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AN EXPERIMENTAL INVESTIGATION ON THE EFFECT OF ANGLES OF ATTACK TO THE FLUTTER SPEED OF A FLAT PLATE IN AXIAL FLOW

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Abstract. The application of flat plates to the field of wind harvesting requires a lot of research toward the understanding of the flutter behavior of the plates. There are shortages of articles that discuss the effect of varying the angles of attack to the flutter speed of a flat plate. This research aims to conduct a basic experimental research on the effect of relative position of a thin-flat plates to the direction of the air flow to its flutter speed. In this study, a thin-flat plate was placed in a subsonic wind tunnel to test its flutter speed. The position of the plate was varied in various angles of attack. The effect of the angles of attack to the flutter speed was observed.

Keywords : flutter, angles of attack, flat plate.

1. INTRODUCTION

Flutter is one of the dynamic phenomena of aeroelasticity in which aerodynamic forces act together with the natural modes of vibration of a structure to produce periodic or quasi-periodic motion. Aerodynamic force functions as input energy to structural vibrations which, if not damped by the system, will increase the vibrations in the end which will cause structural failure (failure). Aeroelasticity is the science that discusses the interaction between inertial, elasticity and aerodynamic forces in a structure. Aeroelasticity is divided into two, namely static aeroelasticity and dynamic aeroelasticity. The static aeroelasticity discusses the interaction between aerodynamic forces and elastic forces on a structure. Meanwhile, in the dynamic of aerelasticity, the effects of inertial forces are added to the discussion.

A large number of scientific articles on the flutter behavior of thin-flat plates can be found in international journals. Due to current global energy scarcity issues, there is a new research trend in leveraging this configuration for wind harvesting applications. Wind harvesting is an alternative technology to utilize wind energy to become a source of electricity. The use of flutter for wind energy harvesting has been explored by Doaré et al. [1] and Dunmon et al. [2]. Allen and Smits [3] also conducted other research on energy harvesting using the slender structure behind the bluff body. The development of the application of thin-flat plates towards wind harvesting has extended this area of research into new settings to seek better configurations for more effective and efficient energy conversion.

The application of thin-flat plates to wind harvesting demands a lot of theoretical research into understanding the flutter behavior of these plates. One of the gaps the authors encounter is the absence of an article discussing the effect of angle of incidence on the flutter speed of thin-flat plates. For this reason, this study aims to carry out basic research on the effect of the position of the thin-flat plates relative to the direction of the wind on the flutter speed.

In this study, several thin-flat plates were placed in the subsonic wind tunnel to test the flutter speed. The positions of the plates were varied in various angles to come so that the effect of incident angle on the flutter speed can be observed for several plates sizes.

2. METHODS

In the history of flutter, the results of the first theoretical research conducted by Lord Rayleigh [4] discussed the instability of plates with infinite dimensions in axial flow. In a more practical way, a scientific understanding of the flutter phenomenon can be traced from the NACA Technical Report No. 496 on General Theory of Aerodynamic Instability and the Mechanism of Flutter. In this report, Theodorsen explains in theory how flutter occurs in airplane wings by explaining the interactions between the elasticity of the structure, the inertia force, and the aerodynamic force. The dynamics of an airplane wing are modeled into a mathematical form and the solution of the model can explain the emergence of flutter. This research was continued as an experimental investigation and was reported in the NACA Technical Report No. 685 [5]. The effect of adding Aeleron and Tab to flutter is further reported in NACA Technical Report No.736 [5].

The Flutter phenomenon is also found in the engineering world outside of aircraft. The collapse of the Tacoma Narrows Bridge in the US state of Washington in 1940 was ultimately concluded as a design failure due to neglect of aerodynamic effects. The bridge experiences flutter when gusts of wind at a speed of 48 km/h come [6].

