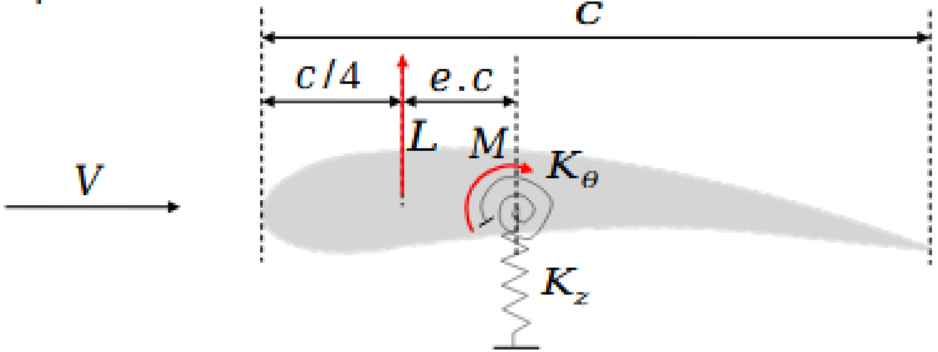
Quinta Aula de Aeroelasticidade

Roteiro

1) Modelo Aeroelástico do Túnel de Vento desenvolvido pelo Prof Juan
2) Programa binário modificado
3) Análise do arquivo f06
4) Representação gráfica do amortecimento e da frequência
5) Perguntas Comuns sobre o trabalho

Esquema Elástico



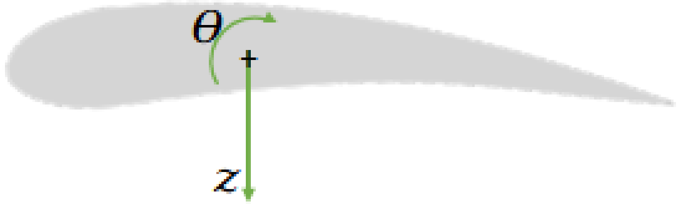
1.- Ecuación de Lagrange

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_i}\right)+\frac{\partial U}{\partial q_i}=Q_i$$

2.- Energía Potencial Elástica

$$U=\frac{1}{2}K_\theta \theta^2+\frac{1}{2}K_z Z^2$$

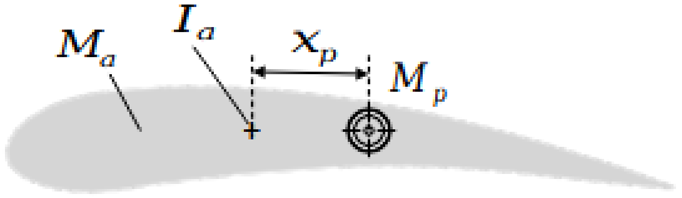
Grados de libertad (2 DoF)



3.- Energía Cinética

$$T=\frac{1}{2}M_a\dot{Z}^2+\frac{1}{2}I_a\dot{\theta}^2+\frac{1}{2}M_p\left(\dot{Z}+x_p\dot{\theta}\right)^2$$

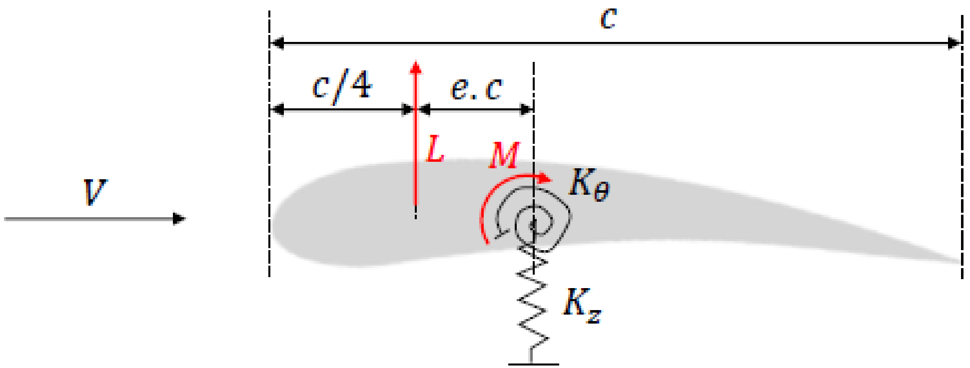
Esquema de inercia



3.- Fuerzas Generalizadas

$$Q_z=-\frac{1}{2}\rho V^2 c\, a_1 s\left(\theta+\frac{\dot{z}}{V}\right)$$

$$Q_\theta=\frac{1}{2}\rho V^2 c^2 s\left(a_1 e\left(\theta+\frac{\dot{z}}{V}\right)+M_{\dot{\theta}}\frac{\dot{\theta}c}{4V}\right)$$



Amortiguamiento
Aerodinámico

Rigidez
Aerodinámica

$$\begin{bmatrix} M_z & M_{z\theta} \\ M_{z\theta} & M_\theta \end{bmatrix} \begin{Bmatrix} \ddot{z} \\ \ddot{\theta} \end{Bmatrix} + \frac{1}{2}\rho V \begin{bmatrix} ca_1 s & 0 \\ -c^2 sea_1 & -\dfrac{c^3 s M_{\dot{\theta}}}{4} \end{bmatrix} \begin{Bmatrix} \dot{z} \\ \dot{\theta} \end{Bmatrix} + \left(\frac{1}{2}\rho V^2 \begin{bmatrix} 0 & ca_1 s \\ 0 & -c^2 sea_1 \end{bmatrix} + \begin{bmatrix} K_z & 0 \\ 0 & K_\theta \end{bmatrix} \right) \begin{Bmatrix} z \\ \theta \end{Bmatrix} = 0$$

$$\mathbf{A}\ddot{q} + \rho V \mathbf{B}\dot{q} + (\rho V^2 \mathbf{C} + \mathbf{E})q = 0$$

$$\begin{bmatrix} M_z & M_{z\theta} \\ M_{z\theta} & M_\theta \end{bmatrix}\begin{Bmatrix}\ddot{z}\\ \ddot{\theta}\end{Bmatrix} + \frac{1}{2}\rho V \begin{bmatrix} ca_1 s & 0 \\ -c^2 sea_1 & -\dfrac{c^3 s M_{\dot{\theta}}}{4}\end{bmatrix}\begin{Bmatrix}\dot{z}\\ \dot{\theta}\end{Bmatrix} + \left(\frac{1}{2}\rho V^2 \begin{bmatrix}0 & ca_1 s\\ 0 & -c^2 sea_1\end{bmatrix} + \begin{bmatrix}K_z & 0\\ 0 & K_\theta\end{bmatrix}\right)\begin{Bmatrix} z\\ \theta\end{Bmatrix} = 0$$

$$\mathbf{A}\ddot{q} + \rho V\mathbf{B}\dot{q} + (\rho V^2\mathbf{C} + \mathbf{E})q = 0$$

$$+$$

$$\mathbf{I}\dot{q} - \mathbf{I}\dot{q} = 0$$

$$\begin{bmatrix}\mathbf{I} & 0\\ 0 & \mathbf{A}\end{bmatrix}\begin{Bmatrix}\dot{q}\\ \ddot{q}\end{Bmatrix} - \begin{bmatrix} 0 & \mathbf{I}\\ -(\rho V^2\mathbf{C} + \mathbf{E}) & -(\rho V\mathbf{B})\end{bmatrix}\begin{Bmatrix} q\\ \dot{q}\end{Bmatrix} = 0$$

$$\begin{Bmatrix}\dot{q}\\ \ddot{q}\end{Bmatrix} - \begin{bmatrix} 0 & \mathbf{I}\\ -\mathbf{A}^{-1}(\rho V^2\mathbf{C} + \mathbf{E}) & -\mathbf{A}^{-1}(\rho V\mathbf{B})\end{bmatrix}\begin{Bmatrix} q\\ \dot{q}\end{Bmatrix} = 0$$

