























Table 4 Natural frequencies of the circular membrane considering the added mass

Case	Model by Eq.(21)				Model by Eq.(12)			
	1st mode	2nd mode	3rd mode	4th mode	1st mode	2nd mode	3rd mode	4th mode
	$f_1$ (Hz)	$f_2$ (Hz)	$f_3$ (Hz)	$f_4$ (Hz)	$f_1$ (Hz)	$f_2$ (Hz)	$f_3$ (Hz)	$f_4$ (Hz)
A1	12.76	24.44	35.97	39.16	12.151	19.90	27.21	28.675
A2	13.81	26.08	38.05	41.36	13.186	21.568	29.455	31.073
A3	15.16	28.10	40.53	43.99	14.541	23.735	32.365	34.194
A4	17.59	31.44	44.44	48.09	17.019	27.653	37.595	39.848
B1	17.76	33.99	50.04	54.47	16.901	27.686	37.849	39.886
B2	19.21	36.28	52.92	57.54	18.342	30.001	40.971	43.221
B3	21.09	39.09	56.37	61.18	20.226	33.013	45.019	47.562
B4	24.47	43.73	61.81	66.90	23.673	38.465	52.294	55.428
C1	22.93	43.91	64.64	70.36	21.832	35.763	48.890	51.522
C2	24.81	46.86	68.36	74.32	23.692	38.753	52.923	55.829
C3	27.25	50.49	72.82	79.03	26.126	42.643	58.151	61.437
C4	31.61	56.49	79.84	86.41	30.579	49.686	67.549	71.597
D1	37.38	67.91	96.83	104.93	36.019	58.648	79.846	84.502
D2	39.61	70.88	100.25	108.51	38.301	62.244	84.633	89.693
D3	42.27	74.28	104.05	112.49	41.080	66.597	90.394	95.975
D4	46.52	79.30	109.49	118.13	45.585	73.568	99.561	106.07
E1	49.57	90.04	128.39	139.12	47.757	77.760	105.87	112.04
E2	52.51	93.98	132.92	143.87	50.783	82.529	112.21	118.92
E3	56.05	98.48	137.96	149.14	54.467	88.295	119.85	127.25
E4	61.68	105.14	145.17	156.63	60.440	97.542	132.01	140.63

#### 4. Conclusions

Added mass estimation is a key issue in wind-induced vibration analysis of membrane structures. In this paper, the boundary element method was applied to estimate the added mass for open flat membranes vibrating in still air. Two added mass models were proposed and discussed, one only considering the effect of the membrane geometric shape, and the other considering the effect of the geometric shape and the mode shape of membranes. Comparison with the data from the tests on the circular membrane, it showed that the estimation of the added mass by the proposed approaches based on the boundary element method was reasonable and suitability. The main findings were:

- 1) Added mass of air has a significant influence on the natural frequency of membrane structures in vibrating.
- 2) The proposed added mass model based on the effect of the geometric shape can have a good agreement with the test results in low-order modes, and the error will be increase as the order of vibration modes increases.

- 3) The proposed added mass model based on the effect of the geometric shape and the mode shape can have a better conformity with the test results both in low-order modes and high-order modes.

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