10.

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A.

Geometric and dynamic similitude

A.1. Introduction

Many examples in the literature are devoted to sectional model results derived from wind tunnel testing. Sometimes the geometric or dynamic characteristics of the full structure are not given, or one is interested in the real weight of the structure, or how the actual wind speed is obtained in terms of wind tunnel testing, and so on. Many interesting questions appeared as the present work was written, and this Appendix is written to address them in a straightforward way.

In the simulation of a physical phenomenon in a different scale than the original one, the fundamental dimensions M, L, T and the related dimensions for force, velocity, acceleration, volume, area, specific mass, etc, must be taken into account. As Newton's law $F_i = m_i a_i$ must be obeyed, only three dimensions may be chosen. The remaining dimensions must be dependent on the three fundamental dimensions. On the other hand, the Navier-Stokes equations must be also obeyed. Thus, for the present problem, the symbolic solution reads:

$$\Pi = f(M,\ RN,\ m/d^3\ ,\ \nu\, t\, /l, \nu^2\, /l\, g)$$

where

M = mass; RN = Reynold's number, m/d^3 = relative mass parameter or relative density parameter; $\nu\, t\, /l = t/(l/\nu) = t/t^*$ = aerodynamic time and $\nu^2\, /l\, g$ = Froude's number.

As the main interest of this work lies in the application rather than in the theoretical aspects of dimensional analysis, it is left to the reader to consult some general references on this subject, as for example, Etkin [14]; Lobo Carneiro [42]; Sédov [69] and Tanaka [82].

A.2. Example

This example was taken from Klöppel & Weber [29] and uses the following dimensional system (system Force-Length-Time = kgf-m-s):

Notation	Bridge scale 1:1	Model scale 1:m	Dimension
Mass per unit of length	m_A	m_M	$kgf.s^2.m^{-2}$
Polar radius of gyration	r_A	r_M	m
Polar moment of inertia per unit length	θ_A	θ_M	$kgf.s^2$
Frequency of heaving mode (bending eigen frequency)	f_{AB}	f_{MB}	s^{-1}
Frequency of pitching mode (torsion eigen frequency)	f_{AT}	f_{MT}	s^{-1}
Circular frequency	ω_A	ω_M	s^{-1}
Wind velocity	v_A	v_M	ms^{-1}
Air density (air specific mass)	ρ	ρ	$kgf.s^2.m^{-4}$
Bridge half width	b_A	b_M	m
Sectional model length	-	l_M	m
Distance between suspension wires	-	$2.e$	m
Spring constant	-	C	$kgf.m^{-1}$
Logarithmic decrement for bending vibrations	δ_B	δ_B	1
Logarithmic decrement for torsion vibrations	δ_T	δ_T	1

The following dimensionless equations must be identical in both model and real structure:

$m/\rho b^2$ (relative mass parameter or relative density parameter) (A2-1)

$\theta/\rho b^4$ (relative polar moment of inertia (A2-2)

$\omega b/\nu$ (reduced frequency) (A2-3)

δ (logarithmic decrement) (A2-4)

The following dimension ratios are free to choose:

$n = b_A / b_M$ (length ratio of real structure and model) (A2-5)

$p = v_A / v_M$ (ratio of real wind velocity and wind tunnel velocity) (A2-6)

Thus, the following dimensionless equations must be obeyed:

$$m_M = m / n^2 \quad \text{(A2-7)}$$

$$\theta_M = \theta_A / n^4 \tag{A2-8}$$

$$\omega_M = n\,\omega_A / p \tag{A2-9}$$

$$\delta_M = \delta_A \tag{A2-10}$$

The above model laws coincide with the ones deemed necessary by R. Barbré and R. Ibing [2], A. Selberg [70], and C. Scrutton [68] for section models experiments. F.B.Farquharson [16] and A. Hirai [20] consider Froude's law also important (the ratio between velocities might be equal to $\sqrt{n}$).

$$v_A{}^2/lg = v_M{}^2/Lg\ ,\ v_A{}^2 = v_M{}^2,\ p^2 = n\ ,\ p = \sqrt{n} \tag{A2-11}$$

Barbré & Ibing [2], and Klöppel [29] wind tunnel tests showed that this condition may be disregarded.

The wind tunnel set up for the test of a suspension bridge to be built over the Rhein river in Köln-Rödenkirche, Germany, in 1963, is explained in this section. The test set up is the same as the one described in detail by Barbré & Ibing [2].

The cross section of the future bridge would be similar to the already built Köln-Müllheim bridge, shown in Figure A-1.

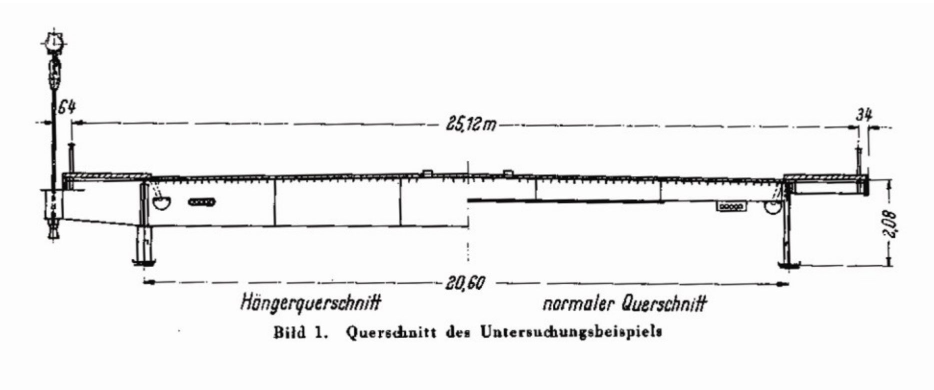

Figure A-1 - Cross section of the suspension bridge to be examined

The lowest circular frequencies of the bridge project were the following:

$$\omega_{AB} = 1.71\ s^{-1},\ \omega_{AT} = 1.96\ s^{-1}.$$

Both frequencies correspond to the antimetric modes. Considering amplitude increase due to wind, those modes are the most probable.

The schematic representation of the suspended model in the wind tunnel is shown in Figure A-2.

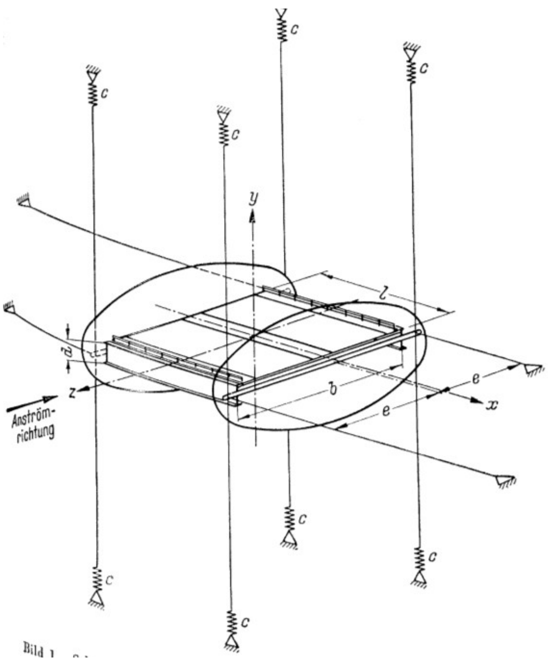

Figure A-2- Wind tunnel set up showing the suspended model under wind flow.

Model dimensions: the geometric scale was chosen to be $\mathrm{n} = 75$.

As the vortex-free region of the wind tunnel had a diameter of D = 60 cm, the length of the model was chosen as $\mathrm{l_M} = 0.56$ m. The width was chosen $\mathrm{b_M} = 35.8$ cm. Therefore, the model represented the following real dimensions:

Real width : $\mathrm{b_A} =$ 35.8 cm x 75 = 26.85 m (compare with the bridge width in Figure A-1).

Real length : $\mathrm{l_A} =$ 0.56 x 75 = 42 m

The model mass was defined as $\mathrm{m_M} =$ 0.236 kgf.s2.m-2 and the model mass moment of inertia θ_M= 3.39 x 10-3 kg.s2.m-2.m2 = 3.39 x 10-3 kgf.s.

The radius of gyration is $\mathrm{r_M} = \sqrt{3.39x10^{-3}/0.236} = 0.12$ m.

The bridge mass can be estimated as

$\mathrm{m_A} = \mathrm{n^2 m_M} = 75^2\ x\ 0.236 = 1327.5$ kgf.s^2.m^{-2}.

And the bridge mass moment of inertia as:

$\theta_A = n^4 .\ \theta_M = 75^4 \text{ x } 3.39 \text{ x } 10^{-3} = 107.262 \text{ kgf.s.}$

The bridge radius of gyration is $\mathrm{r_A} = \sqrt{107.262/1327.5} =$ 9 m.

The bridge weigth per meter is then

$w_g = 1327.5$ kgf.s²$.m^{-2}$ x 9,81 $m.s^{-2}$ / 26.85 = 485 kgf / m.

The low bridge weight is explained by the low weight of the orthotropic plate in the bridge deck.

Model eigen frequencies

The eigen frequencies of the section model are determined by the similitude equation (A2-9). The model eigen frequency ω_{MB} defines the total spring stiffness C_{ges} of the suspension springs:

$C_{ges} = \omega_{MB}^2 \, l_M \, m_M$

The spring stiffness of a single spring is $C_i = C_{ges}/8 = \omega_{MB}^2 \, l_M \, m_M/8$. The distance $2\,e$ between the springs is defined by the model mass moment of inertia $\theta_M \; l_M$ and the model eigen frequency ω_{MT}.

Torsion spring stiffness: $C_d = C_{ges} \, e^2 = \omega_{MT}^2 \, \theta_M \, l_M$

$e^2 = C_d/C_{ges} = \omega_{MT}^2 \, \theta_M \, l_M/\omega_{MB}^2 \, l_M \, m_M = \omega_{MT}^2 \, r_M{}^2 \, m_M \, l_M/\omega_{MB}^2 \, l_M \, m_M$

The bridge circular eigen frequencies were given as:

$\omega_{MB} = 1.71\ s^{-1}$ and $\omega_{AT} = 1.96\ s^{-1}$. Therefore:

$e = r_m \, \omega_{MT}/\omega_{MB} = r_A/n \, . \, \omega_{AT}/\omega_{AB}$ = 9 m x 1.96 / 1.71 x 1 / 75 = 13.75 cm.

or, for $p = 2$,

$\omega\_MT = n / (p) \, \omega\_AT = ((75) / (2)) \, 1.96 = 73.5 \quad 1/s$

$\omega\_MB = n / (p) \, \omega\_AB = ((75) / (2)) \, 1.71 = 64.1 \quad 1/s$

$e = 0.12 \times (73.5/64.1) = 13.76$ cm.

If the model is suspended by 8 springs with a total stiffness equal to :

$C_{ges} = \omega_{MB}^2 \, l_M \, m_M = (64.1)^2 s^{-2} \times 0.56\ m \times 0.236\ kgf\ s^2\ m^{-2} = 543$ kgf/m.

The distance between the bridge center of gravity and the springs equals:

$e = 13.76$ cm, and the flutter velocity obtained in the wind tunnel is v_M , then the real critical velocity is $v_A = 2 \times v_M$.

Recent investigations on model tests can be found in Ukegushi et al [90], Scanlan [61], [64], Wardlaw et al. [93] and Leonhardt [40]. In loco investigations were carried out in the Golden Gate and reported by Vincent [91].

B.

Brazilian Code of Practice

B.1. Fundamentals

The wind climate and design assumptions applicable to structures are given by the Brazilian Code of Practice NBR 6123 / 1988 [102]. However, special provisions must be made for very flexible structures like the long-span bridges considered in this thesis.

The basic velocity V_0 is available all over Brazil, represented by isopleths, as shown in Figure , taken from NBR 6123.