$$\begin{Bmatrix} q\\ \dot{q}\end{Bmatrix} = \{q_0\}e^{\lambda t} \qquad \begin{Bmatrix}\dot{q}\\ \ddot{q}\end{Bmatrix} = \lambda\{q_0\}e^{\lambda t}$$

$$(\mathbf{I}\lambda - \mathbf{Q})\{q_0\} = 0$$

$$\lambda_i = -\xi_i\omega_i \pm i\omega_i\sqrt{1-\xi_i^2}$$

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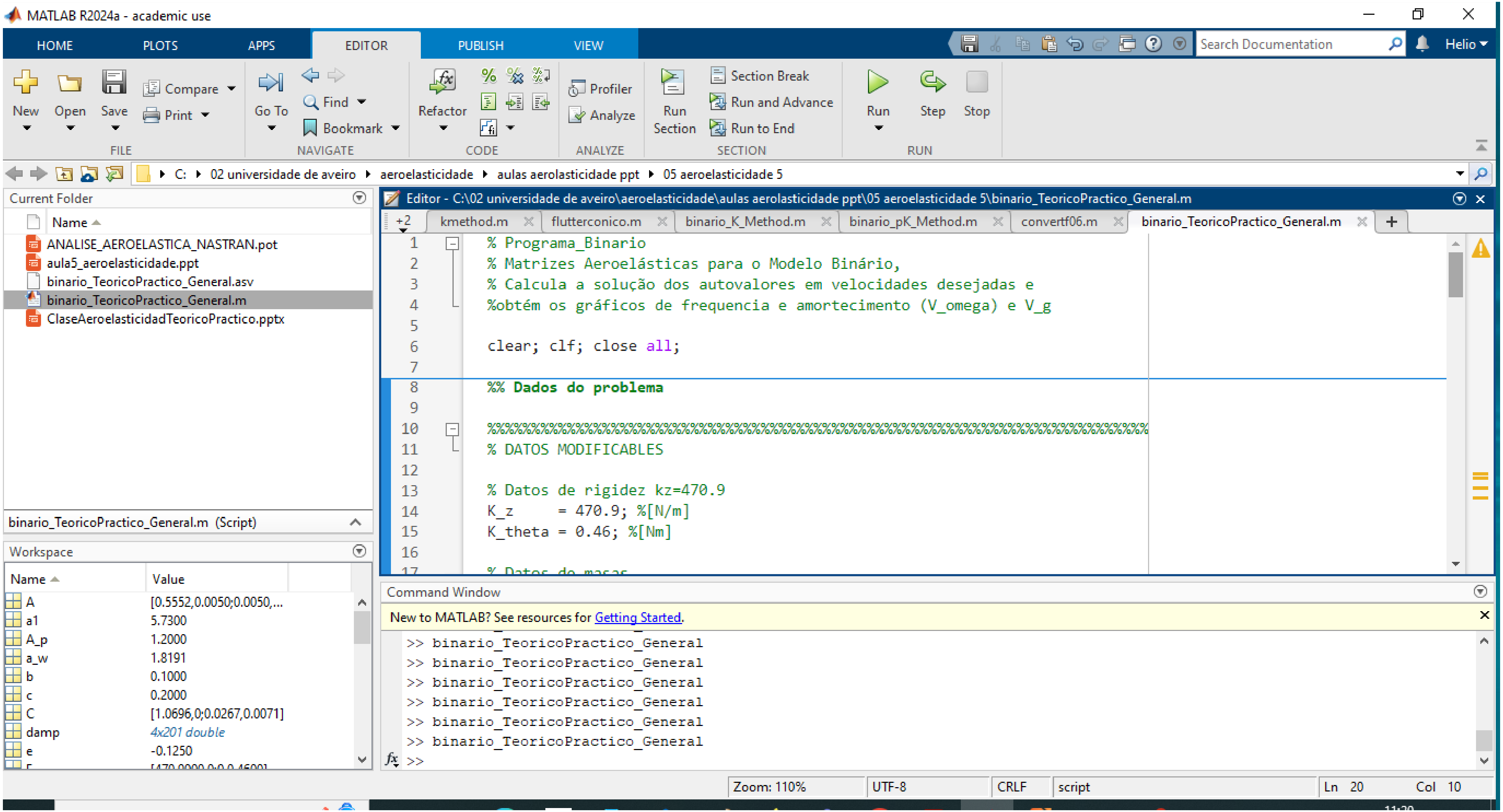
MATLAB R2024a - academic use
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C: ▸ 02 universidade de aveiro ▸ aeroelasticidade ▸ aulas aerolasticidade ppt ▸ 05 aeroelasticidade 5
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aula5_aeroelasticidade.ppt
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binario_TeoricoPractico_General.m
ClaseAeroelasticidadTeoricoPractico.pptx
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Workspace
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Value
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A_p 1.2000
a_w 1.8191
b 0.1000
c 0.2000
C [1.0696,0;0.0267,0.0071]
damp 4x201 double
e -0.1250
Editor - C:\02 universidade de aveiro\aeroelasticidade\aulas aerolasticidade ppt\05 aeroelasticidade 5\binario_TeoricoPractico_General.m
kmethod.m
flutterconico.m
binario_K_Method.m
binario_pK_Method.m
convertf06.m
binario_TeoricoPractico_General.m
% Programa_Binario
% Matrizes Aeroelásticas para o Modelo Binário,
% Calcula a solução dos autovalores em velocidades desejadas e
%obtém os gráficos de frequencia e amortecimento (V_omega) e V_g
clear; clf; close all;
%% Dados do problema
%%%
% DATOS MODIFICABLES
% Datos de rigidez kz=470.9
K_z = 470.9; %[N/m]
K_theta = 0.46; %[Nm]
Command Window
New to MATLAB? See resources for Getting Started.
>> binario_TeoricoPractico_General
>> binario_TeoricoPractico_General
>> binario_TeoricoPractico_General
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>> binario_TeoricoPractico_General
>> binario_TeoricoPractico_General
>>
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script
Ln 20
Col 10

Influência da Rigidez

	Túnel de Vento	Aumento de Kz	Aumento de Kq	Aumento de ambos
Kz	470,9	1000	470,9	1000
Kq	0,46	0,46	2	2
Vf				

Influência da Massa Mp

	Túnel de Vento	Aumento da Massa	Sem Massa	Vf (m/s)
Mp	0,1 kg	0,5 kg	0	-
e1	-	0	0	
e2	-	-0,0875	-0,0875	
e3	-0,125	-0,125	-0,125	

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arquivo *.f06

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Rest. Tamanho

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FLUTTER SUMMARY

CONFIGURATION = AEROSG2D XY-SYMMETRY = ASYMMETRIC XZ-SYMMETRY = ASYMMETRIC

POINT = 1 MACH NUMBER = 0.8000 DENSITY RATIO = 3.1060E-01 METHOD = PK

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0.0022	4.4799179E+02	1.0110000E+04	-2.2838347E-02	3.5917096E+00	-2.5770080E-01	2.2567377E+01
0.0022	4.4751471E+02	1.0120000E+04	-2.2910345E-02	3.5990953E+00	-2.5904480E-01	2.2613783E+01
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0.0023	4.4293365E+02	1.0210000E+04	-2.3601618E-02	3.6686575E+00	-2.7201873E-01	2.3050856E+01
0.0023	4.4239096E+02	1.0220000E+04	-2.3683803E-02	3.6767554E+00	-2.7356848E-01	2.3101736E+01
0.0023	4.4184119E+02	1.0230000E+04	-2.3767188E-02	3.6849325E+00	-2.7514222E-01	2.3153114E+01
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0.0023	4.4071988E+02	1.0250000E+04	-2.3937732E-02	3.7015307E+00	-2.7836475E-01	2.3257404E+01
0.0023	4.4014801E+02	1.0260000E+04	-2.4024976E-02	3.7099555E+00	-2.8001517E-01	2.3310339E+01
0.0023	4.3956866E+02	1.0270000E+04	-2.4113595E-02	3.7184663E+00	-2.8169277E-01	2.3363813E+01
0.0023	4.3898151E+02	1.0280000E+04	-2.4203639E-02	3.7270656E+00	-2.8339854E-01	2.3417845E+01

