

PAPER • OPEN ACCESS

Half Wing N219 Aircraft Model Clean Configuration for Flutter Test On Low Speed Wind Tunnel

To cite this article: Sayuti Syamsuar *et al* 2018 *J. Phys.: Conf. Ser.* **1005** 012040

View the [article online](#) for updates and enhancements.

Half Wing N219 Aircraft Model Clean Configuration for Flutter Test On Low Speed Wind Tunnel

Sayuti Syamsuar¹⁾, Budi Sampurno²⁾, Katia Mayang Mahasti²⁾, Muchamad Bayu Sakti Pratama²⁾, Triyono Widi Sasongko¹⁾, Nina Kartika¹⁾, Adityo Suksmono¹⁾, Mohamad Ivan Aji Saputro¹⁾, Dimas Bahtera Eskayudha¹⁾

- 1) Pusat Teknologi Sistem dan Prasarana Transportasi, Kedeputan Teknologi Industri Rancang Bangun dan Rekayasa, Badan Pengkajian dan Penerapan Teknologi (BPPT), Puspiptek, Serpong, Indonesia
- 2) Flutter Specialist, PT Dirgantara Indonesia, Bandung

Email add: sayutisyamsuar@yahoo.com; and sayuti.syamsuar@bppt.go.id

Abstract. Flutter is a rapid self-feeding motion which is caused by the interaction of aerodynamic, structural and inertial forces. Flutter can cause major damage on aircraft structure which can lead to fatal accident in aviation. Several methods have been evolved to avoid the flutter phenomena occur during the flight envelope of aircraft design. On this study, method was developed by Indonesian Aerospace which consist of Finite Element Method (FEM) analysis, Ground Vibration Test (GVT), and Wind Tunnel Flutter Test (WTT). Based on the study, FEM have similar results toward to Wind Tunnel Flutter Test conjunction the clean configuration of N219 aircraft half wing model.

Keywords: fluid flow, particle, aerodynamic forces, moments, flutter speed, NASTRAN.

1. INTRODUCTION

Flutter is a rapid self-feeding motion which is caused by the interaction of aerodynamic, structural and inertial forces. Flutter can cause major damage on aircraft structure which can lead to fatal accident in aviation. The aims of this research are to validate and compare the results of wind tunnel test to Finite Element Method (FEM) and to earn the critical speed on flutter phenomena based on wind tunnel test. This research was conducted to avoid and ensure the flutter phenomena will not occur when flight test of aircraft is held.

In other paper, flutter suppression has been spotlighted because of its destructive nature (Westin et al, 2009). The materials use is suppressed, especially PZT materials. Instead of the passive suppression will increase the mass of aircraft. The result of the test is to measure of flexible wing design which is suppressed on materials choice. Piezoelectric transduction is used by active and passive flutter suppressions for highly flexible wing (Tsushima et al, 2017). By properly place the piezoelectric actuators and energy harvesters, it was possible to stabilize the wing, while extracting a certain amount energy, both of which would contribute to improving the performance of wing and aircraft.

Furthermore, the methods of flutter analysis of aeroelastic system includes modelling uncertainties is more efficient (Lokatt, 2017). Both of structural and aerodynamic uncertainties can have notable effect on the damping of the flutter modes. The method shows that main advantage is the ability to analyse the combine effect of structural and aerodynamic uncertainties.

Scope:

This paper consists of four sections. Section 1 presents scope of work, objectives as introduction. Section 2 briefly describes procedure of the Wind Tunnel Flutter and FEM analysis result. Section 3



presents the result of Wind Tunnel Flutter Test and comparison with the analysis FEM results. Finally, section 4 describes the conclusions of Low Speed Wind Tunnel Flutter Test.

2. TEST METHOD

2.1 FEM Analysis

Based on method which is described in flow chart below on Figure 1 and then updated with GVT, mode shape and its natural frequency final design half wing model that is mentioned on Table 1.