The development of the printing industry requiring a machine with a higher speed motivated Watanabe et al. [7] investigated the flutter problem in paper. There are two methods used, namely potential flow and numerical Navier-Stokes to explain the flutter mode shape as a function of the mass ratio. Time domain analysis was performed using the Navier-Stokes method. Experimentally, Watanabe et al. [8] observes the minimum speed limit so that the paper stops fluttering.

Fluid Structure Interaction (FSI) on a long flag or band is similar to a thin flat-plate. Research on flags and long bands has been carried out by Connel and Yue [9], Lemaitre et al. [10], Michelin et al. [11], Manela and Howe [12], and Virot et al. [13].

With the advent of computer technology, many analysis of flutter uses the finite element method. LAPAN researchers conducted Flutter Analysis to optimize the Fin design of the satellite launcher rocket [14]. Manikandan performed the finite element method to optimize the mounting system of the aerofoil flutter test [15].

The phenomenon of bimodal flutter was discovered by Drazumeric et al. [16] on a rigid airfoil that is hung flexibly with a flexible plate attached to the trailing edge of the airfoil. The flutter behavior was predicted using the eigenfunction expansion approach and the bimodal flutter behavior was also shown experimentally.

Flutter in human biological systems was investigated by Balint and Lucey [17], Huang [18], and Howell et al. [19]. They found that the snoring phenomenon was similar to the flutter of the cantilevered flexible plate in axial flow. The use of flutter for wind energy harvesting has been explored by Doaré et al. [1] and Dunmon et al. [2], and Allen and Smits [3] also conducted other research on energy harvesting using the slender structure.

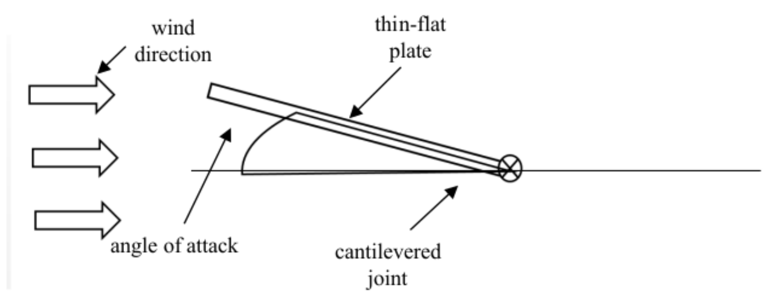

Figure 1. Experimental setup diagram

In this research, thin-flat plates were placed in a wind tunnel test chamber which has laminar airflow. The thin-flat plate was clamped at one end and left free on the other (cantilevered). The incidence angle was defined as the angle between the thin-flat plate and the airflow. The incidence angle was defined as zero (0) when the free end faces the wind direction. Flutter speed was defined as the wind speed when the plate instability occurs. Wind speed was measured using a pitot tube.

The testing procedure carried out in this study is as follows:

1. Thin-flat plate was placed in the wind tunnel test room
2. The airflow was increased slowly until the thin-flat plate flutters.
3. The flutter speed was recorded for one type of plate being tested and one angle of incidence set
4. Steps 1 to. 3 was performed by changing the angle of incidence from 0 degree to 180 degrees.
5. Steps 1 to. 4 was performed for other plate dimensions.

By carrying out the above procedure, it will be obtained the relationship between the incident angle and the flutter speed of various dimensions of thin-flat plates. Appropriate regression analysis will be carried out to describe this relationship.