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(ft/s)

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0.0037	2.7354739E+02	1.0730000E+04	-1.1800372E-03	6.2429128E+00	-2.3143703E-02	3.9225380E+01
0.0036	2.7486902E+02	1.0740000E+04	-8.7167864E-04	6.2186856E+00	-1.7029617E-02	3.9073154E+01
0.0036	2.7622272E+02	1.0750000E+04	-5.4046640E-04	6.1939712E+00	-1.0516901E-02	3.8917870E+01
0.0036	2.7761093E+02	1.0760000E+04	-1.8360102E-04	6.1687312E+00	-3.5581219E-03	3.8759281E+01
0.0036	2.7903592E+02	1.0770000E+04	2.0207943E-04	6.1429319E+00	[illegible]	3.8597179E+01
0.0036	2.8050046E+02	1.0780000E+04	6.2036171E-04	6.1165333E+00	1.1920657E-02	3.8431313E+01
0.0035	2.8201202E+02	1.0790000E+04	1.0763544E-03	6.0893922E+00	2.0591080E-02	3.8260780E+01
0.0035	2.8356540E+02	1.0800000E+04	1.5744823E-03	6.0616469E+00	2.9983222E-02	3.8086452E+01
0.0035	2.8516913E+02	1.0810000E+04	2.1219158E-03	6.0331388E+00	4.0218081E-02	3.7907330E+01
0.0035	2.8682800E+02	1.0820000E+04	2.7269067E-03	6.0037951E+00	5.1433492E-02	3.7722958E+01
0.0035	2.8854739E+02	1.0830000E+04	3.3996431E-03	5.9735351E+00	6.3799113E-02	3.7532829E+01
0.0034	2.9033374E+02	1.0840000E+04	4.1531012E-03	5.9422631E+00	7.7530801E-02	3.7336342E+01
0.0034	2.9219485E+02	1.0850000E+04	5.0040237E-03	5.9098616E+00	9.2906594E-02	3.7132755E+01
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0.0034	2.9618036E+02	1.0870000E+04	7.0935306E-03	5.8410835E+00	1.3016845E-01	3.6700611E+01
0.0034	2.9833002E+02	1.0880000E+04	8.4020877E-03	5.8043294E+00	1.5321071E-01	3.6469677E+01
0.0033	3.0060669E+02	1.0890000E+04	9.9577336E-03	5.7656641E+00	1.8036811E-01	3.6226738E+01
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0.0031	3.1875122E+02	1.0950000E+04	3.5814553E-02	5.4674187E+00	6.1516523E-01	3.4352806E+01
0.0031	3.2277014E+02	1.0960000E+04	4.9707040E-02	5.4042740E+00	8.4392750E-01	3.3956055E+01
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0.0030	3.3479688E+02	1.1020000E+04	1.7194355E-01	5.2386613E+00	2.8298023E+00	3.2915482E+01
0.0030	3.3570212E+02	1.1030000E+04	1.8786402E-01	5.2292757E+00	3.0862780E+00	3.2856510E+01
0.0030	3.3653372E+02	1.1040000E+04	2.0276792E-01	5.2210827E+00	3.3259039E+00	3.2805031E+01
0.0030	3.3731299E+02	1.1050000E+04	2.1682374E-01	5.2137399E+00	3.5514531E+00	3.2758896E+01

Flutter

Ln 1, Col 1 100% Windows (CRLF) UTF-8

Roteiro

1) Modelo Aeroelástico do Túnel de Vento desenvolvido pelo Prof Juan
2) Programa binário modificado
3) Análise do arquivo f06
4) Representação gráfica do amortecimento e da frequência
5) Perguntas Comuns sobre o trabalho

Asa Exemplo - AH 145B

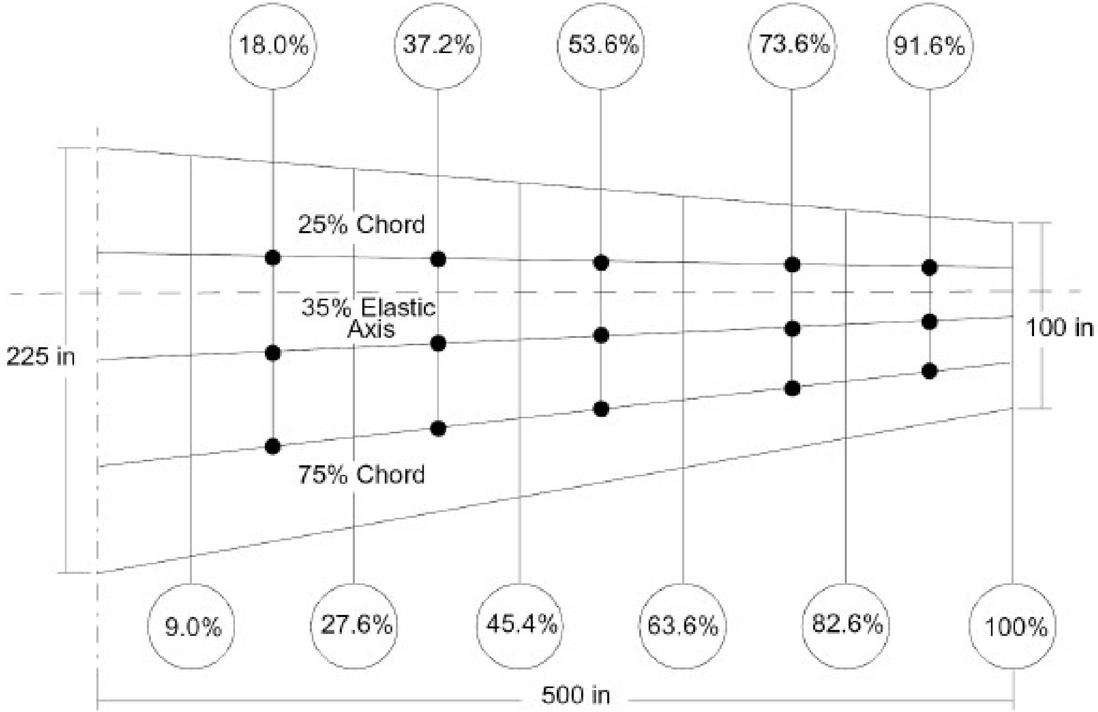
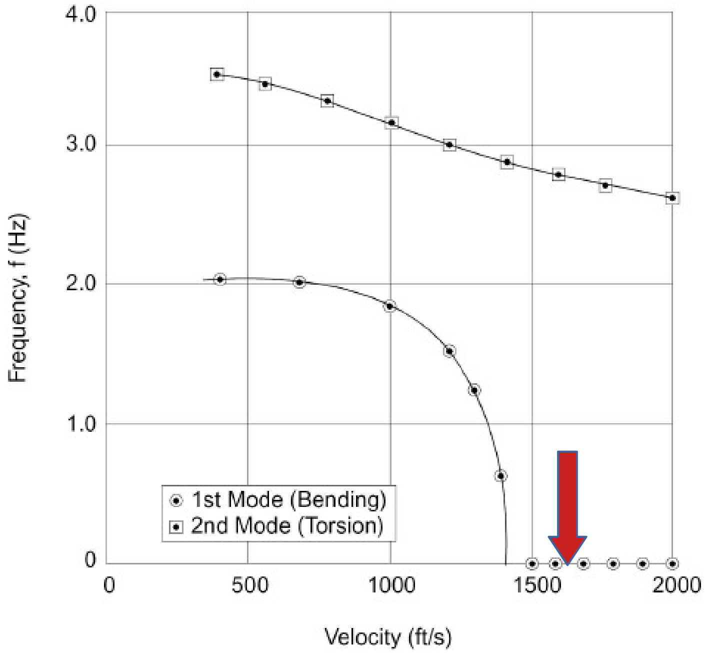
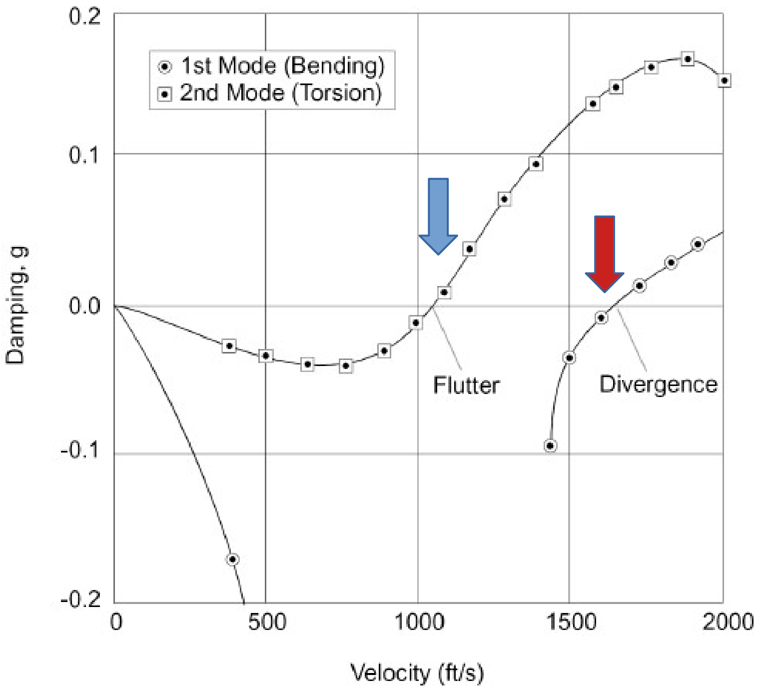