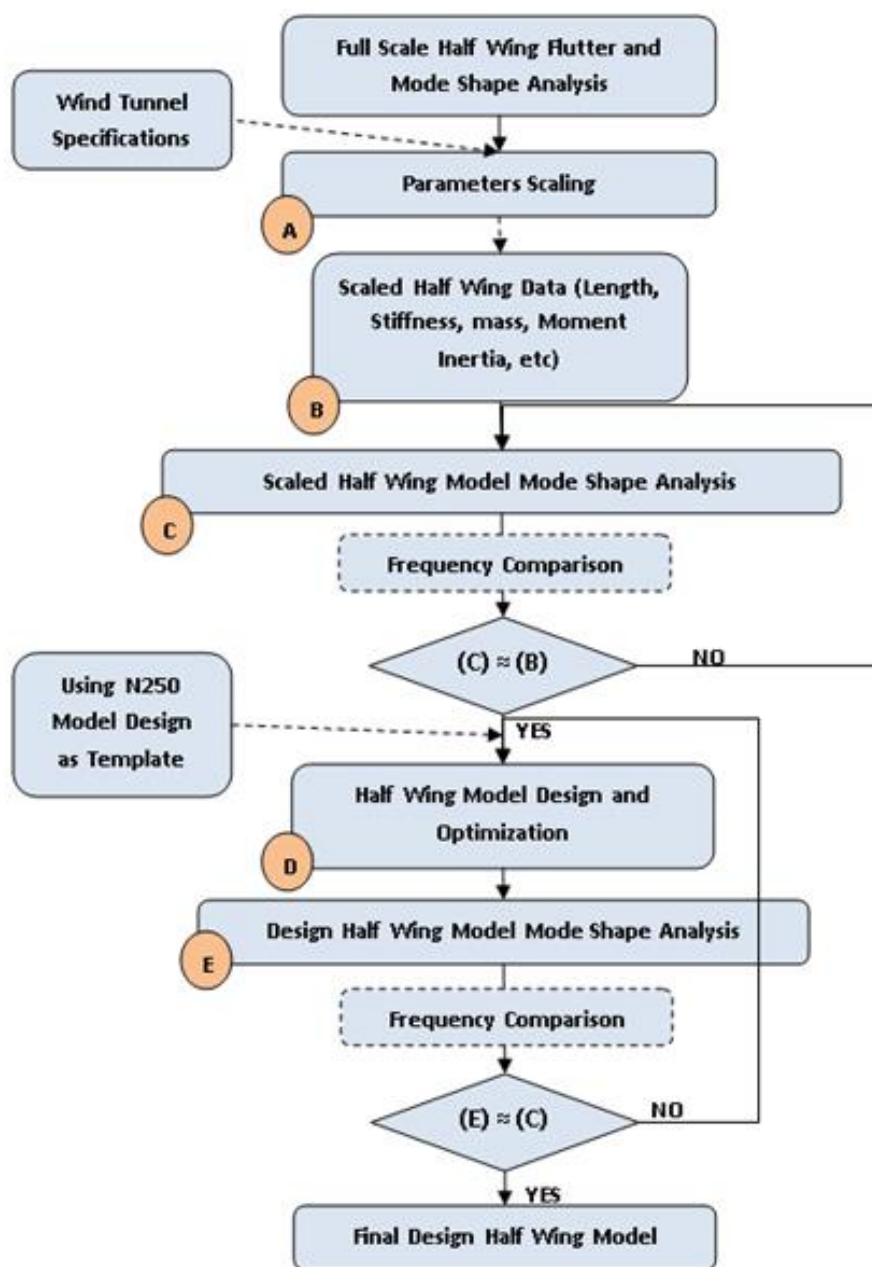


Figure 1 Flowchart of half wing model determination

Table 1 Mode shape and half wing natural frequency

No	Mode Shape	Analysis (Hz)	GVT (Hz)	Analysis Update (Hz)
1	Wing Vertical Bending	3.65	3.20	3.23
2	Wing Inplane Bending	6.90	5.09	5.08
3	Wing Vertical Bending	15.28	13.2	12.46
4	Wing Torsion	24.77	18.20	18.14
5	Wing Inplane Bending	28.16	21.11	20.37
6	Wing Torsion	34.14	28.31	29.09

Then, half wing flutter model will be tested on wind tunnel. The model attached on wind tunnel wall using moderate spring and soft spring. Therefore, spring shall be modeled on FEM and tested on GVT in order to get better accuracy.

2.2. Ground vibration test (GVT)

Ground Vibration Test (GVT) is useful for validating dynamic characteristics of test model from analytical model. The purpose of this GVT is to get structural modes parameters such as natural frequency, mode shapes, and damping. Those modes parameters from GVT result, will be used on flutter analysis and dynamic aeroelastomechanics system responses.

The main instruments that will be used for GVT exciter are accelerometer, and frequency analyzer as showed in Figure 2. The model should have fix supported at the wing root (Fixed on T_x, T_y, T_z, R_x, R_y & R_z). T is torsion which react to external force on model and R is translation force which react to external force on model that both of them is placed on wing root. While x, y, z are the direction based on axis. The excitation method that will be used to produce mechanical vibration on test model is a random excitation ranged up to 50 Hz. Responses on the observation points will be measured using transducer accelerometers. The signal coming from accelerometers and force transducer will amplified using amplifier and continue to be processed on the analyzer for getting its frequency response function. With curve fitting method then the modal parameters of the half wing flutter model can be achieved. The listing of Detail Accelerometer Locations as showed in Table 2.

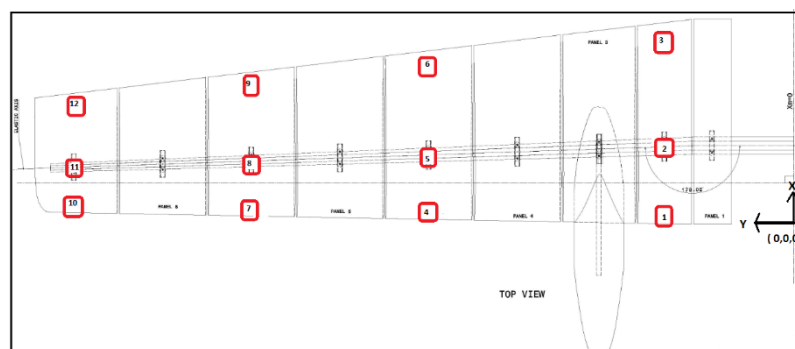


Figure 2. Sketch of Accelerometer Locations

Table 2 Listing of Detail Accelerometer Locations

Accelerator No	Coordinate			DOF
	X	Y	Z	
1	0.001	0.277	0.004	Z
2	0.166	0.277	0.004	Z
3	0.458	0.277	0.004	Z
4	0.014	0.782	0.034	Z
5	0.150	0.782	0.034	Z
6	0.390	0.782	0.034	Z
7	0.023	1.162	0.057	Z
8	0.137	1.162	0.057	Z
9	0.338	1.162	0.057	Z
10	0.032	1.542	0.080	Z
11	0.125	1.542	0.080	Z
12	0.287	1.542	0.080	Z