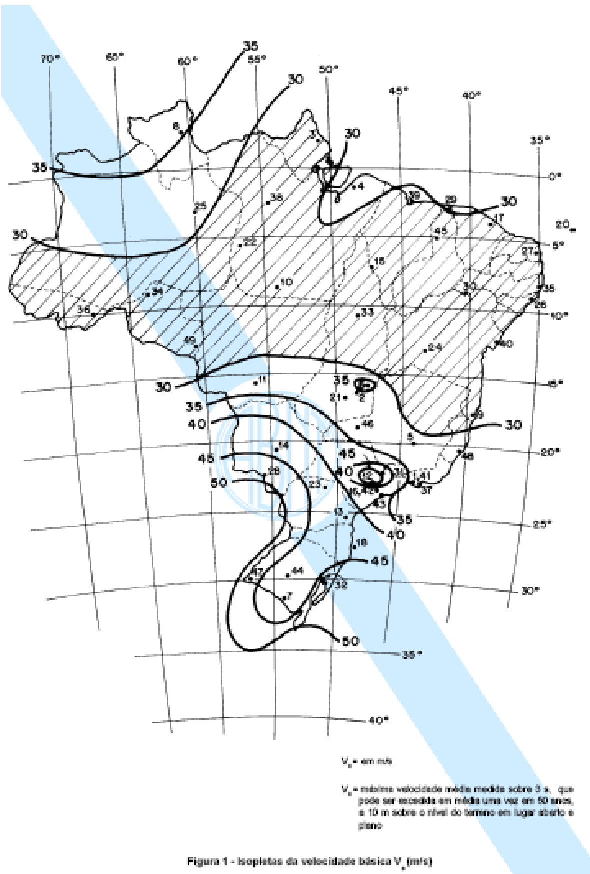

Figure B-1 - Isopleths of the basic velocity V_0 in m/s (from NBR 6122 / 1988)

The definitions of wind velocity are given below:

V_0 Basic wind velocity: velocity of a 3 s wind gust, whose mean value is surpassed once in 50 years, blowing 10m above the ground, in an open and plain terrain.

$\mathrm{V_k}$ Characteristic wind velocity: $\mathrm{V_k = V_0\, S_1 S_2 S_3}$

$\overline{\mathrm{V}}_\mathrm{p}$ Design wind speed : $\overline{\mathrm{V}}_\mathrm{p} = \overline{\mathrm{V}}_{10\ \mathrm{min,II}}\,(10\mathrm{m})\mathrm{S_1 S_3} = 0.69\,\mathrm{V_0\, S_1\, S_3}.$

$\overline{\mathrm{V}}_\mathrm{t}(\mathrm{h})$ Mean wind velocity blowing for t seconds at a height h above the ground.

$\overline{\mathrm{V}}_\mathrm{t,i}(\mathrm{z})$ Mean wind velocity blowing for t seconds at a height z above the ground for class i, without considering the parameters $\mathrm{S_1}$ and $\mathrm{S_3}$.

The parameter S_1 depends on the terrain roughness while $\mathrm{S_3}$ represents a parameter depending on statistic concepts which considers the required safety level and the expected life time of the structure. One must still take into account the height of the structure.

The dynamic effects are discussed in item 9 of NBR 6122 and are summarized as follows.

In the natural wind, the modulus and orientation of the instantaneous air velocity show fluctuations around the mean velocity $\overline{\mathrm{V}}$, called gusts (rajadas). It is assumed that the mean velocity keeps constant during a time interval of 10 min or more, introducing in the structures pure static forces, denoted as mean response. The speed fluctuations can induce important oscillations in very slender structures in the direction of the mean velocity, here denoted as fluctuating response.

The total dynamic pressure is equal to the superposition of mean and fluctuating responses:

$$\mathrm{q(z)} = \overline{\mathrm{q}}_0\, \mathrm{b}^2 \left[\left(\frac{\mathrm{z}}{\mathrm{z_r}}\right)^{2\mathrm{p}} + \left(\frac{\mathrm{h}}{\mathrm{z_r}}\right)^{\mathrm{p}} \left(\frac{\mathrm{z}}{\mathrm{h}}\right)^{\gamma} (1+2\gamma)/(1+\gamma+\mathrm{p})\ \xi\right]$$

The dynamic pressure is given by $\overline{\mathrm{q}}_0$ The first term inside the brackets corresponds to the medium response and the second represents the maximum amplitude of the fluctuating response.

B.2. Critical speed for aerodynamic design of the Great Belt East Bridge

The Danish Code DS 410.3 prescribed for the design wind velocity of the Great Belt East Bridge U_{10} (design wind speed for 10min) and U_g (gust wind), for 100 years return period and at 70m level $U_{10} = 42.2\ m/s$ and $U_g = 47.7\ m/s$, (according to Larsen & Jacobsen [36]).

B.3. Critical speed for aerodynamic design of the Akashi Kaikyo Bridge

According to Myiata et al. [44], the critical velocity U_c corresponding to flutter instability adopted for the Akashi Kaikyo Bridge was:

$U_c = 1.2 \text{ x } \mu_F \text{ x } U_z = 1.2 \text{ x }$ U_c=1.2 x μ_F x U_z

where 1.2 is the principal safety factor considering the reliability of sectional wind tunnel tests, errors in the design and construction of the structure as well as the fact of flutter being a destructive phenomenum, and $\mu_F =$ 1.08 is a safety factor considering other factors related to gust effects.

$U_z = (z/10)^{1/8} \text{ x } U_{ref}$; $U\_ref = 46.5\ m/s$ for $z = 10m$.

$U\_z = (80 / 10)^{1/8}$ x $46.5 = 1.3 \text{ x } 46 = 60\ m/s$ for $z = 80m$.

$U\_c = 1.2 \text{ x } 1.08 \text{ x } 60 = 78\ m/s$.

C.

Values and plot of the Theodorsen function

The Theodorsen function $C(k)$ is defined as:

$$C(k) = F(k) + iG(k) \qquad (C1)$$

The variable $k = \omega b/U$ is defined as the reduced frequency, a dimensionless variable proportional to ω that can be regarded as a modified Strouhal number, and

$$F(k) = \frac{J_1(k)[J_1(k) + Y_0(k)] + Y_1(k)[Y_1(k) + J_0(k)]}{[J_1(k) + Y_0(k)]^2 + [Y_1(k) - J_0(k)]^2}$$

(C2) and (C3)

$$G(k) = \frac{Y_1(k)Y_0(k) + J_1(k)J_0(k)}{[J_1(k) + Y_0(k)]^2 + [Y_1(k) - J_0(k)]^2}$$

K	k	J0(k)	J1(k)	Y0(k)	Y1(k)	F(k)	G(k)
0	0	1.0000	0.0000	-	-	1.0000	0.0000
0.1	0.05	0.9994	0.0250	-1.9793	-12.7899	0.9090	-0.1306
0.2	0.1	0.9975	0.0499	-1.5342	-6.4590	0.8319	-0.1723
0.3	0.15	0.9944	0.0748	-1.2708	-4.3637	0.7728	-0.1865
0.4	0.2	0.9900	0.0995	-1.0811	-3.3238	0.7276	-0.1886
0.5	0.25	0.9844	0.1240	-0.9316	-2.7041	0.6926	-0.1852
0.6	0.3	0.9776	0.1483	-0.8073	-2.2931	0.6650	-0.1793
0.7	0.35	0.9696	0.1723	-0.7003	-2.0004	0.6429	-0.1723
0.8	0.4	0.9604	0.1960	-0.6060	-1.7809	0.6250	-0.1650
0.9	0.45	0.9500	0.2194	-0.5214	-1.6095	0.6102	-0.1577
1	0.5	0.9385	0.2423	-0.4445	-1.4715	0.5979	-0.1507
1.1	0.55	0.9258	0.2647	-0.3739	-1.3572	0.5876	-0.1441
1.2	0.6	0.9120	0.2867	-0.3085	-1.2604	0.5788	-0.1378
1.3	0.65	0.8971	0.3081	-0.2476	-1.1768	0.5713	-0.1319
1.4	0.7	0.8812	0.3290	-0.1907	-1.1032	0.5648	-0.1264
1.5	0.75	0.8642	0.3492	-0.1372	-1.0376	0.5591	-0.1213
1.6	0.8	0.8463	0.3688	-0.0868	-0.9781	0.5541	-0.1165
1.7	0.85	0.8274	0.3878	-0.0393	-0.9236	0.5498	-0.1120
1.8	0.9	0.8075	0.4059	0.0056	-0.8731	0.5459	-0.1078
1.9	0.95	0.7868	0.4234	0.0481	-0.8258	0.5425	-0.1039
2	1	0.7652	0.4401	0.0883	-0.7812	0.5394	-0.1003

Table 10-1– Table with values of Bessel and Theodorsen functions.

Where $J_0(k)$ and $J_1(k)$ are Bessel functions of the first kind, $Y_0(k)$ and $Y_1(k)$ are Bessel functions of the second kind , $i = \sqrt{-1}$, ω is the circular frequency of oscillation of the airfoil, U is the mean wind velocity, b is the half-chord length of the airfoil or half-width of the plate and ρ is the air density (1.225 kg/m3 in SI units or 0.125 kgf.s2.m-4, where 1 kgf = 1 kg x 9.81 m/s2). Figure C-1 shows Bessel functions and Theodorsen functions $F(k)$ and $G(k)$ at appropriate intervals for 0< k <1.0 (0< K < 2.0). Figure shows plots of $F(k)$ and $G(k)$. The critical value of k corresponding to the critical velocity U_c , as far as suspension bridges are concerned, lies below $K = 1$. is an EXCEL spreadsheet where J0=BESSELJ(k,0), J1=BESSELJ(k,1), Y0=BESSELY(k,0) and Y1=BESSELY(k,1).

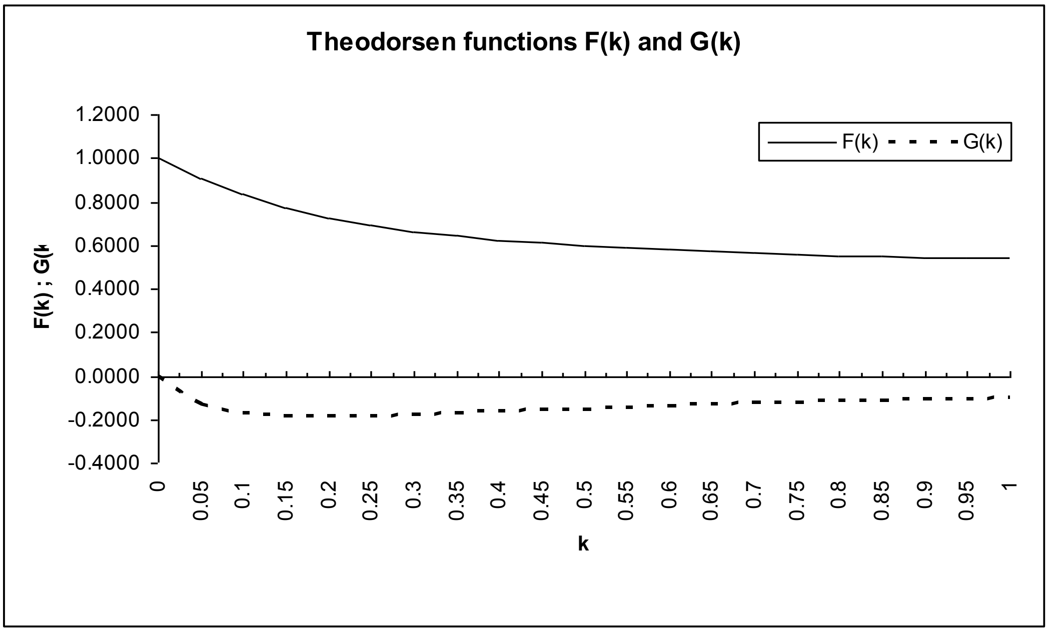

Figure C-1 - Plots of the Theodorsen functions F(k) and G(k).

D.
Plots

D.1. Summary

Plots of Theodorsen aerodynamic derivatives and aerodynamic derivatives of eight profiles characteristic of bridge decks are presented in the next pages. Tables containing the values Q_{ij} and $\widehat{Q}_{ij}$ and the matrices A_0 , A_1 , D, E, R with 3 lag terms are also presented sequencially for those eight profiles.

The rational functions may not represent well the behavior of the aerodynamic derivatives belonging to profiles that do not exhibit aerodynamic characteristics. This may be explained by the irregular pattern of the experimental data itself.