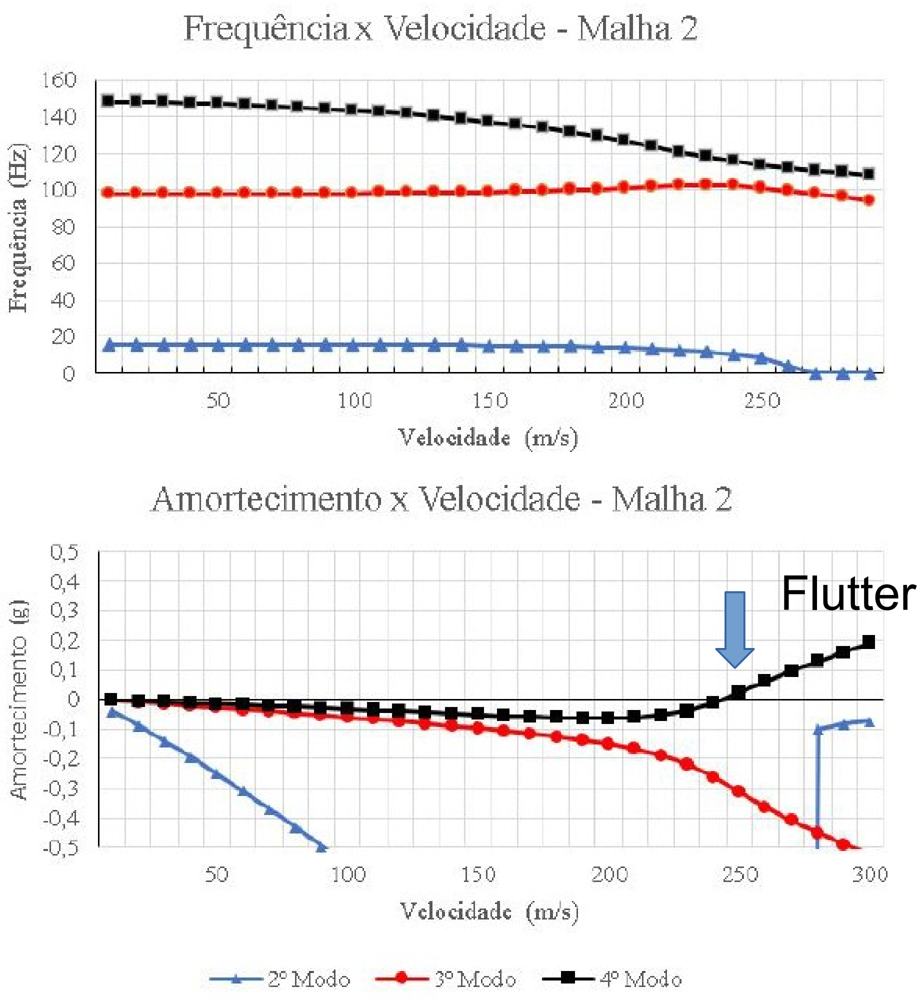
Figure 7-3. BAH Wing Planform and Aerodynamic Strip Idealization