The Ground vibration test (GVT) result of N219 Half Wing Flutter Model are discussed in ref. [11]. The GVT was performed in one mass configurations that the mass configurations are described in Table 3.

The GVT result will be use for updating the structural dynamic model of the half wing flutter test model design, furthermore the updated structural dynamic model will be use for updating the flutter analysis result. Thus, the flutter speed reference will be use to compare wind tunnel flutter test result with flutter speed from updated flutter analysis result.

Table 3 Mass Distribution Half Wing Model N219-B11 Test Configuration (MC01)

Section	Weight (kg)			Center of Gravity (m)			Moment of Inertia (kg Sq.m)					
	Beam	Segment	Total	X	Y	Z	Ixx	Iyy	Izz	Ixy	Ixz	Iyz
SECTION 0	0.136	0.000	0.136	1.206	0.066	0.621	2.034E-04	1.021E-05	2.079E-04	-1.486E-09	9.071E-10	1.599E-07
SECTION 1	0.086	0.374	0.460	1.213	0.174	0.628	3.852E-04	4.000E-03	4.000E-03	-6.074E-07	-7.217E-07	9.413E-05
SECTION 2	0.118	0.315	0.433	1.210	0.276	0.630	5.909E-04	3.000E-03	3.000E-03	2.225E-05	-1.459E-05	7.408E-05
SECTION 3	0.142	1.181	1.323	1.104	0.416	0.608	3.000E-03	2.400E-02	2.400E-02	2.167E-05	-1.239E-04	-2.000E-03
SECTION 4	0.148	0.350	0.498	1.199	0.589	0.646	2.000E-03	3.000E-03	4.000E-03	6.879E-05	-4.504E-05	6.882E-05
SECTION 5	0.127	0.332	0.459	1.193	0.779	0.656	1.000E-03	2.000E-03	4.000E-03	6.377E-05	-4.185E-05	5.732E-05
SECTION 6	0.108	0.302	0.410	1.187	0.968	0.666	1.000E-03	2.000E-03	3.000E-03	5.732E-05	-3.769E-05	4.533E-05
SECTION 7	0.090	0.262	0.352	1.180	1.158	0.676	1.000E-03	1.000E-03	2.000E-03	4.942E-05	-3.252E-05	3.357E-05
SECTION 8	0.074	0.234	0.308	1.174	1.347	0.686	9.084E-04	1.000E-03	2.000E-03	4.337E-05	-2.859E-05	2.540E-05
SECTION 9	0.047	0.216	0.263	1.168	1.527	0.695	6.238E-04	7.556E-04	1.000E-03	3.097E-05	-5.301E-06	1.879E-05
Total Half Wing Flutter Model N219	1.076	3.567	4.643	1.168	0.653	0.641	7.930E-01	5.300E-02	8.330E-01	4.900E-02	6.000E-03	-4.000E-03

2.3 Finite Element Model of Half Wing Flutter Model Test N219

According to the boundary condition (support system) of the tested model, the analysis FEM for GVT needs to be modified to represent the support system. These support systems are connected to Beam combination Spring. Figure 3 is show the FEM of the Half Flutter Model for GVT.

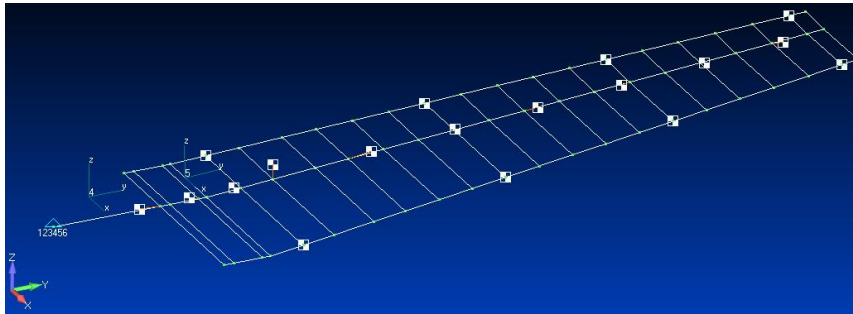


Figure 3 FEM Half Wing Flutter Model Test N219

The analysis FEM that is optimized and updated is the structure FEM described in Ref. 4. The updating is based on the GVT results described in Ref. 7. It must be remembered that frequencies and modes from GVT results actually include some damping of the tested Model.

