	90.	210.	0.98190E 00	25.	
	0.0391	7.5900	90.	0.	0.74820E 01	50.	
	0.0391	7.3000	90.	210.	0.41170E 01	59.	
	0.0391	6.2300	90.	300.	0.48780E 01	76.	
	0.0391	6.0800	90.	300.	0.61320E 01	77.	
	0.0586	6.1300	90.	240.	0.39050E 01	84.	
	0.0488	6.0400	90.	210.	0.15810E 02	216.	
	0.0391	7.5300	90.	330.	0.23740E 02	193.	
	0.0586	7.3200	90.	270.	0.20800E 02	204.	
	0.0391	7.3400	90.	270.	0.26710E 02	255.	
	0.0391	7.7700	90.	210.	0.26530E 02	273.	
	0.0391	6.6700	90.	210.	0.28530E 02	274.	
23	0.0586	6.2400	90.	270.	0.24380E 02	280.	0.13123E 02

Table 2 (cont.)

CLASS NO.	FW (Hz)	TE (secs)	DW (degs)	DMAX (degs)	POWER (kW/m)	SPEC NO.	CLASS AVGE POWER
	0. 0684	7. 0800	90.	240.	0. 85690E 00	3.	
24	0. 0684	6. 4300	90.	270.	0. 22150E 02	285.	0. 11503E 02
	0. 0195	8. 9300	90.	270.	0. 19110E 01	18.	
	0. 0293	9. 0700	90.	270.	0. 18180E 02	95.	
	0. 0293	8. 6600	90.	270.	0. 16500E 02	97.	
	0. 0293	10. 0100	90.	210.	0. 16290E 02	107.	
	0. 0293	8. 7000	90.	300.	0. 27440E 02	158.	
	0. 0195	9. 7400	90.	210.	0. 23100E 02	166.	
	0. 0293	8. 4500	90.	300.	0. 27960E 02	169.	
	0. 0195	9. 6800	90.	210.	0. 23720E 02	170.	
	0. 0293	9. 1000	90.	270.	0. 27140E 02	173.	
	0. 0293	8. 1100	90.	270.	0. 20600E 02	200.	
	0. 0195	8. 8000	90.	300.	0. 34210E 02	234.	
	0. 0293	9. 3300	90.	270.	0. 46110E 02	233.	
	0. 0195	9. 2900	90.	270.	0. 43460E 02	238.	
	0. 0293	9. 1600	90.	270.	0. 41080E 02	239.	
	0. 0293	8. 9100	90.	240.	0. 44500E 02	299.	
	0. 0293	8. 6100	90.	300.	0. 49930E 02	305.	
	0. 0293	8. 0400	90.	0.	0. 55120E 02	333.	
	0. 0293	9. 0600	90.	240.	0. 60720E 02	294.	
	0. 0293	8. 7400	90.	270.	0. 63390E 02	329.	
25	0. 0195	9. 9400	90.	300.	0. 16260E 03	374.	0. 40198E 02
	0. 0391	8. 1500	90.	240.	0. 25540E 01	11.	
	0. 0391	8. 7000	90.	270.	0. 19360E 02	176.	
	0. 0391	8. 3500	90.	270.	0. 48900E 02	308.	
	0. 0391	9. 8200	90.	240.	0. 67700E 02	326.	
	0. 0488	8. 0800	90.	240.	0. 69450E 02	355.	
26	0. 0391	8. 3200	90.	270.	0. 11020E 03	369.	0. 53027E 02
	0. 0293	11. 0100	90.	210.	0. 23820E 02	92.	
	0. 0098	11. 8600	90.	210.	0. 37150E 02	151.	
	0. 0293	11. 3700	90.	270.	0. 12140E 03	337.	
	0. 0293	10. 6900	90.	300.	0. 13640E 03	361.	
	0. 0293	10. 4600	90.	240.	0. 13420E 03	363.	
	0. 0195	11. 9500	90.	270.	0. 14130E 03	357.	
	0. 0293	10. 6000	90.	210.	0. 14860E 03	362.	
	0. 0195	10. 9300	90.	270.	0. 15280E 03	359.	
	0. 0195	10. 0500	90.	300.	0. 16380E 03	372.	
	0. 0293	11. 0400	90.	240.	0. 18260E 03	373.	
	0. 0293	10. 9100	90.	270.	0. 18760E 03	383.	
	0. 0195	10. 8800	90.	270.	0. 19710E 03	385.	
	0. 0293	10. 3300	90.	270.	0. 19780E 03	387.	
	0. 0195	11. 0300	90.	270.	0. 22640E 03	389.	
	0. 0293	10. 4700	90.	240.	0. 24500E 03	391.	
	0. 0293	10. 7800	90.	240.	0. 28710E 03	394.	
	0. 0293	10. 7600	90.	240.	0. 29970E 03	396.	
27	0. 0195	11. 5600	90.	210.	0. 44860E 03	399.	0. 18508E 03

Table 2 (cont.)