Asa Exemplo - AH 145B





Exemplo de um UAV

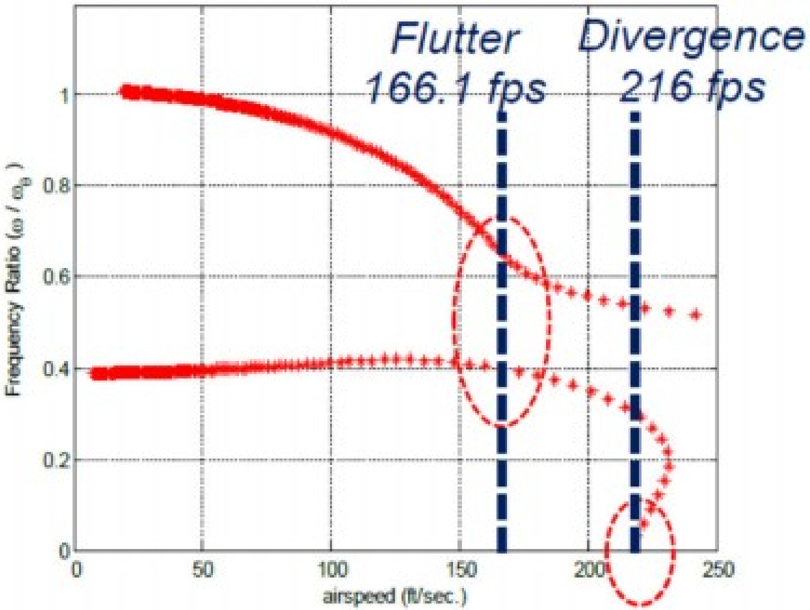


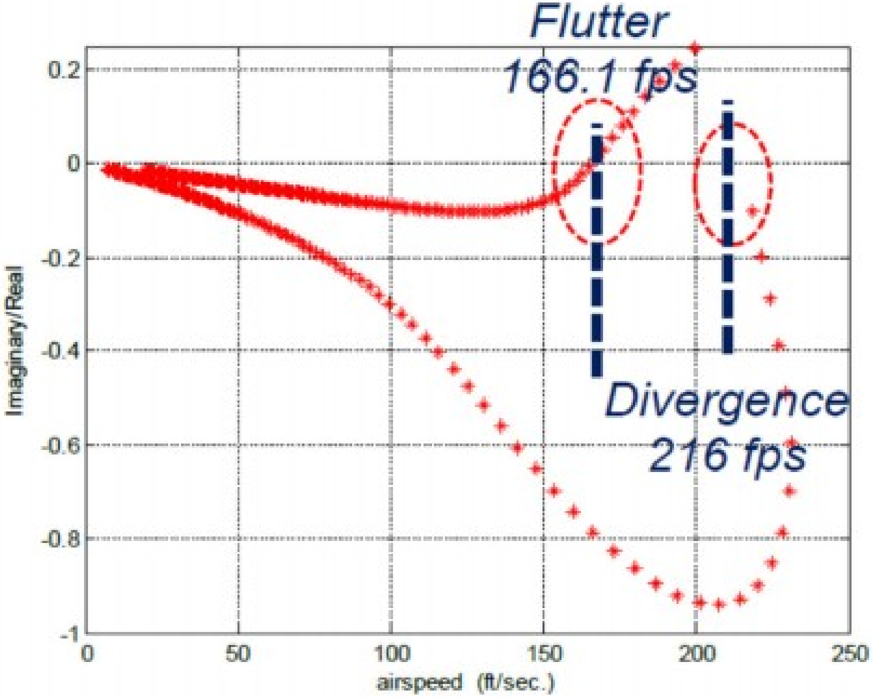
Roteiro

1) Modelo Aeroelástico do Túnel de Vento desenvolvido pelo Prof Juan
2) Programa binário modificado
3) Análise do arquivo f06
4) Representação gráfica do amortecimento e da frequência
5) Perguntas Comuns sobre o trabalho

Perguntas Comuns

1) Como identificar a divergência?
2) Qual é o modo que ocorre o flutter? O de torção ou o de flexão?


Flutter
166.1 fps
Divergence
216 fps
Frequency Ratio (ω / ωθ)
airspeed (ft/sec.)


Flutter
166.1 fps
Divergence
216 fps
Imaginary/Real
airspeed (ft/sec.)

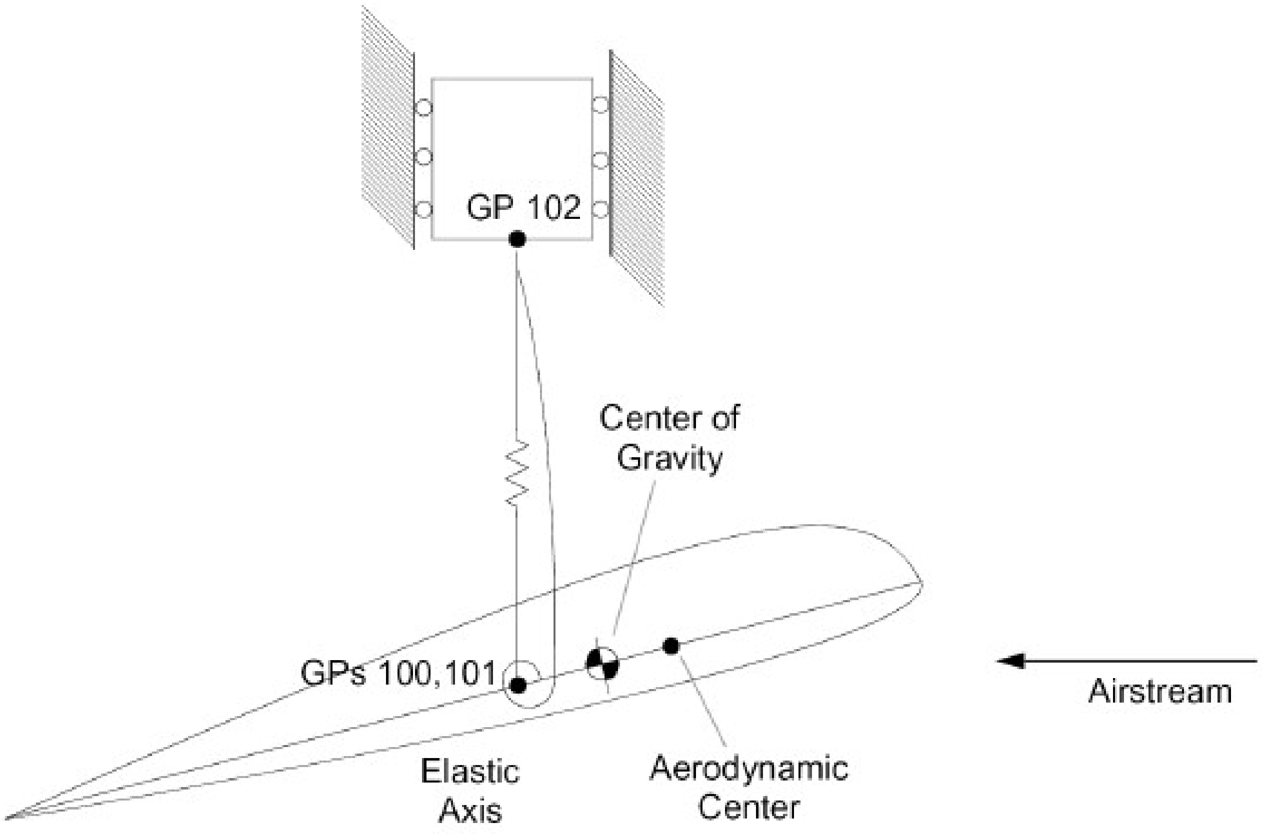
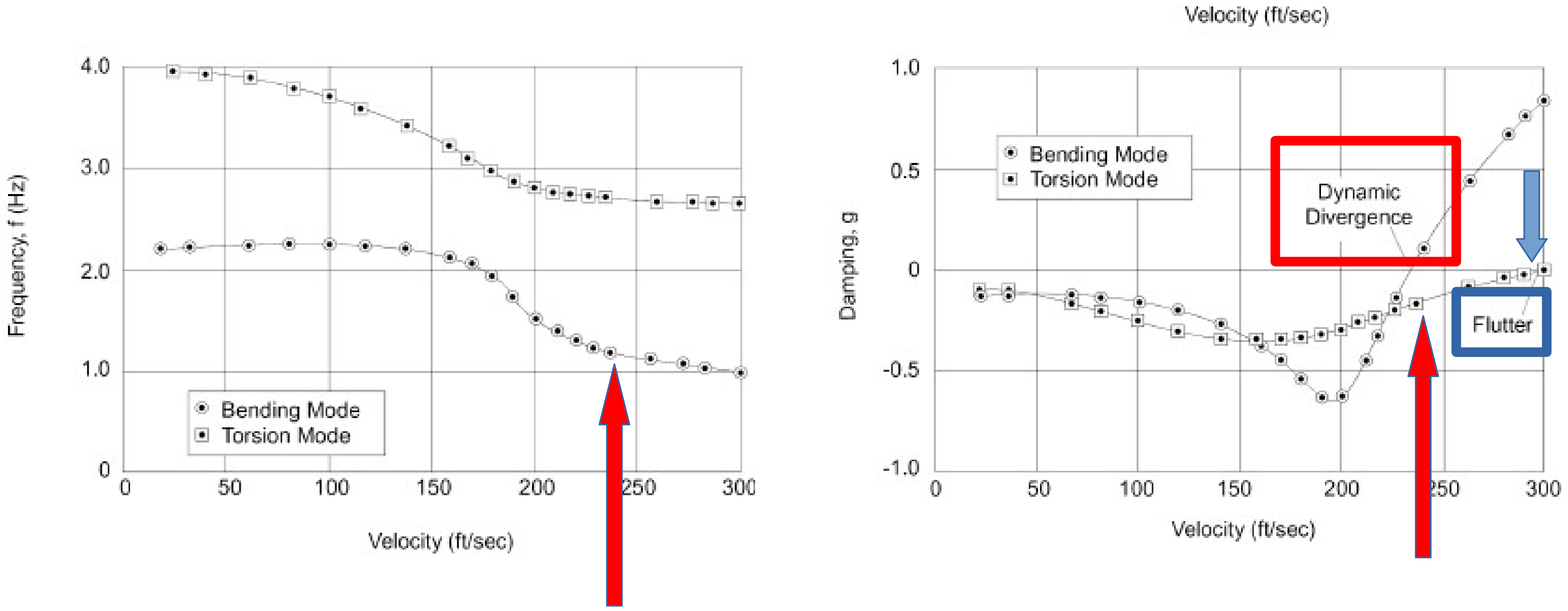