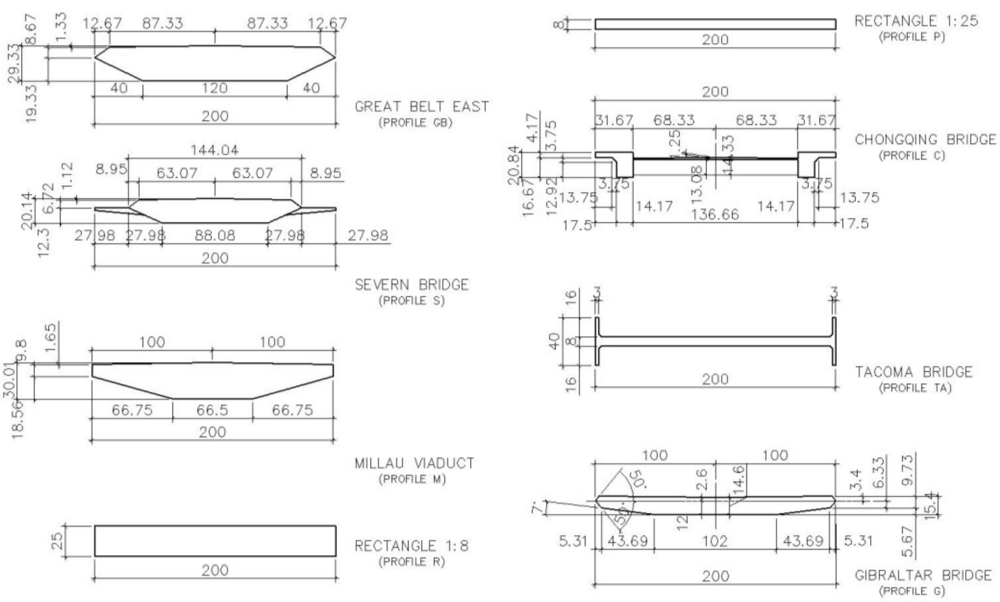

Figure D-1 - Investigated profiles of typical bridge decks.

D.2. Profile GB

GB									
k	H2 *(-1)	H3 *(-1)	A2	A3	k	H1 *(-1)	H4 *(-1)	A1	A4
0.1783	-2.4100	16.2720	-0.9200	4.1750	0.1720	6.1930	2.1250	1.4660	0.4430
0.2676	-0.7750	6.4940	-0.4070	1.7260	0.2580	3.8410	0.9110	0.9170	0.2400
0.3565	-0.1710	3.3680	-0.2100	0.9340	0.3441	2.7430	0.4270	0.6480	0.1600
0.4454	0.0750	2.0240	-0.1270	0.5890	0.4301	1.9780	0.2880	0.5100	0.1060
0.5346	0.2110	1.3520	-0.0850	0.4080	0.5161	1.5880	0.0380	0.4160	0.0750
0.6240	0.2540	0.9640	-0.0610	0.3020	0.6018	1.3100	-0.0260	0.3510	0.0510
0.7129	0.2420	0.7360	-0.0470	0.2340	0.6879	0.9500	-0.3310	0.3100	0.0380
0.8020	0.2440	0.5700	-0.0350	0.1890	0.7736	0.9500	-0.1820	0.2720	0.0290
0.8910	0.2430	0.4550	-0.0290	0.1560	0.8600	0.8620	-0.2280	0.2420	0.0240
0.9805	0.2340	0.3760	-0.0240	0.1320	0.9454	0.7560	-0.2750	0.2230	0.0140
1.0697	0.2230	0.3130	-0.0210	0.1150	1.0314	0.6920	-0.2810	0.2020	0.0110
1.1576	0.2100	0.2640	-0.0170	0.1010	1.1180	0.6490	-0.2890	0.1860	0.0020
1.2472	0.2020	0.2220	-0.0140	0.0910	1.2037	0.5870	-0.3290	0.1750	0.0020
1.3368	0.1960	0.1840	-0.0120	0.0830	1.2897	0.5610	-0.2790	0.1610	-0.0100
1.4254	0.1880	0.1590	-0.0100	0.0760	1.3755	0.4470	-0.2970	0.1600	-0.0170

Table D-1 - GB Derivatives

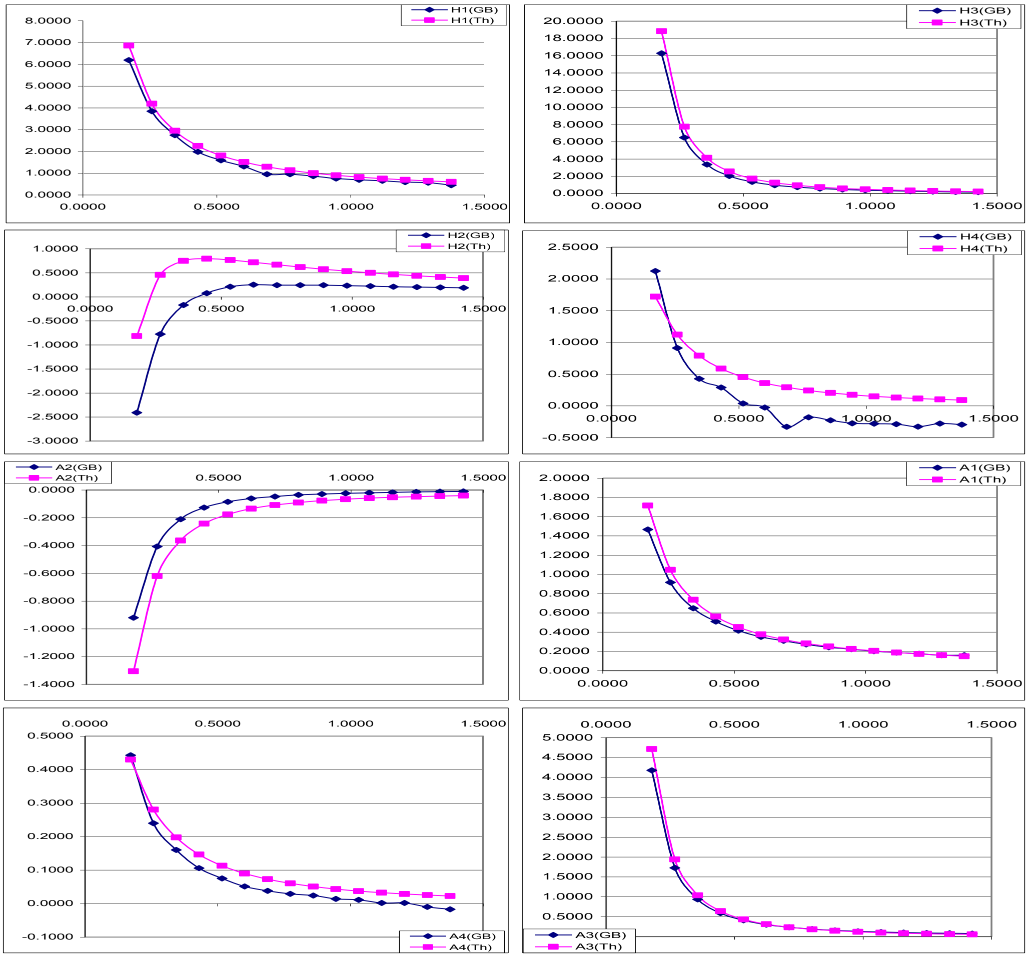

Figure D-2 - Plots of GB and Theodorsen derivatives

$$A0 = \begin{vmatrix} -0.4636738E+02 & 0.8228331E+01 \\ 0.1035637E+01 & 0.1596801E+01 \end{vmatrix}$$

$$A1 = \begin{vmatrix} 0.8914992E+01 & 0.7375850E+00 \\ 0.8926457E+00 & -0.2251520E+00 \end{vmatrix}$$

$$D = \begin{vmatrix} 0.3428018E+00 & -0.3723400E+03 & 0.3051064E+03 \\ 0.1010667E+00 & 0.4536275E+02 & -0.3639534E+02 \end{vmatrix}$$

$$E = \begin{vmatrix} -0.1936388E+01 & 0.2620034E+02 & 0.3299231E+02 \\ 0.2423165E+01 & -0.7610449E+01 & -0.9443313E+01 \end{vmatrix}$$

$$\lambda 11.\ \lambda 22,\ \lambda 33 = \begin{vmatrix} 0.4620845E+00 & 0.4960738E+01 & 0.4998248E+01 \end{vmatrix}$$

K	Q11		Q11		Q12		Q12	
	Q11 r (exp)	Q11 r (app)	Q11 i (exp)	Q11 i (app)	Q12 r (exp)	Q12 r (app)	Q12 i (exp)	Q12 i (app)
0.34	0.5032	0.0287	1.4664	1.5041	4.1369	4.1048	-0.6127	-0.5379
0.52	0.4850	0.2169	2.0449	1.9668	3.7189	3.7250	-0.4438	-0.3823
0.69	0.4045	0.2585	2.5982	2.3312	3.4238	3.4738	-0.1738	-0.1480
0.86	0.4261	0.1905	2.9267	2.6835	3.2126	3.2878	0.1190	0.1239
1.03	0.0810	0.0360	3.3840	3.0444	3.0917	3.1521	0.4825	0.3986
1.2	-0.0753	-0.1902	3.7959	3.4213	3.0024	3.0474	0.7911	0.6714
1.38	-1.2530	-0.4982	3.5963	3.8414	2.9921	2.9632	0.9838	0.9429
1.55	-0.8714	-0.8484	4.5483	4.2604	2.9333	2.8977	1.2557	1.1993
1.72	-1.3490	-1.2528	5.1003	4.7034	2.8896	2.8406	1.5432	1.4721
1.89	-1.9664	-1.7087	5.4057	5.1731	2.8920	2.7951	1.7998	1.7469
2.06	-2.3913	-2.2136	5.8889	5.6726	2.8650	2.7606	2.0412	2.0237
2.24	-2.8898	-2.7987	6.4897	6.2372	2.8299	2.7372	2.2511	2.3024
2.41	-3.8133	-3.3960	6.8037	6.8074	2.7624	2.7252	2.5135	2.5667
2.58	-3.7123	-4.0336	7.4645	7.4163	2.6307	2.7232	2.8023	2.8470
2.75	-4.4953	-4.7078	6.7656	8.0665	2.5844	2.7321	3.0558	3.1267
ε_{ij}	ε_{11} =		0.5684926E-01		ε_{12} =		0.7832406E-02	

K	Q21		Q21		Q22		Q22	
	Q21 r (exp)	Q21 r (app)	Q21 i (exp)	Q21 i (app)	Q22 r (exp)	Q22 r (app)	Q22 i (exp)	Q22 i (app)
0.36	0.1049	0.0949	0.3471	0.4283	1.0614	1.1063	-0.2339	-0.2412
0.54	0.1278	0.1649	0.4882	0.5592	0.9884	1.0124	-0.2331	-0.2399
0.71	0.1516	0.1977	0.6138	0.6640	0.9495	0.9614	-0.2135	-0.2162
0.89	0.1568	0.2057	0.7546	0.7681	0.9349	0.9363	-0.2016	-0.1887
1.07	0.1598	0.1969	0.8865	0.8779	0.9330	0.9307	-0.1944	-0.1657
1.25	0.1478	0.1770	1.0171	0.9953	0.9406	0.9378	-0.1900	-0.1493
1.43	0.1439	0.1478	1.1735	1.1285	0.9513	0.9535	-0.1911	-0.1396
1.6	0.1388	0.1153	1.3022	1.2624	0.9726	0.9737	-0.1801	-0.1364
1.78	0.1420	0.0802	1.4319	1.4040	0.9907	0.9990	-0.1842	-0.1388
1.96	0.1001	0.0438	1.5945	1.5526	1.0153	1.0271	-0.1846	-0.1468
2.14	0.0936	0.0074	1.7190	1.7079	1.0526	1.0570	-0.1922	-0.1600
2.32	0.0200	-0.0301	1.8599	1.8788	1.0827	1.0878	-0.1822	-0.1778
2.49	0.0232	-0.0637	2.0284	2.0457	1.1323	1.1172	-0.1742	-0.1986
2.67	-0.1331	-0.0948	2.1422	2.2172	1.1867	1.1483	-0.1716	-0.2244
2.85	-0.2573	-0.1231	2.4217	2.3927	1.2353	1.1789	-0.1625	-0.2538
ε_{ij}	ε_{21} =		0.1366064E-01		ε_{22} =		0.2025828E-01	