The natural frequencies and modes of the structural FEM are obtained by solving the real ‘undamped’ eigenvalue equation (1).

$$[[\mathbf{K}] - \omega_i^2 [\mathbf{M}]] \{\phi\}_i = \{0\} \quad (1)$$

Where:

$[\mathbf{M}]$	= generalized mass matrix	size (ndof x ndof)
$[\mathbf{K}]$	= generalized stiffness matrix	size (ndof x ndof)
$\{\phi\}_i$	= modal eigenvector	size (ndof x 1)
$[\Phi] = [\{\phi\}_1, \{\phi\}_2, \dots, \{\phi\}_{n_{mode}}]$	= modal matrix	size (ndof x nmodes)
ω_i	= natural frequency	(rad/sec)
ndof	= number of total degrees of freedom	
n mode	= number of modes extracted	

The above equation of motion is solved using MSC/NASTRAN SOL 103 (Normal Mode Analysis). Care must be taken in comparing frequencies between damped GVT results and undamped analysis results of the structural FEM. The actual amount of damping should not significantly affect the matching of frequencies and the correlation of modes.

A method that is used to establish the degree of correlation between the real eigenvectors from test and from the analysis model is visual examination by plotting and animation of the test and analytical modes. The test modes are related to the analytical modes that correspond.

The visual method evaluates the quality of modes correlation. In this document, the grades of modes correlation are divided into three categories. The first category is '*good*', this category explains similar mode shape between test and analysis FEM. The second category is '*fair*', this one declares the dominant modes are similar. Finally the third category is '*poor*', this one affirms weak or no corresponding between the test and analytical FEM.

In a simplistic sense the Bayesian parameter estimation procedure has some similarity to the minimization of error by the method of least squares. The former permits a balanced model updating approach by incorporating uncertainties in both test data and in modeling parameters. In this approach each 'piece' of test data has a confidence associated with it. Then the test data as a whole is weighed relative to the initial model as a whole. The Bayesian parameter estimation procedure is an iterative approach wherein an error is minimized. The error is written as:

$$E = wt * \sum WR * (RT - RA)^2 + wp * \sum WP * (PF - PO)^2 \quad (2)$$

Where:

- E = a measure of the error between test data and analysis
- RT = target response quantities (i. e. test data)
- RA = responses from the analysis
- WR = weighting factors (confidences) for response
- PF = parameters for the final model
- PO = parameters of the original model
- WP = weighting factors (confidences) for the parameter
- wt = scalar weighting for the test data as a whole
- wp = scalar weighting for the model parameter as a whole

The above equation is solved iteratively to find PF, the final model parameter that minimize the error.

Model response and test data can be static displacements, resonant frequencies and mode shapes, and element forces, stresses, and strains any quantity that can be measured or computed with MSC/NASTRAN. Model parameters consist of beam areas and inertias card entries. Weighting matrices are usually diagonal, and are scaled such that they are divided by the square of the initial value. The units for all computations are therefore, fractional changes rather than absolute changes to avoid numerical problem caused by a wide variance of units.

The minimization of Equation 2 is performed with the use of MSC/NASTRAN SOL 200. This approach follows closely the paper presented in Ref.9.

The GVT results are considered as the baseline standard data. This means that the GVT data are assumed correct a priori. The relative error is defined as the discrepancy between the corresponding measures frequencies of GVT and the computed frequencies of the structural FEM. The minimum of the relative error in the corresponding frequencies of GVT and structural FEM implies the optimization of the member properties corresponding to the selected design variable in the optimization process. Considering the selection criteria described above, these design variable are the member properties I1, I2, and J of the equivalent beam replacements of the structural FEM. Recall the optimization process to minimize the relative error using MSC/NASTRAN SOL 200.

2.4. Wind Tunnel Flutter Test

The test model is valid to use on wind tunnel flutter test after confirmed through GVT and validation tests. Likewise the wind tunnel itself must be already fulfilled the wind tunnel safety requirement.

The main objectives of the wind tunnel flutter test are:

- To compare the dynamic and flutter characteristics between the computational/analysis model with the test model.
- To calculate the level of accuracy and representativeness of the test model on dynamic and flutter characteristics of wing of the N219.
- To simulate and understand flutter testing process and methodology.

The wind tunnel model flutter test will be carried out by sweeping the speed which started from the lowest speed up to flutter speed (if possible).

The execution of test will be conducted into two steps sweep speeds are as follows:

- The first step is to obtain preliminary data and as an exercise test procedure (Familiarization) prior to testing at higher and more critical speed (close to flutter speed). The speed sweeps of test will be conducted gradually started from speed 5.0 m/s, 10.0 m/s and 15.0 m/s. From the previous analysis document, it shows that the cruising speed on wind tunnel is around 15 m/s and the diving speed is around 21.0 m/s.
- The second step will focus to observe interaction of structural dynamic with aerodynamic force (Flutter phenomenon), and to predict flutter occurrence speed. The second step will started from speed 20.0 m/s, and continue with 5.0 m/s speed increment (situational), if the test is closing to flutter speed, then the speed increment can be reduce to increase the flutter speed prediction accuracy. The test will be continue until the test model structural dynamic behavior show signs of near flutter occurrence. This wind tunnel flutter test is not destructive testing, so the test will be stop if the test model shows sign of destructive possibility (i.e. large displacement).