Figure 7-1. Three Degree of Freedom Airfoil and Fuselage

and unrestrained systems is a subject for further study. From Figure 7-2 and the printed Flutter Summary for Point 2, the "dynamic divergence" speed (i.e., the speed at which the oscillatory instability finds its origin in a tendency to static divergence) and frequency are 232.0 ft/s and 1.177 Hz, respectively. From Figure 7-2 and the Flutter Summary for Point 3, the flutter speed and frequency are 283.1 ft/s and 2.692 Hz, respectively. These results are only slightly different from



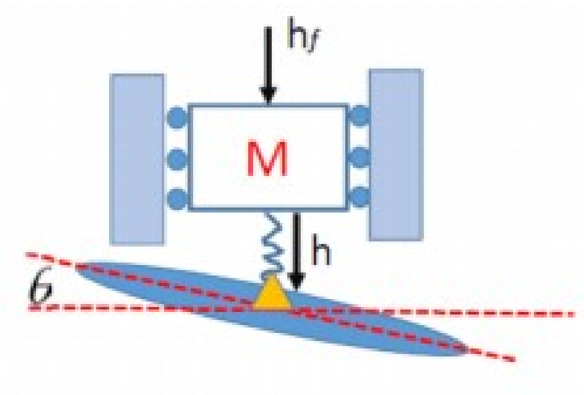
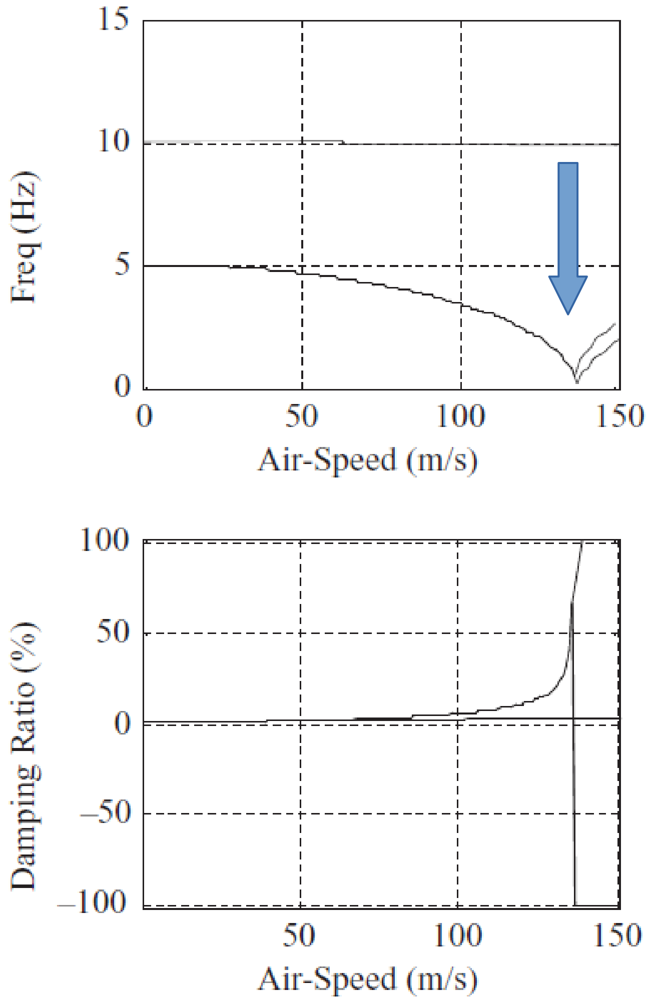


Figure 4.4.18 – Body-freedom model with fuselage mass plunge degree of freedom.

Figure 4.4.19 shows two figures that compare frequency merging results with and without pitch freedom. The figure on the right shows that flutter, through frequency merging, will not happen if pitch freedom is included. Instead, static divergence is the system mode of instability. Rodden[243] calls this phenomenon "dynamic divergence." It is an instability that involves the entire vehicle and is a function of the system frequencies and relative masses. On the other hand, it is also an aperiodic instability, like classical fully restrained divergence, so the adjective "dynamic" is superfluous. A better term might be "vehicle divergence." We will see this type of instability when we consider joined wing body-freedom flutter.