CLASS NO.	FW (Hz)	TE (secs)	DW (degs)	DMAX (degs)	POWER (kW/m)	SPEC NO.	CLASS AVGE POWER
	0. 0293	12. 8700	90.	270.	0. 22390E 03	381.	
28	0. 0293	12. 6600	90.	270.	0. 24520E 03	382.	0. 23455E 03
29	0. 0488	5. 0800	120.	270.	0. 35120E 01	86.	0. 35120E 01
30	0. 0781	5. 6900	120.	270.	0. 53200E 01	75.	0. 53200E 01
	0. 1270	5. 2300	150.	270.	0. 37630E 01	80.	
31	0. 1172	4. 7000	210.	210.	0. 32350E 01	83.	0. 34990E 01
	0. 0293	7. 1200	120.	270.	0. 69190E 01	47.	
	0. 0293	7. 0200	120.	0.	0. 74690E 01	53.	
	0. 0293	7. 0800	120.	300.	0. 14820E 02	196.	
	0. 0293	7. 2700	120.	240.	0. 29230E 02	268.	
32	0. 0293	7. 5100	120.	330.	0. 43530E 02	317.	0. 20394E 02
	0. 0391	7. 7100	120.	270.	0. 17680E 01	20.	
	0. 0391	7. 4000	120.	270.	0. 26670E 01	21.	
	0. 0391	6. 8400	120.	270.	0. 58580E 01	51.	
	0. 0488	6. 7600	120.	270.	0. 68070E 01	65.	
	0. 0488	6. 9800	120.	270.	0. 49330E 01	67.	
	0. 0488	6. 3000	120.	270.	0. 73470E 01	74.	
	0. 0391	6. 2000	120.	270.	0. 40310E 01	79.	
	0. 0488	7. 4000	120.	270.	0. 94470E 01	119.	
	0. 0488	7. 1700	120.	270.	0. 93650E 01	132.	
	0. 0391	6. 3900	120.	0.	0. 80700E 01	134.	
	0. 0586	6. 4200	150.	270.	0. 10870E 02	131.	
	0. 0488	6. 6700	120.	270.	0. 10820E 02	133.	
	0. 0391	7. 2100	120.	270.	0. 22160E 02	218.	
	0. 0488	7. 1100	120.	270.	0. 24370E 02	262.	
	0. 0391	7. 1800	120.	240.	0. 27760E 02	266.	
	0. 0391	6. 9500	120.	270.	0. 25930E 02	270.	
	0. 0488	7. 2300	120.	270.	0. 25060E 02	271.	
	0. 0586	6. 5900	120.	240.	0. 26530E 02	272.	
	0. 0391	6. 4800	120.	270.	0. 20910E 02	284.	
	0. 0488	7. 7500	150.	0.	0. 32830E 02	253.	
	0. 0391	7. 8200	180.	330.	0. 33390E 02	256.	
	0. 0391	7. 0000	120.	240.	0. 32670E 02	279.	
	0. 0586	7. 2000	120.	270.	0. 36280E 02	318.	
	0. 0586	7. 6400	120.	210.	0. 46070E 02	313.	
	0. 0488	7. 5200	120.	330.	0. 49740E 02	334.	
33	0. 0586	7. 6100	120.	210.	0. 58150E 02	332.	0. 20917E 02

Table 2 (cont.)

CLASS NO.	FW (Hz)	TE (secs)	DW (degs)	DMAX (degs)	POWER (kW/m)	SPEC NO.	CLASS AVGE POWER
	0. 0781	7. 3400	120.	270.	0. 12500E 02	125.	
	0. 0781	6. 2700	120.	210.	0. 17130E 02	217.	
	0. 0684	6. 4600	120.	270.	0. 20750E 02	212.	
34	0. 0684	7. 4900	180.	300.	0. 37970E 02	316.	0. 22088E 02
	0. 0293	8. 7500	120.	270.	0. 20260E 01	5.	
	0. 0195	8. 6800	120.	270.	0. 15500E 01	12.	
	0. 0293	9. 3400	120.	270.	0. 96300E 01	43.	
	0. 0293	9. 6300	120.	270.	0. 13070E 02	88.	
	0. 0195	9. 7500	120.	270.	0. 13740E 02	89.	
	0. 0195	9. 2000	120.	300.	0. 17350E 02	96.	
	0. 0293	8. 0900	120.	300.	0. 24440E 02	179.	
	0. 0293	8. 8100	120.	240.	0. 31160E 02	230.	
	0. 0195	8. 7800	120.	270.	0. 34910E 02	241.	
	0. 0293	8. 1700	120.	270.	0. 39920E 02	310.	
	0. 0293	8. 6700	120.	210.	0. 43170E 02	296.	
	0. 0293	8. 7800	210.	270.	0. 85270E 02	347.	
	0. 0293	8. 3600	120.	210.	0. 83840E 02	351.	
	0. 0293	8. 9300	120.	300.	0. 96790E 02	350.	
	0. 0195	9. 4900	120.	270.	0. 96730E 02	352.	
	0. 0293	8. 3300	120.	180.	0. 12150E 03	379.	
	0. 0293	8. 7800	120.	210.	0. 12900E 03	380.	
	0. 0195	9. 5300	120.	300.	0. 13430E 03	376.	
	0. 0293	8. 9800	210.	270.	0. 13680E 03	377.	
35	0. 0293	9. 4900	120.	300.	0. 15900E 03	375.	0. 63710E 02
	0. 0488	8. 2900	120.	270.	0. 14650E 01	9.	
	0. 0391	8. 2000	120.	330.	0. 21280E 02	190.	
	0. 0391	9. 0900	120.	240.	0. 48870E 02	293.	
36	0. 0391	8. 0700	120.	330.	0. 70380E 02	354.	0. 35499E 02
	0. 0195	10. 1200	120.	270.	0. 24490E 01	17.	
	0. 0098	11. 9200	120.	240.	0. 83200E 01	49.	
	0. 0195	10. 7500	120.	270.	0. 10400E 02	32.	
	0. 0293	10. 6400	120.	270.	0. 23720E 03	390.	
	0. 0195	11. 2600	150.	270.	0. 26330E 03	388.	
	0. 0098	11. 7700	120.	240.	0. 28460E 03	392.	
	0. 0293	10. 9900	120.	240.	0. 31730E 03	395.	
37	0. 0293	11. 7700	120.	240.	0. 45690E 03	398.	0. 19756E 03
38	0. 0195	12. 1100	120.	270.	0. 40180E 03	397.	0. 40180E 03