According to spring value, there are 3 configurations model: Soft spring, Moderate spring, and hard spring. The wing tunnel flutter test only performed on soft spring model and moderate spring model. The Wind Tunnel Flutter Test for N219 half wing ideally has procedure shown on Figure 4. Remark: the block diagram of Flutter Margin Use Zimmerman is not recognized.

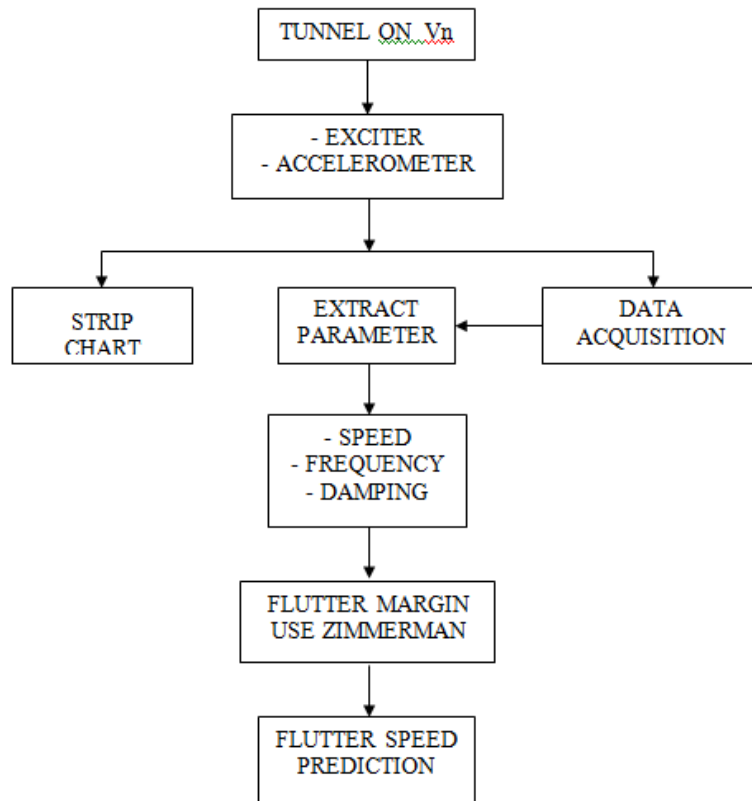


Figure 4 Procedure of Wind Tunnel Flutter Test

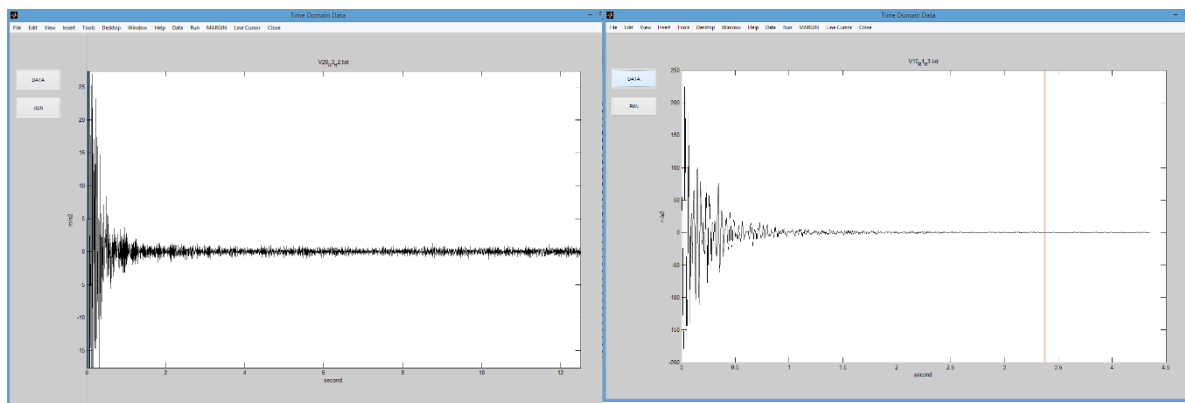
The half wing model was placed in wind tunnel then the accelerometer will received response from the exciter. The response will be read by data acquisition system then forwarded to extract parameter software to determine flutter margin. Figure 5 is the model installation in test section of wind tunnel.



Figure 5 The half wing model installation in test section of wind tunnel.

The flutter margin cannot be resulted online due to delay of data transfer from data acquisition system to the extract parameter, therefore flutter speed from FEM analysis was used as speed limitation. The strip chart also cannot be used due to technical error in the software.

Data acquisition system forwarded data response to be analyzed by extract parameter software. The extract parameter was generated by Matlab coding will result speed, frequency, and damping data by curve fitting process. The extract parameter data for soft spring and moderate spring as showed in Figure 6.



(a).....(b).

Figure 6 Extract parameter data for soft spring (a) and moderate spring (b).

3. RESULTS

Table 4 Comparison Mode Shape & Frequency FEM Test, GVT and FEM Up Date Soft Spring model.