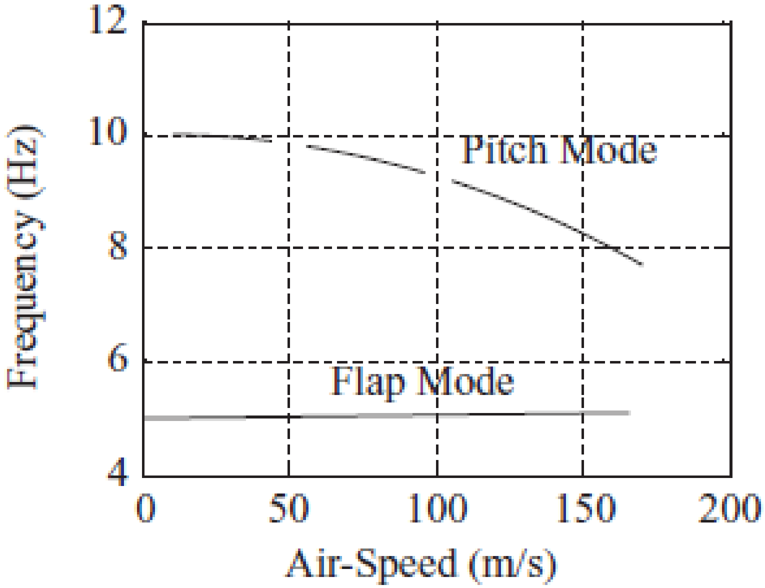
ANÁLISE WRIGHT E COOPER

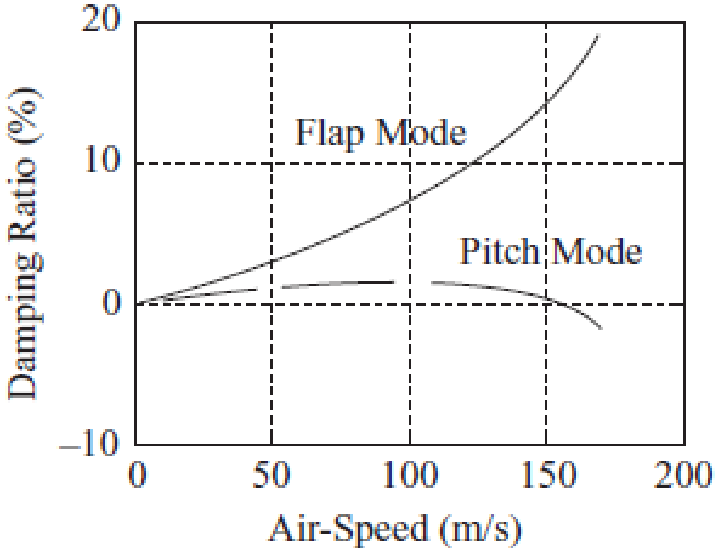


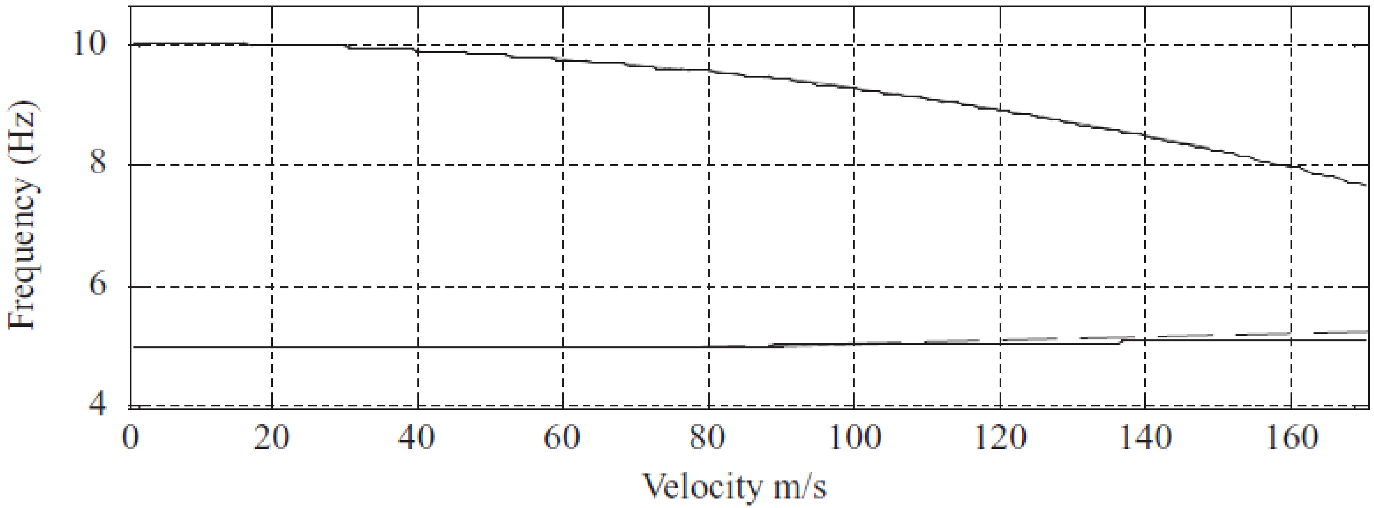
dIVERGêNCIA

FREQUêNCIA ZERO
=> PARTE IMAGINÁRIA VAI A ZERO

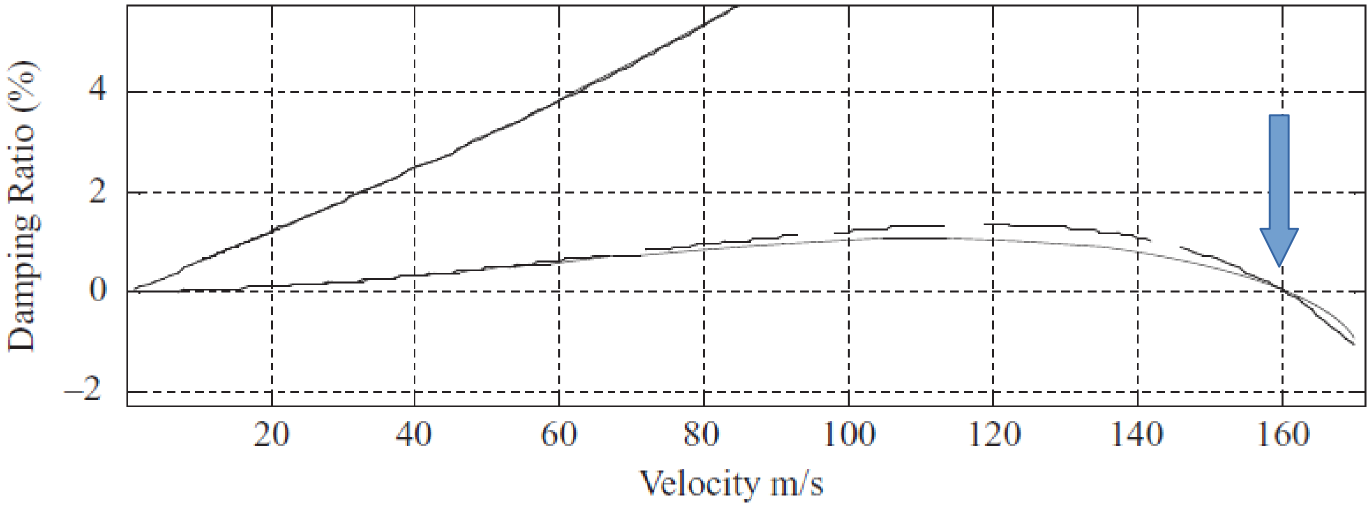
Modos do Flutter



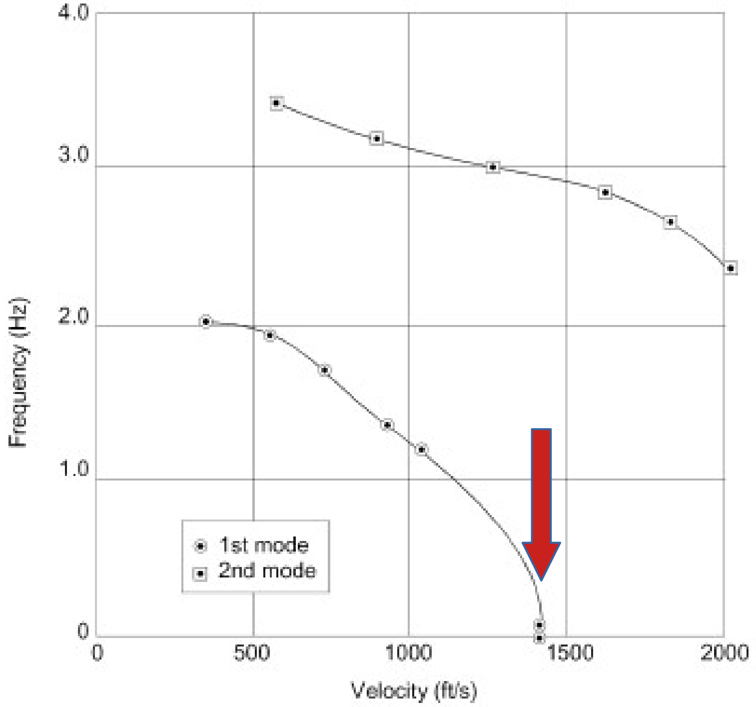


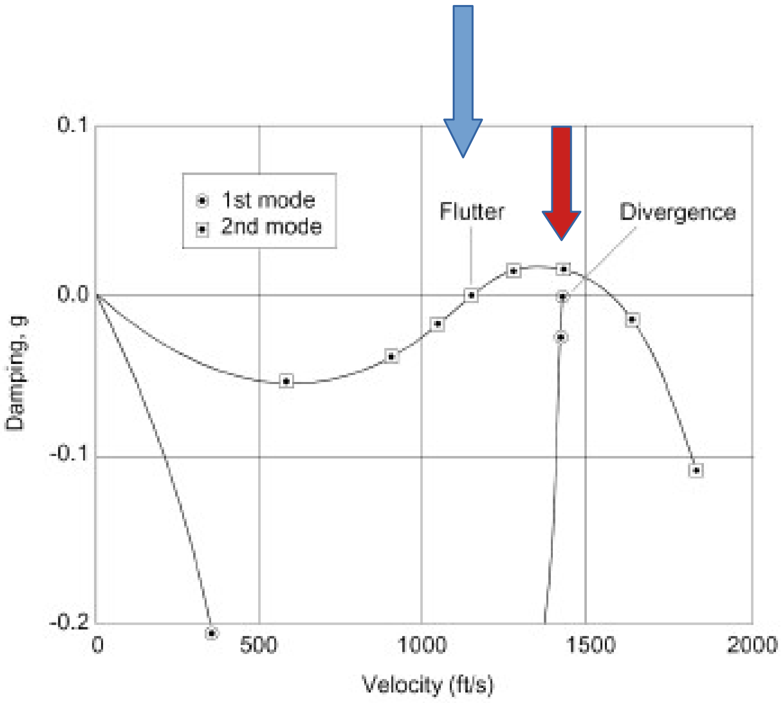


10
8
6
4
Frequency (Hz)
0
20
40
60
80
100
120
140
160
Velocity m/s



4
2
0
−2
Damping Ratio (%)
20
40
60
80
100
120
140
160
Velocity m/s


4.0
3.0
2.0
1.0
0
Frequency (Hz)
0
500
1000
1500
2000
Velocity (ft/s)
1st mode
2nd mode