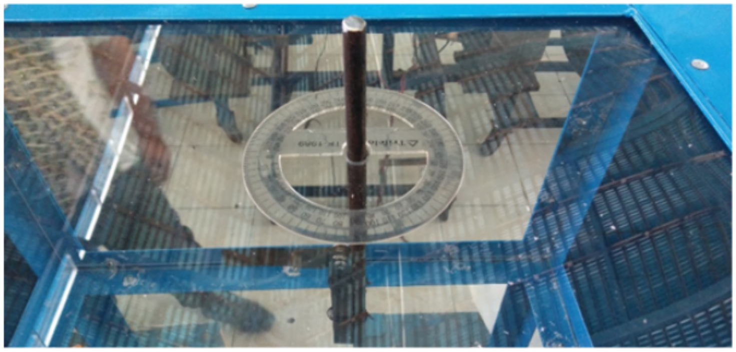

Figure 2. The physical photo of the experimental setup

Table 1. Plate Dimension of 60micronsX1.5cmX9cm

Angle of Attack (degree(s))	Flutter Speed (mmH2O)	Flutter Speed (m/s)
0	0.41	3.66
5	0.30	3.13
10	0.15	2.21
15	0.12	1.98
20	0.10	1.81
25	0.04	1.14
30	0.02	0.81
90	0.00	0.06
150	0.50	4.04
155	0.60	4.43
160	1.50	7.00
165	1.70	7.45
170	3.00	9.90
175	5.50	13.40
180	6.20	14.23
185	4.50	12.12
190	3.00	9.90
195	3.50	10.69
200	1.50	7.00
205	0.80	5.11
210	0.50	4.04
270	0.00	0.06
330	0.04	1.14
335	0.05	1.28
340	0.13	2.06
345	0.14	2.14
350	0.20	2.56
355	0.25	2.86
360	0.40	3.61

3. RESULTS AND DISCUSSION

Three sizes of thin-flat plate made of copper were tested in this study. Of the three plates tested, two plates had a thickness of 60 microns. These two plates each have a widthxlength: 1.5cmx9cm and 1.2cmx7.2cm. Another plate is 80 microns thick with dimensions of 1.5cmx9cm. For each plate, the flutter speed is measured with various angles coming from 0 degree to 360 degrees.

Table 3,4,5 is the measurement result of futter velocity from the three tested plates with various angle incidence. Flutter speed was measured by a pitot tube in mm H2O and then converted to m/s.

Figure 3 is the result of data measurement in graphical form. In Figure 3, the flutter speeds of the three types of plate sizes are plotted with various angles coming from 0 degree to 360 degrees. The air velocity when flutter occurs is shown in m/s units which is the result of converting the measurement results with the pitot tube in mmH2O.

Table 2. Plate Dimension of 60micronsX1.2cmX7.2cm

Angle of Attack (degree(s))	Flutter Speed (mmH2O)	Flutter Speed (m/s)
0	1.50	7.00
5	0.80	5.11
10	0.70	4.78
15	0.30	3.13
20	0.20	2.56
25	0.15	2.21
30	0.10	1.81
90	0.00	0.06
150	1.30	6.52
155	2.00	8.08
160	3.00	9.90
165	4.00	11.43
170	7.00	15.12
175	10.00	18.07
180	12.00	19.80
185	9.00	17.15
190	8.00	16.17
195	7.00	15.12
200	4.00	11.43
205	2.00	8.08
210	1.00	5.72
270	0.00	0.06
330	0.10	1.81
335	0.15	2.21
340	0.25	2.86
345	0.30	3.13
350	0.70	4.78
355	0.90	5.42
360	1.40	6.76

The flutter speed recorded when measuring is the first critical flutter speed. First critical speed for the angle attack from 0 degree to 90 degrees is to take the first mode shape and the one with angle incidence from 90 degree to 180 degrees is the second mode of the free-free vibration. In the range 30 degrees to 90 degrees and 90 degrees to 150 degrees the first critical speeds are so small and then the plates show their higher order critical speeds.The higher order critical speed that appears in the range 30 degrees to 90 degrees and 90 degrees to 150 degrees is not a concern in this study.

The mode shape of the free-free vibration of the these type of plates was reported by previous work of Rahtika et al. [20] and [21]. This study shows that the first critical speed of a free leading edge cantilevered thin-flat plate is related to its first mode of the free-free configuration. Meanwhile, the first critical speed of a fixed leading edge cantilevered thin-flat plate is related to its second mode of the free-free configuration.