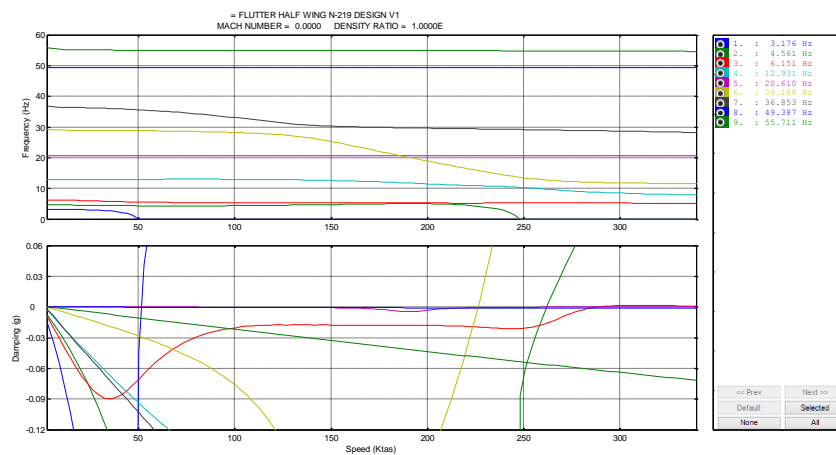
No	Mode Shape	Analysis (Hz)	GVT (Hz)	Analysis Update (Hz)
1	Wing Vertical Bending	3.23	3.11	3.23
2	Wing Inplane Bending	5.08	5.21	4.58
3	Wing Torsion		5.93	6.20
4	Wing Vertical Bending	12.46	12.88	13.15
5	Wing Torsion	18.14		
6	Wing Inplane Bending	20.37	20.03	20.61
7	Wing Torsion		25.91	
8	Wing Bending Torsion	29.09	28.51	29.37

Table 5 Comparison Mode Shape & Frequency FEM Test, GVT and FEM Up Date Moderate Spring model.

No	Mode Shape	Analysis (Hz)	GVT (Hz)	Analysis Update (Hz)
1	Wing Vertical Bending	3.23	3.06	3.19
2	Wing Inplane Bending	5.08	5.21	5.03
3	Wing Torsion		8.72	8.62
4	Wing Vertical Bending	12.46	12.70	13.28
5	Wing Torsion	18.14		
6	Wing Inplane Bending	20.37	20.02	20.61
7	Wing Torsion		26.58	
8	Wing Bending Torsion	29.09	28.60	29.41

There are 86% of the test modes that correspond to the analytical FEM Update modes.

The Figure7 and Figure 8 are the results of the NASTRAN calculation of half wing model of N219 aircraft.

**Figure 7** V-g-f Curve of Model Half Wing N219-B11 update Based on GVT BBTA3 Soft Spring Model

Flutter Speed 51 ktas (26.23m/s) at damping 0% and 52 ktas (26.75 m/s) at damping 3%.
Main Flutter Mechanisms *Wing Bending* (3.23 Hz) couple with *Wing Torsion* (6.20 Hz).

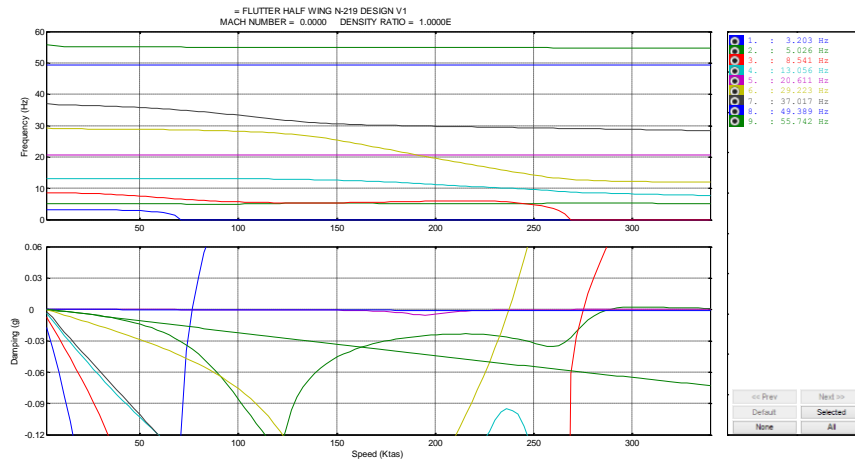


Figure 8 V-g-f Curve of Model Half Wing N219-B11 update Based on GVT BBTA3 Moderate Spring Model

Flutter Speed 76.29 ktas (39.24m/s) at damping 0% and 79 ktas (40.83m/s) at damping 3%.
Main Flutter Mechanisms *Wing Bending (3.26 Hz) couple with Wing Torsion (8.6 Hz)*.

Based on data result from extract parameter there was coupling between bending mode and torsion mode on moderate spring model, shown in Figure 9. During a coupling the damping value approached zero on moderate spring model, it can be seen in Figure 10.