Table 2 (cont.)

SPECTRUM SERIAL NUMBER	NUMBER OF SPECTRA IN CLASS	SPECTRUM SERIAL NUMBER	NUMBER OF SPECTRA IN CLASS
29	3	70	2
82	1	30	2
122*	4	180*	12
63	7	280*	15
14	4	285	2
228*	15	238*	20
168*	8	355*	6
360*	9	359*	18
137	2	381*	2
81	2	86	1
210*	28	75	1
201*	41	80	2
278	5	268*	5
244*	56	218*	26
108*	12	212*	4
7	1	347*	20
324*	30	190	4
364	2	388*	8
291*	18	397	1
		TOTAL	399

THE SPECTRA COMPRISING SET 1

(Spectra marked with * are common to Set 2)

TABLE 3

STATISTICS OF SEA STATES EXCLUDED FROM SET 2

NUMBER OF SPECTRA EXCLUDED	CLASS NUMBER IN EACH PARAMETER				NUMBER OF SPECTRA EXCLUDED	CLASS NUMBER IN EACH PARAMETER			
	DW	FW	TE	P		DW	FW	TE	P
3	1	2	1	1	2	3	2	1	1
1	1	3	1	1	2	3	4	1	1
4	1	2	2	1	6	3	1	2	1
4	1	3	2	1	8	3	2	2	1
1	1	1	3	1	1	3	3	2	1
1	1	1	3	4	1	3	3	2	2
1	1	1	3	5	1	3	1	3	1
1	1	2	3	4	1	3	1	3	7
1	1	1	4	4	1	3	2	3	1
1	1	1	4	5	1	3	2	3	2
1	1	1	4	8	1	3	2	3	3
					1	3	2	3	7
2	2	2	1	1	1	3	1	4	2
2	2	3	1	1	1	3	1	4	3
4	2	1	2	1	1	3	1	4	9
11	2	2	2	1					
1	2	2	2	4	1	4	2	1	1
1	2	3	2	1	1	4	3	1	1
4	2	3	2	2	2	4	4	1	1
9	2	1	3	1	2	4	1	2	1
4	2	2	3	1	1	4	1	2	3
1	2	2	3	4	10	4	2	2	1
1	2	3	3	1	1	4	2	2	4
1	2	1	4	8	1	4	3	2	3
1	2	2	4	2	3	4	1	3	1
1	2	2	4	7	1	4	2	3	1
1	2	1	5	1	1	4	2	3	2
1	2	1	5	2	1	4	2	3	3
2	2	1	5	4	1	4	2	3	5
1	2	1	5	6	2	4	1	4	1
1	2	1	5	8	2	4	1	4	9
					1	4	1	5	9

TABLE 4

SPECTRUM SERIAL NUMBER	NUMBER OF SPECTRA IN CLASS	SPECTRUM SERIAL NUMBER	NUMBER OF SPECTRA IN CLASS
122*	4	371	5
177	6	242	4
228*	3	291*	5
366	3	336	3
168*	7	180*	6
112	3	280*	7
360*	3	200	9
210*	20	238*	6
267	4	294	3
201*	21	355*	2
319	8	359*	11
171	19	268*	2
244*	15	218*	9
292	7	318	6
346	4	212*	3
378	2	89	4
108*	4	241	4
249	3	347*	2
154	8	352	2
223	5	377	5
220	4	388*	3
324*	3	381*	2
322	4	391	4
		TOTAL	267

THE SPECTRA COMPRISING SET 2

(Spectra marked with * are common to Set 1)

TABLE 5