J = 0.3140073E+00

Table D-2 - Unsteady Aerodynamic Data - Experimental and approximations

D.3. Profile S

S									
k	H2 *(-1)	H3 *(-1)	A2	A3	k	H1 *(-1)	H4 *(-1)	A1	A4
0.1870	0.1820	11.8240	-0.8140	4.1390	0.1867	3.7370	-0.6990	1.4690	0.3240
0.2805	0.7170	4.9160	-0.3970	1.7570	0.2802	2.7460	-0.4930	0.9510	0.2210
0.3741	0.7130	2.7020	-0.2500	0.9660	0.3739	2.0310	-0.4200	0.6850	0.1750
0.4676	0.6820	1.6980	-0.1700	0.6140	0.4673	1.5930	-0.4030	0.5350	0.1260
0.5612	0.6130	1.1890	-0.1310	0.4260	0.5609	1.3190	-0.4550	0.4390	0.1080
0.6545	0.5420	0.8770	-0.1010	0.3170	0.6542	1.1150	-0.4590	0.3700	0.0930
0.7482	0.4930	0.6840	-0.0840	0.2460	0.7478	0.9630	-0.4970	0.3240	0.0750
0.8416	0.4530	0.5430	-0.0710	0.1980	0.8413	0.8530	-0.5370	0.2890	0.0620
0.9347	0.4160	0.4520	-0.0610	0.1650	0.9344	0.7800	-0.5540	0.2590	0.0590
1.0280	0.3820	0.3820	-0.0540	0.1400	1.0280	0.7180	-0.5650	0.2350	0.0510
1.1212	0.3500	0.3320	-0.0470	0.1220	1.1216	0.6760	-0.5730	0.2180	0.0470
1.2148	0.3230	0.2930	-0.0420	0.1080	1.2158	0.6420	-0.5790	0.2010	0.0440
1.3090	0.3020	0.2610	-0.0390	0.0980	1.3085	0.6090	-0.5760	0.1870	0.0410
1.4019	0.2830	0.2360	-0.0370	0.0890	1.4025	0.5890	-0.5830	0.1770	0.0360
1.4953	0.2650	0.2150	-0.0340	0.0830	1.4960	0.5780	-0.5810	0.1690	0.0360

Table D-3 - S Derivatives

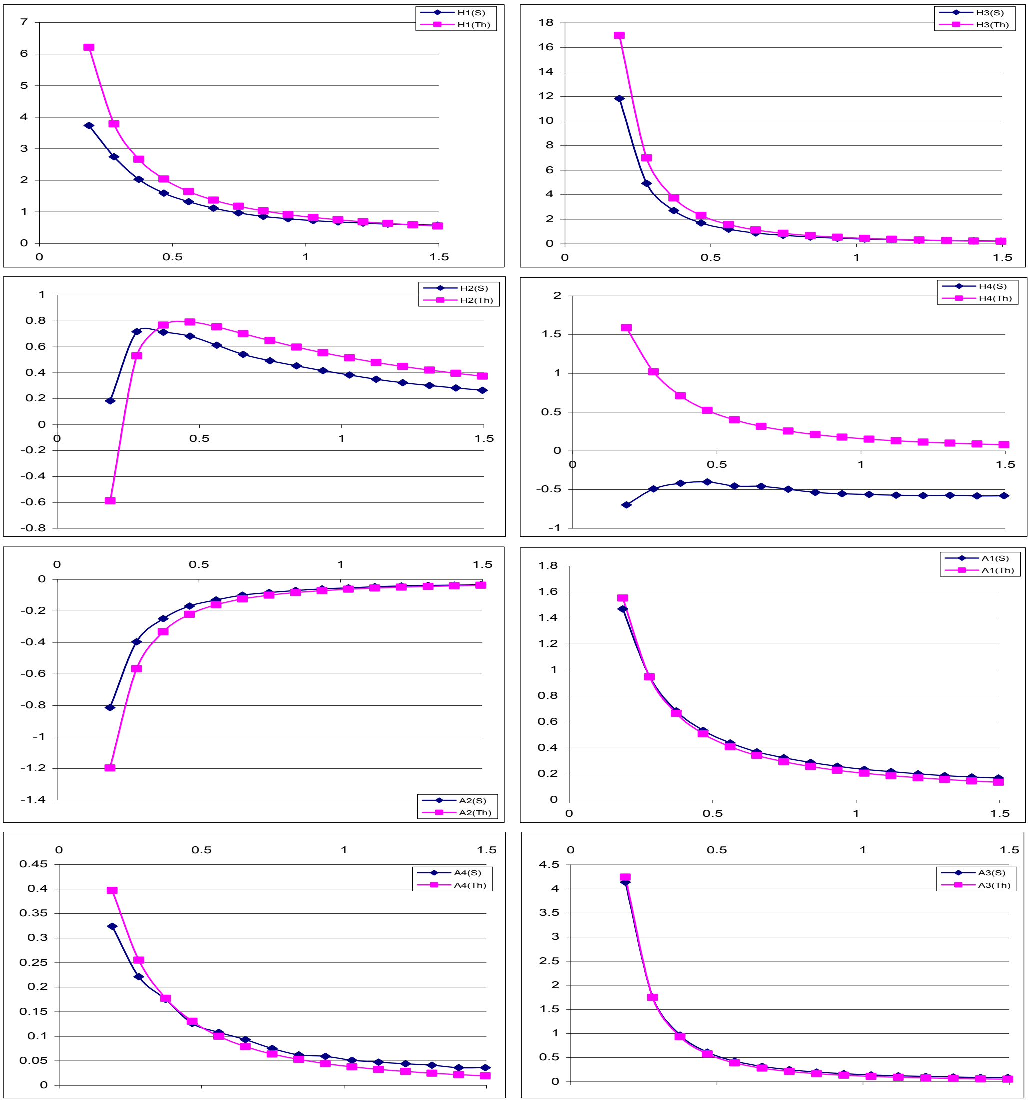

Figure D-3- Plots of S and Theodorsen derivatives

A0 =	-0.6216372E+02	0.1647552E+02	
	0.2179667E+02	0.4522766E+00	
A1 =	0.1209033E+02	-0.3895692E-01	
	-0.7804527E+00	-0.4248660E+00	
D =	0.2487929E+08	-0.1675641E+09	0.1443836E+10
	0.5315850E+08	-0.6806189E+09	0.2841914E+11
E =	-0.4173372E-04	-0.9753603E-05	-0.1624806E-06
	0.1550400E-04	0.3280318E-05	0.5030544E-07
λ11. λ22, λ33 =	0.4090739E+01	0.4479433E+01	0.4802952E+01

K	Q11		Q11		Q12		Q12	
	Q11 r (exp)	Q11 r (app)	Q11 i (exp)	Q11 i (app)	Q12 r (exp)	Q12 r (app)	Q12 i (exp)	Q12 i (app)
0.37	-0.1949	-0.0937	1.0422	1.0522	3.3093	3.1601	0.0509	0.4350
0.56	-0.3097	-0.2594	1.7250	1.5854	3.0949	3.1338	0.4514	0.6723
0.75	-0.4696	-0.5013	2.2711	2.1124	3.0257	3.1026	0.7984	0.9250
0.93	-0.7040	-0.8071	2.7828	2.6081	2.9697	3.0715	1.1928	1.1962
1.12	-1.1452	-1.2177	3.3197	3.1321	2.9958	3.0475	1.5445	1.4714
1.31	-1.5717	-1.7249	3.8179	3.6646	3.0054	3.0332	1.8574	1.7809
1.5	-2.2235	-2.3334	4.3083	4.2156	3.0631	3.0357	2.2077	2.1082
1.68	-3.0410	-3.0057	4.8305	4.7650	3.0766	3.0578	2.5667	2.4319
1.87	-3.8699	-3.8163	5.4487	5.3862	3.1593	3.1052	2.9077	2.7843
2.06	-4.7767	-4.7278	6.0703	6.0620	3.2296	3.1798	3.2296	3.1430
2.24	-5.7666	-5.6794	6.8032	6.7635	3.3388	3.2767	3.5198	3.4845
2.43	-6.8467	-6.7696	7.5917	7.5790	3.4594	3.4070	3.8136	3.8421
2.62	-7.8891	-7.9387	8.3411	8.4806	3.5777	3.5651	4.1398	4.1923
2.8	-9.1741	-9.1093	9.2685	9.4206	3.7104	3.7392	4.4493	4.5137
2.99	-10.4023	-10.4007	10.3485	10.5084	3.8457	3.9464	4.7401	4.8387
ε_{ij}	ε_{11} =		0.1452171E-02		ε_{12} =		0.9683110E-02	

K	Q21		Q21		Q22		Q22	
	Q21 r (exp)	Q21 r (app)	Q21 i (exp)	Q21 i (app)	Q22 r (exp)	Q22 r (app)	Q22 i (exp)	Q22 i (app)
0.37	0.0904	0.0962	0.4097	0.4081	1.1584	1.1473	-0.2278	-0.1367
0.56	0.1388	0.1314	0.5974	0.6079	1.1061	1.1322	-0.2499	-0.1992
0.75	0.1957	0.1755	0.7660	0.7975	1.0817	1.1147	-0.2800	-0.2535
0.94	0.2201	0.2214	0.9346	0.9674	1.0739	1.0980	-0.2973	-0.2984
1.12	0.2718	0.2699	1.1049	1.1375	1.0733	1.0861	-0.3301	-0.3325
1.31	0.3184	0.3152	1.2669	1.3010	1.0863	1.0804	-0.3461	-0.3605
1.5	0.3355	0.3548	1.4495	1.4619	1.1016	1.0844	-0.3762	-0.3824
1.68	0.3511	0.3865	1.6366	1.6161	1.1219	1.0988	-0.4023	-0.3999
1.87	0.4121	0.4148	1.8092	1.7849	1.1533	1.1259	-0.4264	-0.4178
2.06	0.4312	0.4400	1.9868	1.9640	1.1836	1.1653	-0.4565	-0.4381
2.24	0.4730	0.4643	2.1939	2.1458	1.2269	1.2133	-0.4727	-0.4620
2.43	0.5203	0.4943	2.3768	2.3523	1.2751	1.2739	-0.4959	-0.4945
2.62	0.5616	0.5333	2.5612	2.5743	1.3434	1.3428	-0.5346	-0.5363
2.8	0.5665	0.5825	2.7853	2.7982	1.3993	1.4138	-0.5817	-0.5855
2.99	0.6445	0.6512	3.0258	3.0474	1.4846	1.4927	-0.6082	-0.6483
ε_{ij}	ε_{21} =		0.1451748E-02		ε_{22} =		0.7396717E-02	

J = 0.1413639E+00

Table D-4 - Unsteady Aerodynamic Data - Experimental and approximations

D.4. Profile M

M									
k	H2 *(-1)	H3 *(-1)	A2	A3	k	H1 *(-1)	H4 *(-1)	A1	A4
0.1910	-0.2860	15.3370	-0.8300	4.1350	0.1899	5.5610	0.9110	1.5750	0.4150
0.2865	0.4630	6.3610	-0.4120	1.7540	0.2850	3.5630	0.1190	0.9990	0.2240
0.3820	0.6240	3.4620	-0.2570	0.9720	0.3797	2.6120	0.0070	0.7270	0.1810
0.4779	0.6250	2.1790	-0.1790	0.6210	0.4750	2.0270	-0.1800	0.5750	0.1380
0.5732	0.5880	1.5080	-0.1370	0.4350	0.5697	1.6480	-0.2870	0.4710	0.1100
0.6686	0.5330	1.1140	-0.1110	0.3230	0.6649	1.3840	-0.3310	0.3960	0.0870
0.7644	0.4800	0.8570	-0.0920	0.2500	0.7598	1.1980	-0.4060	0.3410	0.0730
0.8595	0.4370	0.6780	-0.0790	0.2010	0.8549	1.0410	-0.4420	0.3050	0.0620
0.9552	0.4000	0.5500	-0.0680	0.1670	0.9503	0.9200	-0.4820	0.2720	0.0500
1.0496	0.3680	0.4550	-0.0600	0.1430	1.0462	0.8350	-0.5080	0.2490	0.0440
1.1453	0.3420	0.3840	-0.0530	0.1240	1.1407	0.7580	-0.5360	0.2290	0.0390
1.2408	0.3200	0.3300	-0.0480	0.1090	1.2359	0.7060	-0.5560	0.2110	0.0360
1.3357	0.3020	0.2900	-0.0440	0.0980	1.3312	0.6590	-0.5760	0.1980	0.0310
1.4319	0.2850	0.2580	-0.0410	0.0890	1.4254	0.6260	-0.5870	0.1860	0.0300