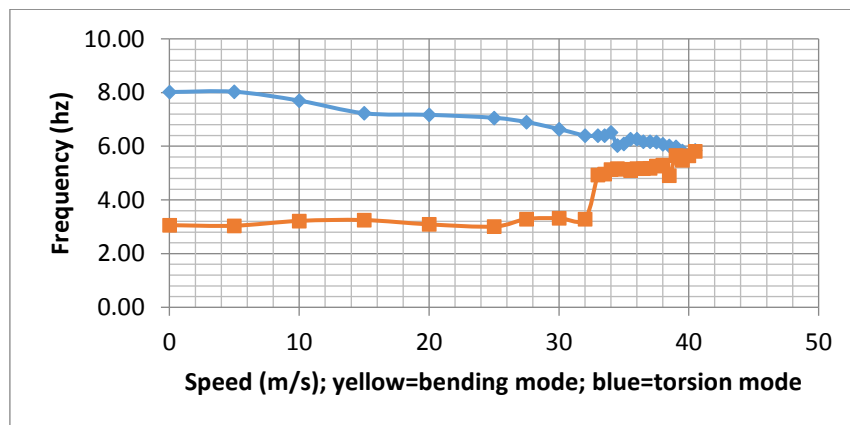


Figure 9 Frequency of bending and torsion mode at moderate spring model

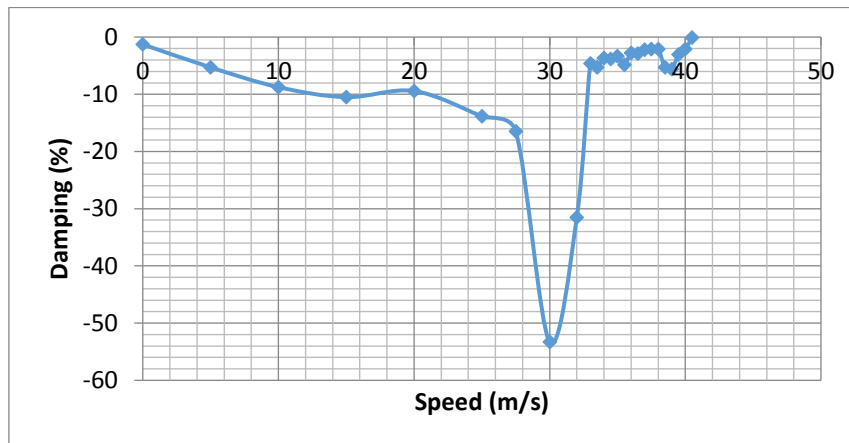


Figure 10 Damping of torsion mode at moderate spring model

The bending frequency increased and torsion mode decreased then coupling occurred at speed 40.5 m/s, frequency 5.8 Hz and damping 0.06 %. According to these data can be concluded that flutter speed happened at 40.5 m/s while FEM analysis result showed flutter speed at 40.83 m/s. Therefore the flutter speed based on FEM analysis and Wind Tunnel Test was nearly the same.

For the soft spring model case, the data that was sent by data acquisition system cannot be processed properly in extract parameter due to spring property. The spring was very responsive therefore other frequency appeared.

When wind speed reached 24 m/s, half wing model vibrated without excitation, it showed that half model wing already unstable. Frequency of bending and torsion mode were difficult to be extracted thus frequency of coupling mode also hard to be determined. Figure 11 and Figure 12 are shows the frequency and damping of bending and torsion mode at soft spring model.

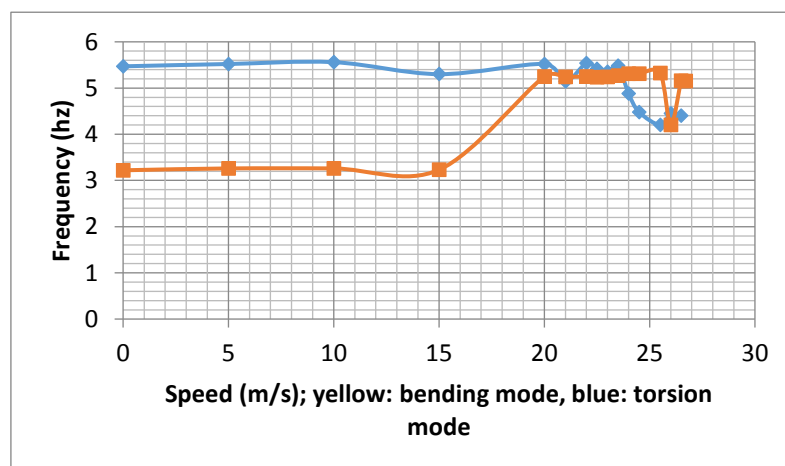


Figure 11 Frequency of bending and torsion mode at soft spring model

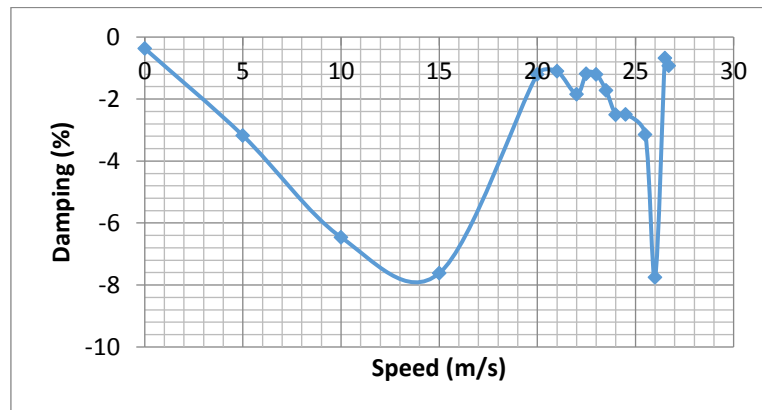


Figure 12 Damping of torsion mode at soft spring model

Based on the V-f curve and V-g curve, there can be seen that there is an existence of coupling mode at speed of 24.0 m/s, yet it does not indicate the phenomenon of flutter. The noise made it difficult to extract the data, therefore this coupling mode was not necessarily caused by the frequency of bending or torsion mode. In order for the data extraction process to be more convenient, it is recommended that the data is filtered beforehand.