0.1
0.0
-0.1
-0.2
Damping, g
0
500
1000
1500
2000
Velocity (ft/s)
1st mode
2nd mode
Flutter
Divergence

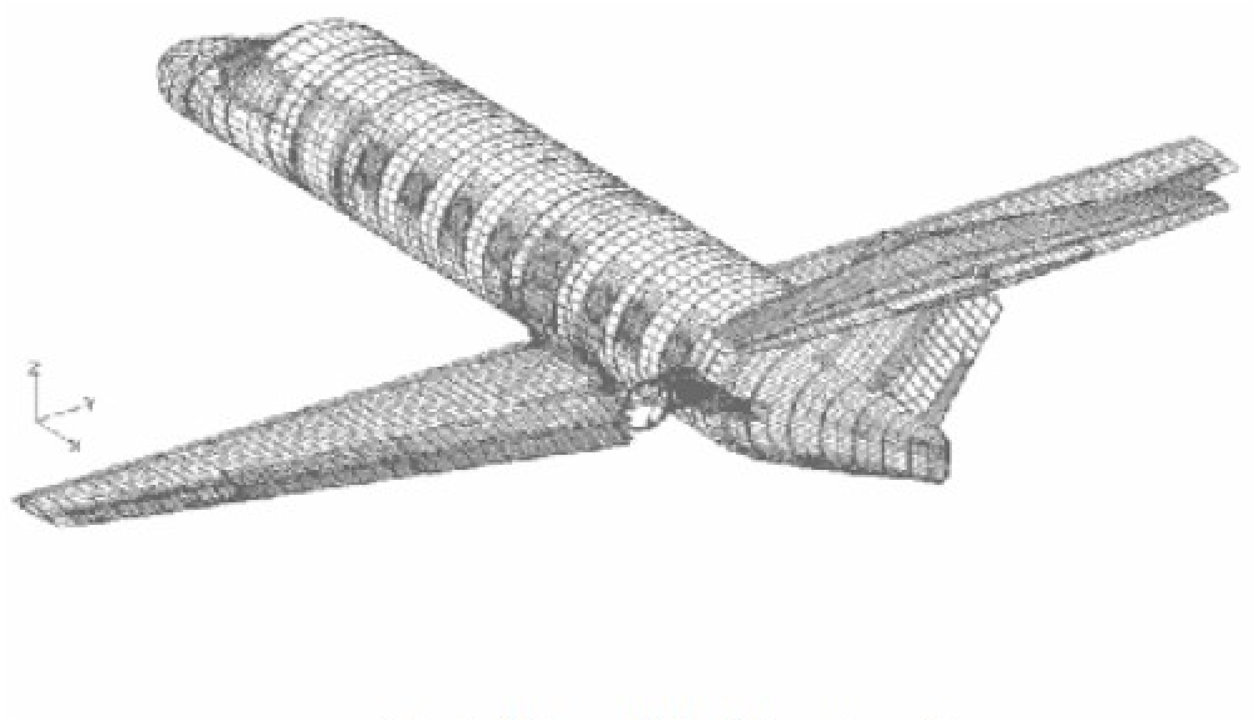
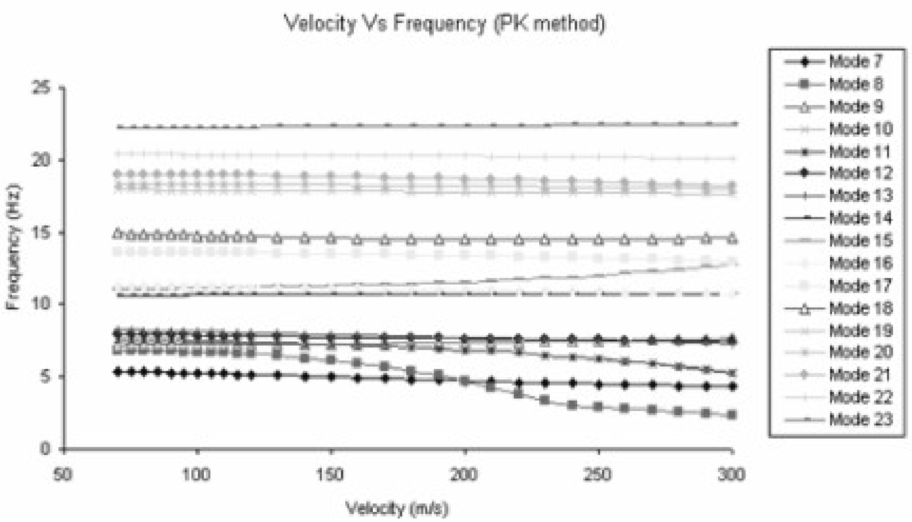


Fig.1 FE model of the aircraft

VITTALA N.G. V., PANKAJ A.C. e SWARNALATHA R. DYNAMIC AND AEROELASTIC ANALYSIS OF A TRANSPORT AIRCRAFT. Proceedings of the International Conference on Aerospace Science and Technology 26 - 28 June 2008, Bangalore, India.



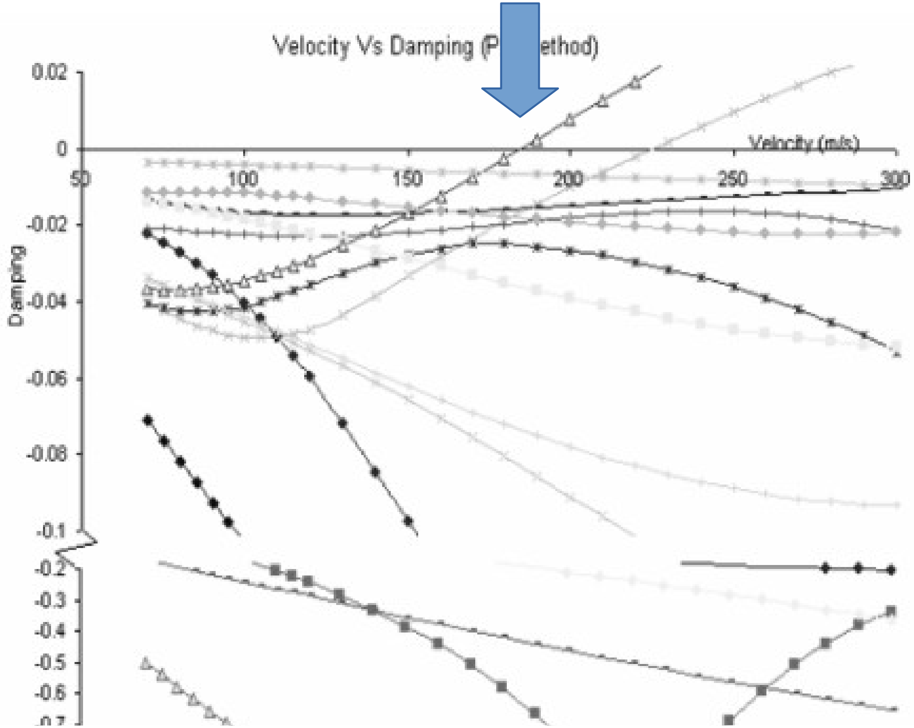


Table 3 Flutter Results of the Aircraft

Configuration	Method	Mode No	Flutter Velocity (Vf) (m/s)	Flutter frequency (Hz)	Flutter Margins (%)
1	PK	18	179.59	14.3359	27.76
	KE	18	179.68	14.3378	27.83