Table D-5- M derivatives

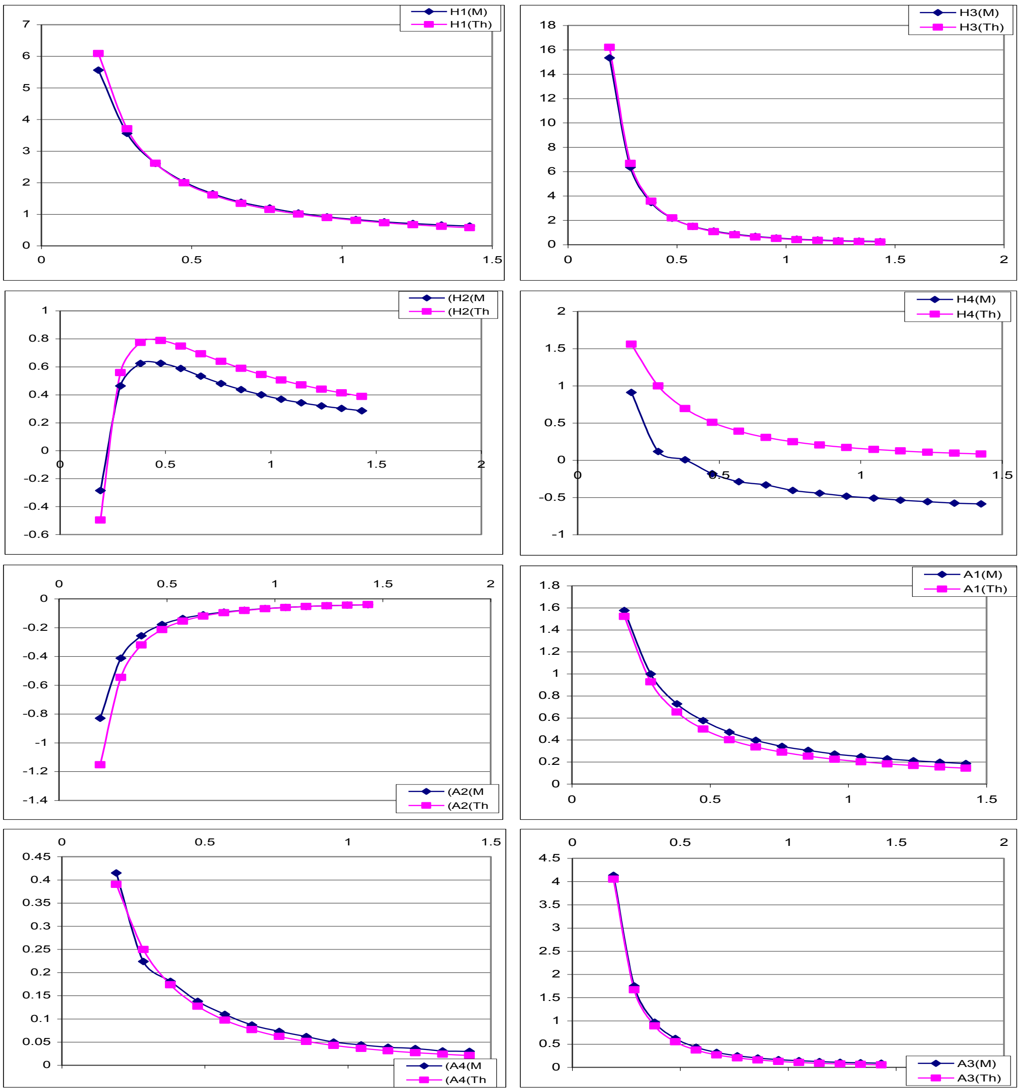

Figure D-4 - Plots of M derivatives and comparisons with Theodorsen’s flat plate

$$A0 = \begin{vmatrix} -0.7615748E+02 & 0.1425849E+02 \\ 0.7812135E+01 & 0.7378987E+00 \end{vmatrix}$$

$$A1 = \begin{vmatrix} 0.1379135E+02 & 0.5682146E+00 \\ 0.2550696E+00 & -0.2898359E+00 \end{vmatrix}$$

$$D = \begin{vmatrix} 0.1798890E+02 & 0.3674439E+06 & 0.3035072E+06 \\ 0.8673246E+01 & -0.6475102E+05 & -0.6040177E+05 \end{vmatrix}$$

$$E = \begin{vmatrix} -0.3447142E-01 & 0.4754779E-02 & -0.4141133E-02 \\ 0.2613000E-01 & -0.1084968E-02 & 0.1054008E-02 \end{vmatrix}$$

$$\lambda 11.\ \lambda 22,\ \lambda 33 = \begin{vmatrix} 0.5095066E+00 & 0.4946449E+01 & 0.4553581E+01 \end{vmatrix}$$

K	Q11		Q11		Q12		Q12	
	Q11 r (exp)	Q11 r (app)	Q11 i (exp)	Q11 i (app)	Q12 r (exp)	Q12 r (app)	Q12 i (exp)	Q12 i (app)
0.38	0.2629	0.0863	1.6048	1.7234	4.4767	4.4943	-0.0835	0.1070
0.57	0.0773	0.1207	2.3145	2.3155	4.1766	4.2966	0.3040	0.3730
0.76	0.0081	-0.0110	3.0133	2.8465	4.0426	4.1554	0.7286	0.6954
0.95	-0.3249	-0.2923	3.6586	3.3689	3.9810	4.0532	1.1419	1.0572
1.14	-0.7453	-0.7060	4.2797	3.9043	3.9634	3.9867	1.5454	1.4104
1.33	-1.1706	-1.2418	4.8947	4.4636	3.9835	3.9426	1.9059	1.7700
1.52	-1.8748	-1.8942	5.5322	5.0555	4.0058	3.9177	2.2436	2.1353
1.71	-2.5840	-2.6594	6.0859	5.6885	4.0072	3.9110	2.5828	2.5056
1.9	-3.4820	-3.5338	6.6462	6.3717	4.0144	3.9227	2.9196	2.8800
2.09	-4.4478	-4.5129	7.3108	7.1146	4.0104	3.9530	3.2436	3.2568
2.28	-5.5799	-5.5913	7.8910	7.9265	4.0297	4.0024	3.5889	3.6343
2.47	-6.7938	-6.7621	8.6267	8.8162	4.0642	4.0707	3.9411	4.0102
2.66	-8.1656	-8.0170	9.3422	9.7915	4.1392	4.1576	4.3104	4.3824
2.85	-9.5412	-9.3469	10.1752	10.8590	4.2319	4.2626	4.6748	4.7487
ε_{ij}	ε_{11} =		0.9113238E-02		ε_{12} =		0.4745304E-02	

K	Q21		Q21		Q22		Q22	
	Q21 r (exp)	Q21 r (app)	Q21 i (exp)	Q21 i (app)	Q22 r (exp)	Q22 r (app)	Q22 i (exp)	Q22 i (app)
0.38	0.1198	0.1092	0.4545	0.579379	1.2070	1.2587	-0.2423	-0.2493
0.57	0.1455	0.2086	0.6489	0.7454	1.1517	1.1866	-0.2705	-0.2783
0.76	0.2088	0.2657	0.8387	0.8883	1.1350	1.1488	-0.3001	-0.2876
0.96	0.2491	0.2929	1.0378	1.0334	1.1345	1.1367	-0.3270	-0.2967
1.15	0.2857	0.3027	1.2231	1.1897	1.1433	1.1424	-0.3601	-0.3115
1.34	0.3077	0.3045	1.4005	1.3596	1.1550	1.1589	-0.3969	-0.3342
1.53	0.3371	0.3049	1.5747	1.5429	1.1685	1.1820	-0.4300	-0.3652
1.72	0.3625	0.3085	1.7831	1.7383	1.1880	1.2090	-0.4669	-0.4039
1.91	0.3612	0.3188	1.9650	1.9441	1.2189	1.2380	-0.4963	-0.4500
2.1	0.3852	0.3384	2.1801	2.1580	1.2604	1.2673	-0.5288	-0.5025
2.29	0.4060	0.3689	2.3840	2.3778	1.3012	1.2959	-0.5562	-0.5609
2.48	0.4399	0.4114	2.5782	2.6012	1.3424	1.3229	-0.5912	-0.6243
2.67	0.4395	0.4666	2.8069	2.8257	1.3988	1.3477	-0.6280	-0.6919
2.86	0.4876	0.5343	3.0233	3.0494	1.4598	1.3698	-0.6725	-0.7630
ε_{ij}	ε_{21} =		0.6215548E-02		ε_{22} =		0.1864355E-01	

J = 0.1967680E+00

Table D-6 - Unsteady Aerodynamic Data - Experimental and approximations

D.5. Profile P

P									
k	H2 *(-1)	H3 *(-1)	A2	A3	k	H1 *(-1)	H4 *(-1)	A1	A4
0.1884	-2.6090	18.9870	-1.1440	4.5960	0.1881	6.5240	1.4840	1.7350	0.5690
0.2826	-0.4970	7.6440	-0.5700	1.9790	0.2821	3.9970	0.6220	1.0760	0.3420
0.3766	0.1310	4.0810	-0.3610	1.1050	0.3760	2.8860	0.1920	0.7800	0.2500
0.4709	0.3180	2.5390	-0.2600	0.7130	0.4702	2.2560	-0.0090	0.6170	0.1900
0.5651	0.3690	1.7430	-0.2040	0.5040	0.5641	1.8710	-0.0970	0.5110	0.1770
0.6593	0.3790	1.2830	-0.1710	0.3770	0.6582	1.5910	-0.2160	0.4400	0.1500
0.7536	0.3640	0.9910	-0.1450	0.2980	0.7523	1.3940	-0.2710	0.3830	0.1400
0.8475	0.3380	0.7950	-0.1310	0.2420	0.8466	1.2400	-0.3220	0.3410	0.1260
0.9417	0.3160	0.6550	-0.1190	0.2020	0.9409	1.1300	-0.3500	0.3080	0.1170