4. CONCLUSION

Wind tunnel flutter test represents the real flight condition, therefore its result was used to validate Finite Element Model analysis result. Comparison between FEM analysis and wind tunnel flutter test show at Table 6.

Table 6 Comparison between Analysis FEM and Wind Tunnel Test Result

Case	Flutter Speed (m/s)	
	Analysis	Wind Tunnel Test
Moderate Spring	40.8	40.5
Soft Spring	25.7	24.0

In moderate spring case, flutter speed resulted by FEM analysis and wind tunnel flutter test showed nearly the same result. In soft spring case, FEM analysis resulted flutter speed at 26.75 m/s however in wind tunnel flutter test at speed 24.0 m/s the half wing structure already unstable. According to the comparison between FEM analysis and wind tunnel flutter test, can be concluded that the methodology of FEM analysis has been correctly validated.

References

- [1] Blakely, K, *MSC/NASTRAN Basic Dynamic Analysis*, Los Angeles, MacNeal-Schwendler Corporation, 1993.
- [2] Blackely, Ken, “*Updating MSC/NASTRAN Models to Match Test Data*”, MSC 1991 World User’s Conference, Volume II, March 11-15, 1991.
- [3] Brenner, M.J., “*Aeroservoelastic Modeling and Validation of a ThrustVectoring F/A-18 Aircraft*”, *NASA Technical Paper 3647*, September 1996.
- [4] Cheng, P.Y. and Hirner, T.J., “*Aircraft Aeroservoelastic Compensation Using Constrained Optimization*”, *AIAA Structures, Structural Dynamics, and Materials Conference*, AIAA-1992-2399, April 1992.

- [5] Daniel Norrison, Nomad Flutter and Flow Simulation Acceleration for Elastics Wing, School of Mathematical and Geospatial Sciences, College of Science, Engineering and Health, RMIT University, 2009
- [6] Gupta, K.K., Brenner, M.J., and Voelker, L.S., “Development of an Integrated Aeroservoelastic Analysis Program and Correlation with Test Data”, *NASA Technical Paper 3120*, May 1991.
- [7] Lokatt, Mikaela *Aeroelastic flutter analysis considering modeling uncertainties*. Journal of fluids and structures:2017
- [8] Moore, G. J. “MSC/NASTRAN, Design Sensitivity and Optimization, User’s Guide V68”, May 1994.
- [9] Pendleton, E., Lee, M., and Wasserman, L., “Application of Active Flexible Wing Technology to the Agile Falcon”, *AIAA Journal of Aircraft*, Vol. 29, No. 3, May-June 1992.
- [10] Pratt, R.W., Taylor, R., and Caldwell, B.D., “Aeroservoelasticity: Key Issues Affecting the Design of Flight Control Systems”, *IEEE Control Conference Publication No. 389*, March 1994
- [11] Sayuti Syamsuar, Muhammad Kusni, Adityo Suksmo, Mohamad Ivan Aji Saputro, The Analysis Of Half Wing Flutter Test N219 Aircraft Model In The Low Speed Wind Tunnel, *Warta Ardhia, Volume 42 No. 4, ISSN: 0215-9066*, Kemen-Hub, Jakarta, Desember 2016
- [12] Sayuti Syamsuar, Leonardo Gunawan, Martina Widiramdhani, Nina Kartika, The The Design and Experiment of Ground Vibration Test of N219 Aircraft Half Wing Model, *Warta Ardhia, Volume 42 No. 3, ISSN: 0215-9066*, Kemen-Hub, Jakarta, Desember 2016
- [13] Schaeffer, H.G, *MSC/NASTRAN Primer—Static and Normal Modes Analysis*, Milford, Wallace Press, 1988.
- [14] Strass, H.K., and Stephens, E.W., “An Engineering Method for Determination of Aeroelastic Effects upon the Rolling Effectiveness of Ailerons on Swept Wings”, *NACA Research Memorandum L53H14*, November 1953 22 of 23 American Institute
- [15] Tang, D and E. H Dowell, Experimental Aeroelastic Models Design and Wind Tunnel Testing for Correlation with New Theory, *Aerospace*, 2016
- [16] Tsushima, Natsuki and Su, Weihua. *Flutter suppression for highly flexible wings using passive and active piezoelectric effects*. Aerospace science and technology:2017.
- [17] Westin, Michelle F et all. *Aeroservoelastic modeling of a flexible wing for wing tunnel flutter test*. Proceedings of COBEM 2009
- [18] Wilson, J.R., “Active Aeroelastic Wing: a New/Old Twist on Flight”, Aerospace America, September 2002.