The results showed that the flutter speed decreased with increasing angle of incidence. The flutter speed for the freeleading edge is lower than the free trailing edge. This findings agrees with the theory since the second mode shape has higher frequencies than the first one. The higher frequency vibration has higher vibration energy, then it needs a higher air speed to invoke flutter.

Table 3. Plate Dimension of 80micronsX1.5cmX9cm

Angle of Attack (degree(s))	Flutter Speed (mmH2O)	Flutter Speed (m/s)
0	2.50	9.04
5	1.50	7.00
10	1.00	5.72
15	0.60	4.43
20	0.40	3.61
25	0.30	3.13
30	0.20	2.56
90	0.00	0.06
150	2.00	8.08
155	4.00	11.43
160	5.00	12.78
165	8.00	16.17
170	11.00	18.96
175	15.00	22.14
180	25.00	28.58
185	14.00	21.39
190	13.00	20.61
195	8.00	16.17
200	6.00	14.00
205	5.00	12.78
210	1.50	7.00
270	0.00	0.06
330	0.15	2.21
335	0.20	2.56
340	0.40	3.61
345	0.70	4.78
350	1.50	7.00
355	2.00	8.08
360	3.00	9.90

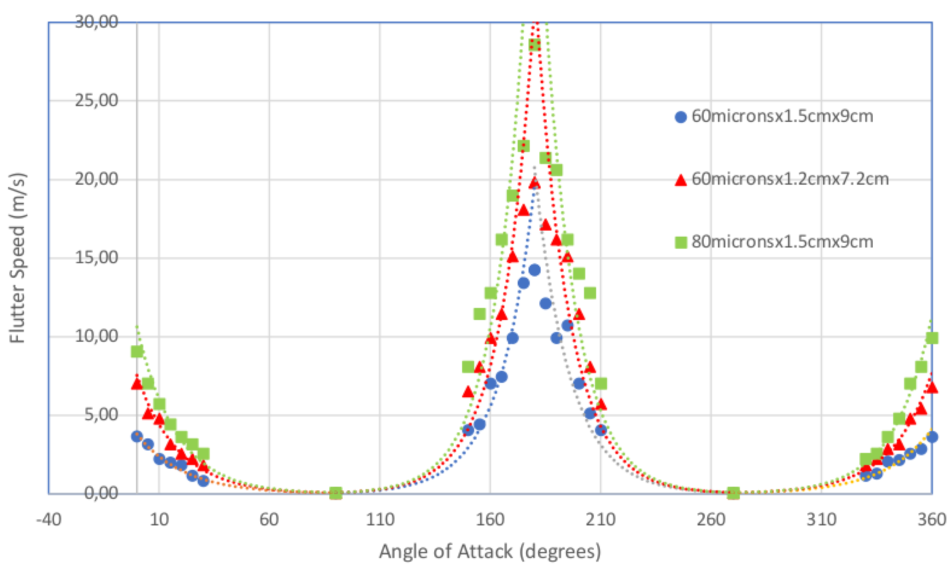

Figure 3. The effect of the angle of attack to the flutter speed

4. CONCLUSION

The effect of the angle of attack on flutter speed was observed for three sizes of copper thin-flat plates in this study. Measurements have been made by placing thin-flat plates in the subsonic wind tunnel to test the flutter speed.

The results showed that the flutter speed decreased with increasing angle of attack. The flutter speed for the free leading edge is lower than the free trailing edge.

The flutter speed recorded during measurement is the first order flutter or first critical speed. The first critical speeds for the angle of attack from 0 degree to 90 degrees are the first mode shape and the one with the angle of attack from 90 degrees to 180 degrees is the second mode shape. Higher order critical speed that appears in the range of 30 degrees to 90 degrees and 90 degrees to 150 degrees could be a good topic for a future study.