Table D-7 - P Derivatives

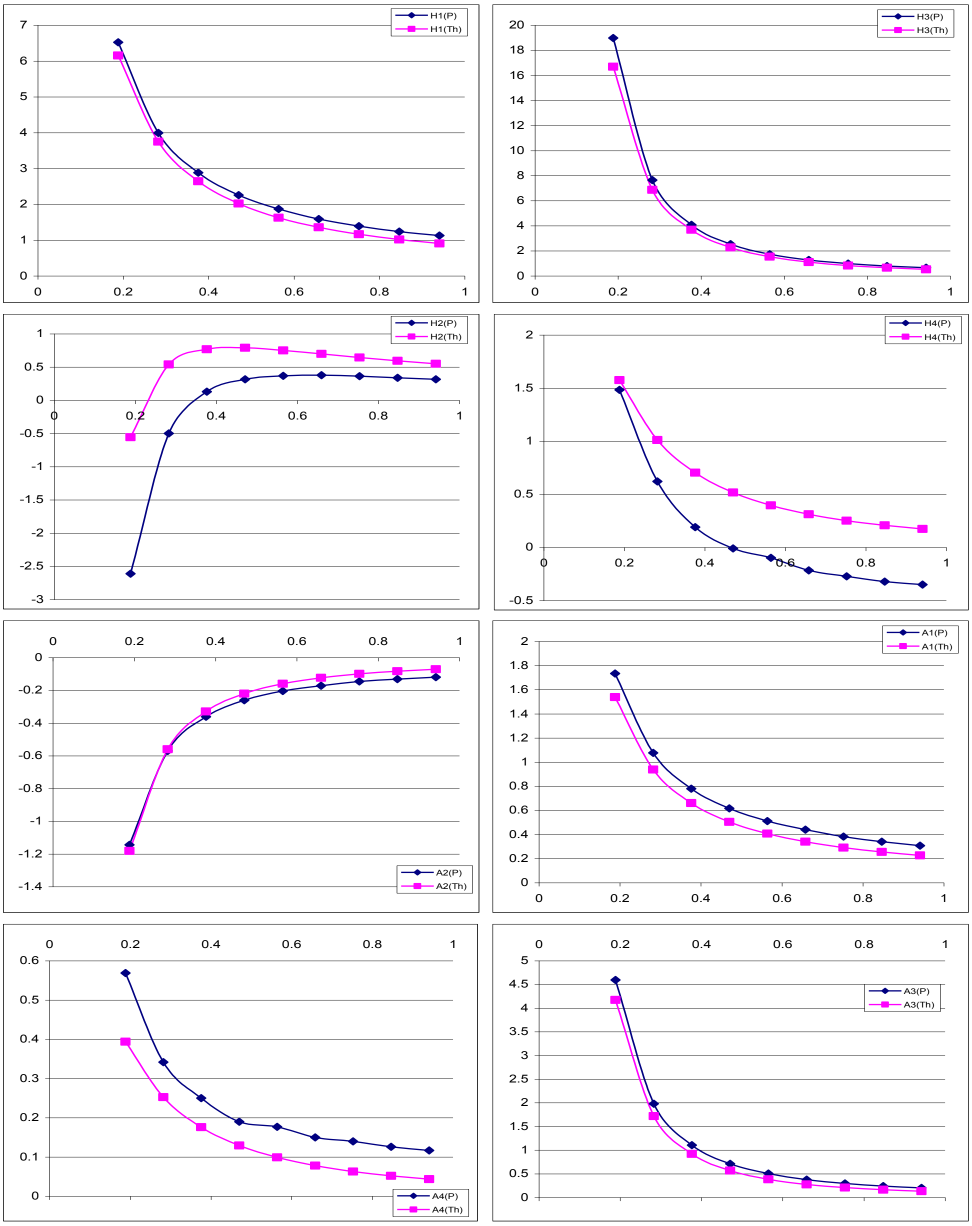

Figure D-5 - Plots of P and Theodorsen derivatives

A0 = | -0.3878034E+02 | 0.1179900E+02 |
| 0.1736960E+02 | -0.3271855E-01 |

A1 = | 0.1031018E+02 | 0.3890370E+00 |
| -0.9762490E+00 | -0.4880674E+00 |

D = | 0.1445158E+02 | -0.2722159E+02 | -0.1114228E+02 |
| 0.2344997E+01 | 0.2788701E+02 | 0.1023353E+02 |

E = | -0.2788161E-01 | 0.3257732E+02 | -0.1003661E+03 |
| 0.6916698E-01 | -0.1007044E+02 | 0.2898910E+02 |

λ11. λ22, λ33 = | 0.3904822E+00 | 0.4824437E+01 | 0.4999693E+01 |

K	Q11		Q11		Q12		Q12	
	Q11 r (exp)	Q11 r (app)	Q11 i (exp)	Q11 i (app)	Q12 r (exp)	Q12 r (app)	Q12 i (exp)	Q12 i (app)
0.38	0.4201	0.3979	1.8470	1.9200	5.3922	5.3514	-0.7409	-0.6976
0.56	0.3961	0.4140	2.5453	2.5680	4.8853	4.8802	-0.3176	-0.3218
0.75	0.2171	0.2741	3.2635	3.2418	4.6304	4.6428	0.1486	0.0963
0.94	-0.0159	0.0137	3.9907	3.9444	4.5034	4.5201	0.5640	0.5243
1.13	-0.2469	-0.3416	4.7633	4.6872	4.4534	4.4736	0.9428	0.9245
1.32	-0.7486	-0.7769	5.5141	5.4748	4.4616	4.4743	1.3180	1.2984
1.5	-1.2270	-1.2539	6.3115	6.2653	4.5019	4.5070	1.6536	1.6500
1.69	-1.8461	-1.8185	7.1093	7.1494	4.5678	4.5599	1.9421	1.9654
1.88	-2.4787	-2.4388	8.0027	8.0872	4.6471	4.6339	2.2419	2.2819
ε_{ij}	ε_{11} =		0.6332079E-03		ε_{12} =		0.4066785E-03	

K	Q21		Q21		Q22		Q22	
	Q21 r (exp)	Q21 r (app)	Q21 i (exp)	Q21 i (app)	Q22 r (exp)	Q22 r (app)	Q22 i (exp)	Q22 i (app)
0.38	0.1611	0.1787	0.4912	0.496049	1.3052	1.3238	-0.3249	-0.3202
0.57	0.2178	0.2330	0.6852	0.6891	1.2648	1.2650	-0.3643	-0.3669
0.75	0.2827	0.2877	0.8820	0.8915	1.2538	1.2487	-0.4096	-0.4054
0.94	0.3361	0.3477	1.0914	1.0982	1.2646	1.2567	-0.4612	-0.4538
1.13	0.4506	0.4185	1.3009	1.3100	1.2877	1.2803	-0.5212	-0.5134
1.32	0.5199	0.5038	1.5250	1.5259	1.3110	1.3135	-0.5946	-0.5844
1.51	0.6339	0.6004	1.7341	1.7329	1.3538	1.3521	-0.6587	-0.6664
1.69	0.7224	0.7211	1.9551	1.9520	1.3905	1.3913	-0.7527	-0.7535
1.88	0.8286	0.8621	2.1813	2.1694	1.4331	1.4332	-0.8443	-0.8547
ε_{ij}	ε_{21} =		0.8538965E-03		ε_{22} =		0.3365859E-03	

J = 0.4722678E-01

Table D-8 - Unsteady Aerodynamic Data - Experimental and approximations

D.6. Profile R

R									
k	H2 *(-1)	H3 *(-1)	A2	A3	k	H1 *(-1)	H4 *(-1)	A1	A4
0.1868	-5.5250	22.8360	0.1430	3.6810	0.1866	8.6300	3.8360	1.1550	-0.1580
0.2802	-1.9840	8.7850	-0.0820	1.8180	0.2798	4.8570	2.0770	0.8400	-0.1680
0.3735	-0.6880	4.4190	-0.1040	1.0960	0.3731	3.4130	1.2180	0.6680	-0.1710
0.4669	-0.1330	2.6410	-0.1200	0.7400	0.4664	2.4500	0.6590	0.5960	-0.1050
0.5603	0.1350	1.7430	-0.1210	0.5380	0.5597	1.8770	0.2490	0.5320	-0.0580
0.6534	0.2010	1.2400	-0.1200	0.4100	0.6530	1.4890	0.0550	0.4860	-0.0500
0.7471	0.2670	0.9140	-0.1130	0.3250	0.7462	1.2200	-0.0800	0.4420	-0.0230
0.8407	0.2910	0.7060	-0.1100	0.2630	0.8398	1.0070	-0.2030	0.4150	-0.0030
0.9336	0.3000	0.5670	-0.1050	0.2160	0.9328	0.8670	-0.3450	0.3820	0.0250
1.0270	0.3110	0.4650	-0.1000	0.1790	1.0263	0.8160	-0.4670	0.3450	0.0490
1.1208	0.3140	0.4030	-0.0960	0.1490	1.1200	0.7400	-0.5480	0.3130	0.0660
1.2134	0.3060	0.3610	-0.0900	0.1250	1.2139	0.7130	-0.6320	0.2800	0.0820

Table D-9 - R derivatives

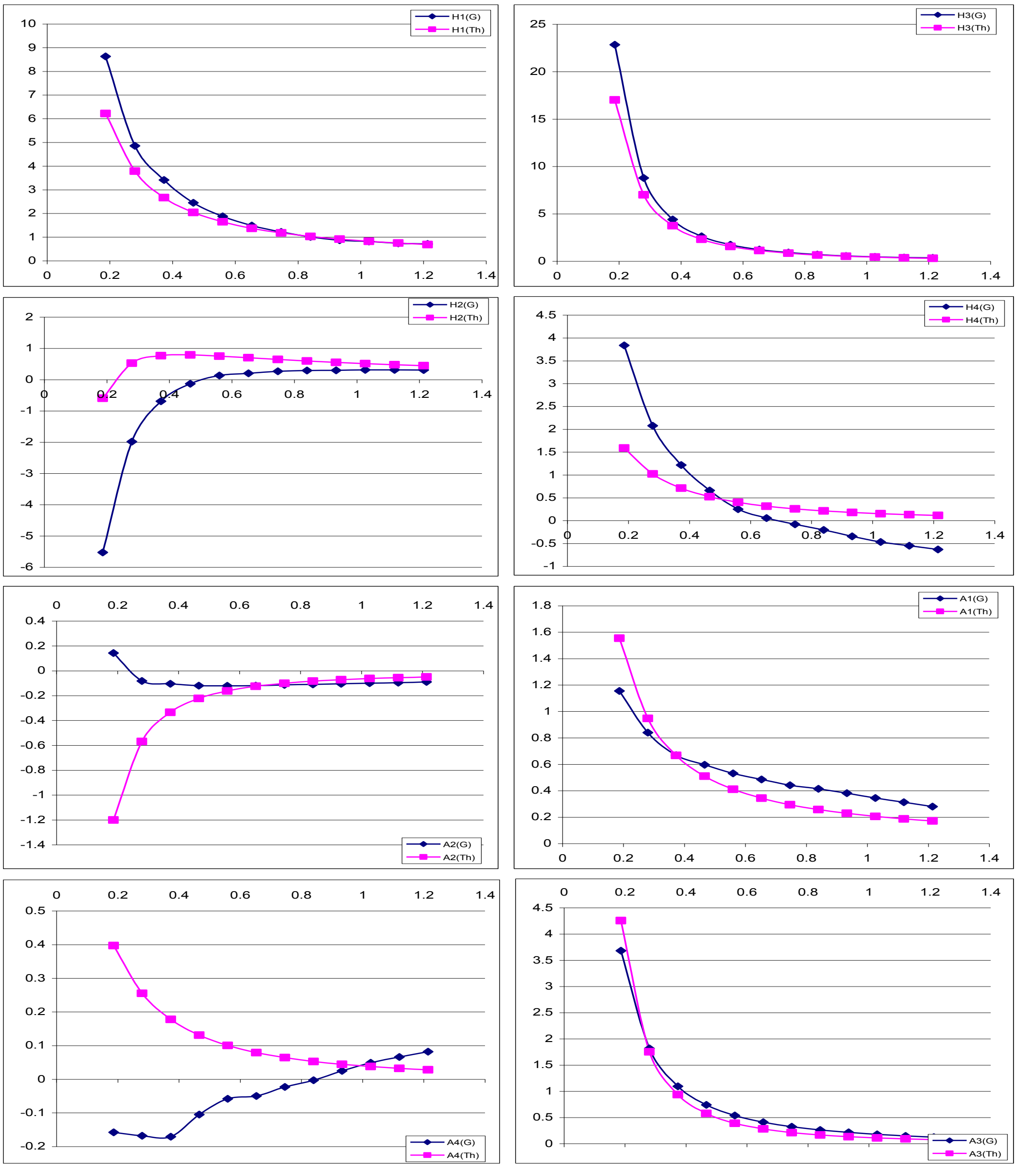

Figure D-6 - Plots of R and Theodorsen derivatives

$$A0 = \begin{vmatrix} -0.7015957E+02 & 0.1227222E+02 \\ 0.1193326E+02 & 0.1235425E+00 \end{vmatrix}$$

$$A1 = \begin{vmatrix} 0.1548062E+02 & 0.5953427E+00 \\ -0.5559490E+00 & -0.3316040E+00 \end{vmatrix}$$

$$D = \begin{vmatrix} 0.1297802E+02 & -0.1105907E+02 & -0.1443114E+02 \\ -0.8607228E+00 & 0.2337023E+01 & 0.2664362E+01 \end{vmatrix}$$

$$E = \begin{vmatrix} -0.3307328E-01 & 0.9982782E+01 & -0.3243901E+02 \\ 0.9181806E-01 & -0.2605759E+01 & 0.5358793E+01 \end{vmatrix}$$

$$\lambda 11.\ \lambda 22,\ \lambda 33 = \begin{vmatrix} 0.3378882E+00 & 0.2416326E+01 & 0.3989396E+01 \end{vmatrix}$$

K	Q11		Q11		Q12		Q12	
	Q11 r (exp)	Q11 r (app)	Q11 i (exp)	Q11 i (app)	Q12 r (exp)	Q12 r (app)	Q12 i (exp)	Q12 i (app)
0.37	1.0683	0.9634	2.4034	2.4059	6.3717	6.3093	-1.5416	-1.5376
0.56	1.3013	1.2175	3.0430	3.1266	5.5168	5.5214	-1.2459	-1.1811
0.75	1.3565	1.2900	3.8010	3.7140	4.9319	5.0223	-0.7679	-0.7308
0.93	1.1468	1.1936	4.2634	4.1758	4.6067	4.6852	-0.2320	-0.2901
1.12	0.6240	0.8962	4.7040	4.5851	4.3775	4.4148	0.3390	0.1859
1.31	0.1876	0.3731	5.0794	4.9485	4.2353	4.2112	0.6865	0.6759
1.49	-0.3564	-0.3451	5.4348	5.2907	4.0814	4.0736	1.1923	1.1520
1.68	-1.1453	-1.3405	5.6812	5.6954	3.9916	3.9841	1.6453	1.6623
1.87	-2.4014	-2.5690	6.0348	6.1896	3.9537	3.9497	2.0919	2.1735
2.05	-3.9353	-3.9288	6.8763	6.7759	3.9236	3.9648	2.6242	2.6515
2.24	-5.4993	-5.5435	7.4260	7.5490	4.0499	4.0264	3.1555	3.1428
2.43	-7.4504	-7.3106	8.4053	8.5021	4.2524	4.1296	3.6045	3.6149
ε_{ij}	ε_{11} =		0.2806254E-02		ε_{12} =		0.1856888E-02	

K	Q21		Q21		Q22		Q22	
	Q21 r (exp)	Q21 r (app)	Q21 i (exp)	Q21 i (app)	Q22 r (exp)	Q22 r (app)	Q22 i (exp)	Q22 i (app)
0.37	-0.0440	-0.0745	0.3217	0.2999529	1.0271	1.1031	0.0399	0.0417
0.56	-0.1053	-0.1274	0.5263	0.5102	1.1417	1.1791	-0.0515	-0.0206
0.75	-0.1904	-0.1710	0.7439	0.7519	1.2232	1.2421	-0.1161	-0.0975
0.93	-0.1827	-0.1956	1.0371	1.0094	1.2908	1.2957	-0.2093	-0.1798
1.12	-0.1454	-0.1940	1.3332	1.3081	1.3512	1.3470	-0.3039	-0.2765
1.31	-0.1706	-0.1556	1.6579	1.6275	1.4004	1.3918	-0.4099	-0.3827
1.49	-0.1025	-0.0800	1.9690	1.9409	1.4512	1.4270	-0.5046	-0.4908
1.68	-0.0169	0.0439	2.3413	2.2735	1.4870	1.4553	-0.6219	-0.6108
1.87	0.1740	0.2124	2.6589	2.5982	1.5062	1.4742	-0.7322	-0.7347
2.05	0.4129	0.4106	2.9072	2.8909	1.5104	1.4832	-0.8438	-0.8539
2.24	0.6623	0.6561	3.1410	3.1772	1.4974	1.4840	-0.9648	-0.9796
2.43	0.9667	0.9333	3.3008	3.4352	1.4724	1.4765	-1.0602	-1.1038
ε_{ij}	ε_{21} =		0.3653706E-02		ε_{22} =		0.5290542E-02	

J = 0.1166507E+00

Table D-10 - Unsteady Aerodynamic Data - Experimental and approximations

D.7. Profile C

C									
k	H2 *(-1)	H3 *(-1)	A2	A3	k	H1 *(-1)	H4 *(-1)	A1	A4
0.1872	1.4070	19.5320	0.6280	2.0210	0.1863	8.0320	0.7750	0.7500	0.0010
0.2806	-0.0650	8.8000	0.1790	1.0850	0.2794	5.2110	0.8450	0.5550	-0.1630
0.3741	-0.2840	4.8040	0.0520	0.6790	0.3725	3.8840	0.1690	0.4490	-0.0810
0.4676	-0.2730	2.9640	-0.0110	0.4620	0.4657	2.8800	0.3170	0.3980	-0.0250
0.5608	-0.2240	1.9480	-0.0210	0.3380	0.5587	2.2570	0.2840	0.3300	-0.0090
0.6544	-0.1640	1.3420	-0.0260	0.2610	0.6522	1.9090	0.0690	0.2860	0.0180
0.7476	-0.1400	0.9310	-0.0250	0.2130	0.7452	1.5570	0.1300	0.2470	-0.0040
0.8407	-0.0820	0.6300	-0.0220	0.1830	0.8380	1.3090	0.1230	0.2280	-0.0050
0.9339	-0.0050	0.4310	-0.0260	0.1630	0.9314	1.0960	0.0680	0.2030	0.0020
1.0270	0.0560	0.3060	-0.0280	0.1470	1.0247	0.9280	0.0330	0.1900	-0.0130
1.1204	0.1030	0.2300	-0.0310	0.1330	1.1184	0.7280	-0.0110	0.1880	-0.0180
1.2144	0.1550	0.1740	-0.0390	0.1240	1.2116	0.6080	-0.0900	0.1820	-0.0210
1.3085	0.2150	0.1540	-0.0460	0.1130	1.3046	0.4780	-0.2280	0.1880	-0.0190
1.4025	0.2480	0.1640	-0.0510	0.0990	1.3981	0.3710	-0.3420	0.1940	-0.0060
1.4960	0.2500	0.1910	-0.0540	0.0840	1.4917	0.2950	-0.4860	0.2110	0.0060

Table D-11 - C Derivatives

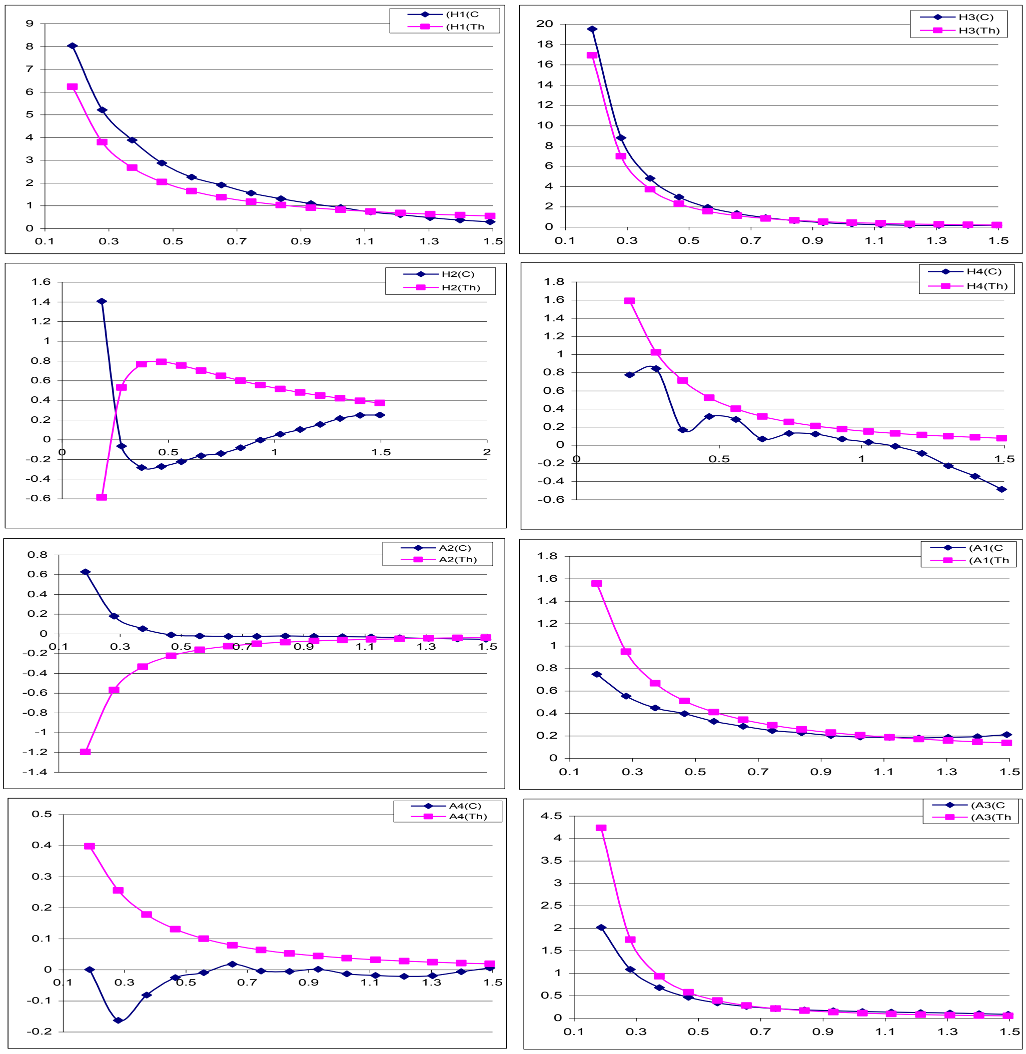

Figure D-7 - Plots of C and Theodorsen derivatives

$$A0 = \begin{vmatrix} -0.2056546E+03 & 0.6813178E+02 \\ 0.1800625E+02 & -0.4204705E+01 \end{vmatrix}$$

$$A1 = \begin{vmatrix} 0.2392765E+02 & -0.4138189E+01 \\ -0.5919932E+00 & 0.2390796E-01 \end{vmatrix}$$

$$D = \begin{vmatrix} -0.5259069E+03 & 0.1695228E+01 & -0.8942568E+01 \\ -0.1223348E+02 & -0.1792081E+00 & 0.9454919E+00 \end{vmatrix}$$

$$E = \begin{vmatrix} -0.3665337E-03 & 0.7386826E+06 & 0.1398486E+06 \\ 0.9839661E-03 & -0.3118553E+06 & -0.5905491E+05 \end{vmatrix}$$

$$\lambda 11.\ \lambda 22,\ \lambda 33 = \begin{vmatrix} 0.2610189E-01 & 0.4995768E+01 & 0.4993358E+01 \end{vmatrix}$$

K	Q11		Q11		Q12		Q12	
	Q11 r (exp)	Q11 r (app)	Q11 i (exp)	Q11 i (app)	Q12 r (exp)	Q12 r (app)	Q12 i (exp)	Q12 i (app)
0.37	0.2151	-0.0605	2.2291	2.0154	5.4732	6.0680	0.3943	0.6896
0.56	0.5276	0.1425	3.2538	3.3721	5.5420	5.8552	-0.0409	-0.0706
0.74	0.1876	0.3919	4.3112	4.4493	5.3783	5.5192	-0.3179	-0.5132
0.93	0.5500	0.6671	4.9968	5.3888	5.1839	5.1071	-0.4775	-0.7608
1.12	0.7092	0.9064	5.6362	6.1235	4.9011	4.6745	-0.5636	-0.8456
1.3	0.2348	1.0539	6.4959	6.6304	4.5970	4.2010	-0.5618	-0.7886
1.49	0.5775	1.0779	6.9164	6.9735	4.1632	3.7375	-0.6260	-0.5888
1.68	0.6910	0.9204	7.3536	7.1365	3.5619	3.3316	-0.4636	-0.2762
1.86	0.4719	0.5659	7.6062	7.1490	3.0072	2.9613	-0.0349	0.1727
2.05	0.2772	-0.0579	7.7946	7.0446	2.5820	2.6842	0.4725	0.6973
2.24	-0.1101	-0.9638	7.2848	6.8579	2.3097	2.4859	1.0344	1.3393
2.42	-1.0569	-2.0978	7.1398	6.6435	2.0528	2.3974	1.8286	2.0533
2.61	-3.1046	-3.5942	6.5089	6.4191	2.1092	2.4275	2.9447	2.8194
2.8	-5.3482	-5.3979	5.8017	6.2386	2.5807	2.5699	3.9025	3.5750
2.98	-8.6519	-7.3838	5.2516	6.1447	3.4197	2.8418	4.4760	4.3856
ε_{ij}	ε_{11} =		0.7625500E-01		ε_{12} =		0.7123245E-01	