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] Doaré, O.; and Michelin, S. (2011). Piezoelectric coupling in energy-harvesting fluttering flexible plates: linear stability analysis and conversion efficiency. Journal of Fluids and Structures 27, 1357–1375.
[2] Dunnmon, J.; Stanton, S.; Mann, B.; and Dowell, E. (2011). Power extraction from aeroelastic limit cycle oscillations. Journal of Fluids and Structures. 27, 1182–1198.
[3] Allen, J.J.; and Smits, A.J. (2001). Energy harvesting eel. Journal of Fluids and Structures. 15(3–4), 629–640.
[4] Rayleigh, Lord, 1978. On the instability of jets. Proceedings of the London Mathematical Society 10, 4-13
[5] Theodorsen, T.,1935. General Theory of Aerodynamic Instability and the Mechanism of Flutter. National Advisory Committee for Aeronautics' Technical Report No. 496
[6] Fox, Robert W. dan McDonald, Alan. T. (1994). Introduction to Fluid Mechanics. John Wiley & Son, Inc.
[7] Watanabe, Y., Isogai, K., Suzuki, S., Sugihara, M., 2002. A theoretical study of paper flutter. Journal of Fluids and Structures 16, 543–560.
[8] Watanabe, Y., Suzuki, S., Sugihara, M., Sueoka, Y., 2002b. An experimental study of paper flutter. Journal of Fluids and Structures 16, 529–542.
[9] Connell, B.S.H.; and Yue,D.K.P. (2007). Flapping dynamics of a flag in a uniform stream. Journal of Fluid Mechanics 581, 33–67.
[10] Lemaitre, C.; Hémon, P.; and deLangre, E. (2005). Instability of a long ribbon hanging in axial air flow. Journal of Fluids and Structures 20(7), 913–925.
[11] Michelin, S.; Smith, S. G. L.; and Glover, B.J. (2008). Vortex shedding model of a flapping flag. Journal of Fluid Mechanics 617, 1–10.
[12] Manela, A.; and Howe, M.S. (2009). On the stability and sound of an unforced flag. Journal of Sound and Vibration 321,994–1006.
[13] 12. Virot, E., Amandolese, X., Hémona, P., 2013. Fluttering flags: An experimental study of fluid forces. Journal of Fluids and Structures. 43,385–401
[14] Andria, Novi dan Triharjanto Robertus Heru (2010) Optimal Design of RX-420 Fin Using Flutter Analysis. The ITB Regional Conference on Mechanical and Aerospace Engineering. 17-19 Februari 2010, Denpasar, Bali
[15] Manikandan,G. dan Rao, M. Ananda (2011) Aerofoil Flutter Analysis, Simulation and Optimization. International Journal of Advance Engineering Sciences and Technologies, 4 (1), 053-068.
[16] Drazumeric, R.; Gjerek, B.; Kosel, F.; and Marzocca, P. (2014). On bimodal flutter behavior of a flexible airfoil. Journal of Fluids and Structures 45, 164–179.
[17] Balint, T.; and Lucey, A. (2005). Instability of a cantilevered flexible plate in viscous channel flow. Journal of Fluids and Structures 20, 893–912.
[18] Huang, L. (1995). Flutter of cantilevered plates in axial flow. Journal of Fluids and Structures 9(2), 127–147.
[19] Howell, R.M.; and Lucey, A.D. (2015). Flutter of spring-mounted flexible plates in uniform flow. Journal of Fluids and Structures. 59, 370–393.
[20] Rahtika, I.P.G. Sopan; Wardana, I.N.G.; Sonief, A.A.; dan Siswanto, E. (2017a) Experimental Investigation on Flutter Similitude of Thin-Flat Plates. Advances in Acoustics and Vibration.
[21] Rahtika, I.P.G. Sopan; Wardana, I.N.G.; Sonief, A.A.; dan Siswanto, E. (2017b) Numerical and experimental investigation on the flutter of cantilevered plates with free leading edge in axial flow. Journal of Engineering Science and Technology. Vol. 12, No. 10 (2017) 2805 – 2825

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