K	Q21		Q21		Q22		Q22	
	Q21 r (exp)	Q21 r (app)	Q21 i (exp)	Q21 i (app)	Q22 r (exp)	Q22 r (app)	Q22 i (exp)	Q22 i (app)
0.37	0.0003	0.2822	0.2081	0.1402	0.5663	0.6523	0.1760	0.0789
0.56	-0.1018	0.2300	0.3465	0.2382	0.6833	0.6937	0.1127	0.0831
0.75	-0.0899	0.1663	0.4984	0.3458	0.7602	0.7481	0.0582	0.0828
0.94	-0.0434	0.0883	0.6905	0.4806	0.8080	0.8135	-0.0192	0.0718
1.12	-0.0225	0.0048	0.8241	0.6404	0.8504	0.8830	-0.0528	0.0489
1.31	0.0613	-0.0736	0.9732	0.8168	0.8941	0.9615	-0.0891	0.0100
1.5	-0.0178	-0.1499	1.0972	1.0295	0.9525	1.0420	-0.1118	-0.0450
1.68	-0.0281	-0.2135	1.2808	1.2686	1.0347	1.1172	-0.1244	-0.1119
1.87	0.0139	-0.2573	1.4088	1.5173	1.1373	1.1928	-0.1814	-0.1974
2.05	-0.1092	-0.2816	1.5959	1.8001	1.2404	1.2582	-0.2363	-0.2915
2.24	-0.1801	-0.2796	1.8812	2.0999	1.3356	1.3189	-0.3113	-0.4031
2.43	-0.2466	-0.2511	2.1373	2.3956	1.4629	1.3690	-0.4601	-0.5254
2.62	-0.2587	-0.1911	2.5600	2.7154	1.5477	1.4074	-0.6300	-0.6564
2.8	-0.0938	-0.0996	3.0338	3.0385	1.5579	1.4320	-0.8025	-0.7866
2.99	0.1068	0.0160	3.7563	3.3435	1.5039	1.4453	-0.9668	-0.9283
ε_{ij}	ε_{21} =		0.6929462E-01		ε_{22} =		0.4441194E-01	

J = 0.5110714E+00

Table D-12 - Unsteady Aerodynamic Data - Experimental and approximations

D.8. Profile TC

Tacoma									
k	H2 *(-1)	H3 *(-1)	A2	A3	k	H1 *(-1)	H4 *(-1)	A1	A4
0.1890	-2.0180	23.7260	1.9830	-1.2590	0.1897	12.4580	3.4800	1.5310	-1.1750
0.2836	0.9950	11.0460	1.0820	-0.2320	0.2845	6.0030	-0.9210	0.8970	0.2340
0.3780	-0.4730	6.7710	0.6530	0.1610	0.3790	4.1100	2.0070	0.5820	0.3340
0.4721	-1.4050	4.0530	0.3530	0.2660	0.4738	3.6850	0.0920	-0.3380	-0.4280
0.5661	-1.2590	2.2990	0.2360	0.2720	0.5687	2.6280	1.1150	-0.4070	0.2900
0.6597	-1.0180	1.2600	0.1410	0.2660	0.6633	2.2900	0.7940	0.1070	-0.3450
0.7532	-0.6830	0.5460	0.1110	0.2760	0.7583	1.6830	1.0230	0.1280	-0.3110
0.8454	0.3470	-0.2030	0.0120	0.2770	0.8525	1.1850	0.9520	0.1750	-0.2730
0.9389	0.2930	0.1450	-0.0600	0.2160	0.9480	0.8840	0.7180	0.1720	-0.2550
1.0338	0.1390	0.2580	-0.0690	0.1970	1.0430	0.1500	0.5240	0.2420	-0.2960
1.1333	0.4180	0.3700	-0.1510	0.1620	1.1395	-0.3110	-0.0350	0.3680	-0.2640
1.2272	0.3620	0.4740	-0.1530	0.0960	1.2344	-0.2650	-0.4020	0.4020	-0.1420
1.3222	0.2300	0.5140	-0.1260	0.0540	1.3301	-0.2110	-1.5380	0.4940	0.0650
1.4164	0.1160	0.5100	-0.0970	0.0310	1.4254	0.8450	-1.7510	0.3360	0.2360

Table D-13 - TC derivatives

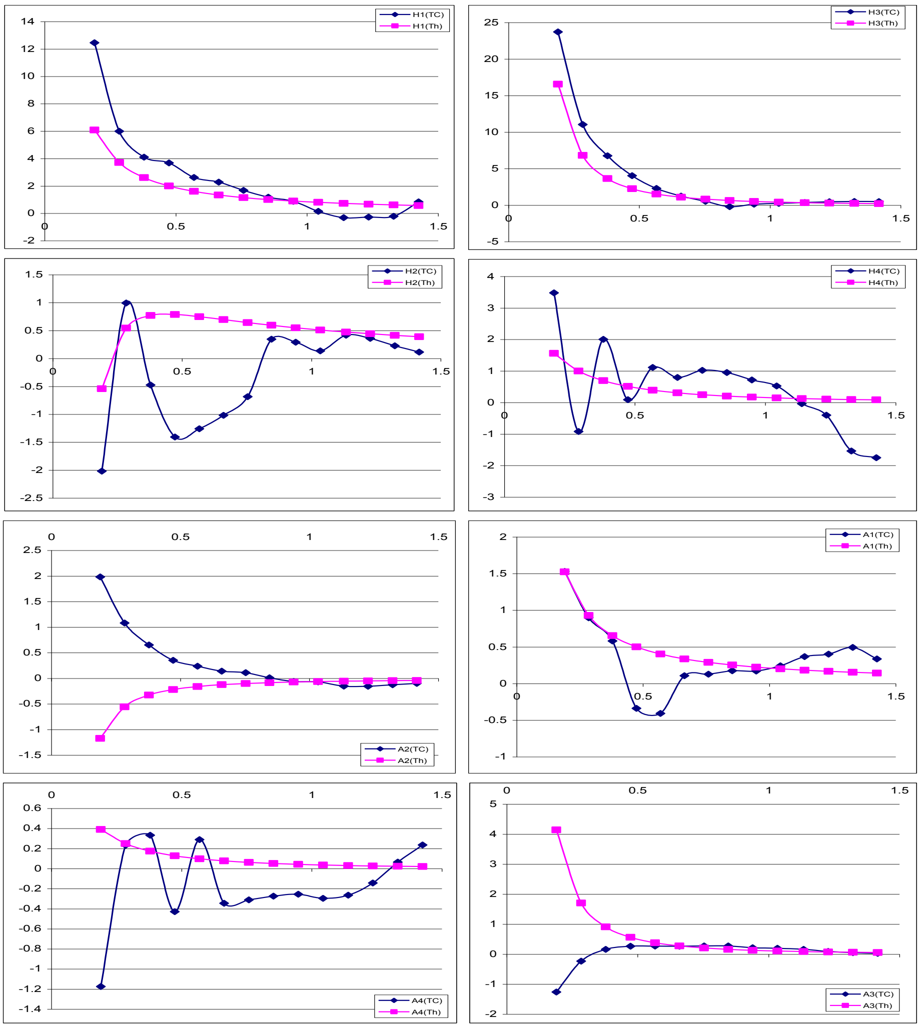

Figure D-8 - Plots of TC and Theodorsen derivatives

A0 =	-0.1545739E+02	0.4288549E+00	
	-0.2694613E+01	0.3400656E+01	
A1 =	0.6283213E+01	0.2084439E+01	
	0.2112671E+01	-0.1167155E+01	
D =	0.1444638E+03	0.9907199E+04	-0.3690009E+04
	0.7118608E+00	0.3574415E+04	-0.2289577E+03
E =	-0.3285084E-01	0.1425661E-02	-0.1041667E-01
	0.1176005E+00	-0.3036590E-02	-0.7812500E-02
λ11. λ22, λ33 =	0.2505000E+01	0.2505000E+01	0.2505000E+01

K	Q11		Q11		Q12		Q12	
	Q11 r (exp)	Q11 r (app)	Q11 i (exp)	Q11 i (app)	Q12 r (exp)	Q12 r (app)	Q12 i (exp)	Q12 i (app)
0.38	1.0016	3.2015	3.5856	-0.4429	6.7835	6.5683	-0.5770	-0.1392
0.57	-0.5963	2.6912	3.8867	-0.5482	7.1068	6.4004	0.6402	-0.1707
0.76	2.3058	2.0220	4.7220	-0.5279	7.7418	6.1801	-0.5408	-0.1607
0.95	0.1652	1.2307	6.6171	-0.3598	7.2277	5.9343	-2.5055	-0.1065
1.14	2.8851	0.3559	6.8000	-0.0336	5.8931	5.6476	-3.2272	0.0013
1.33	2.7950	-0.5667	8.0612	0.4506	4.3871	5.3446	-3.5445	0.1611
1.52	4.7058	-1.5059	7.7418	1.0849	2.4780	5.0356	-3.0998	0.3706
1.71	5.5354	-2.4367	6.8902	1.8559	-1.1607	4.7450	1.9841	0.6108
1.9	5.1619	-3.3401	6.3553	2.7474	1.0226	4.4466	2.0664	0.9035
2.09	4.5605	-4.2032	1.3055	3.7422	2.2057	4.1610	1.1883	1.2307
2.28	-0.3636	-5.0177	-3.2306	4.8237	3.8019	3.8776	4.2952	1.6065
2.47	-4.9005	-5.7790	-3.2304	5.9763	5.7107	3.6389	4.3613	1.9673
2.66	-21.7664	-6.4856	-2.9862	7.1864	7.1889	3.4045	3.2168	2.3669
2.85	-28.4612	-7.1379	13.7348	8.4419	8.1853	3.1880	1.8618	2.7818
ε_{ij}	ε_{11} =		0.1584989E+01		ε_{12} =		0.2368647E+01	

K	Q21		Q21		Q22		Q22	
	Q21 r (exp)	Q21 r (app)	Q21 i (exp)	Q21 i (app)	Q22 r (exp)	Q22 r (app)	Q22 i (exp)	Q22 i (app)
0.38	-0.3382	0.2155	0.4406	0.3613662	-0.3600	-0.1042	0.5670	0.0881
0.57	0.1515	0.1359	0.5808	0.5602	-0.1493	-0.0083	0.6961	0.1104
0.76	0.3837	0.0315	0.6687	0.7785	0.1841	0.1174	0.7466	0.1091
0.94	-0.7686	-0.0919	-0.6069	1.0200	0.4744	0.2578	0.6295	0.0822
1.13	0.7504	-0.2283	-1.0531	1.2861	0.6972	0.4214	0.6049	0.0250
1.32	-1.2145	-0.3722	0.3767	1.5768	0.9262	0.5944	0.4909	-0.0619
1.51	-1.4306	-0.5187	0.5888	1.8910	1.2526	0.7708	0.5038	-0.1771
1.69	-1.5874	-0.6639	1.0175	2.2264	1.5839	0.9367	0.0686	-0.3102
1.88	-1.8333	-0.8048	1.2366	2.5807	1.5233	1.1071	-0.4231	-0.4729
2.07	-2.5762	-0.9394	2.1062	2.9510	1.6842	1.2701	-0.5899	-0.6554
2.27	-2.7423	-1.0664	3.8226	3.3349	1.6646	1.4319	-1.5516	-0.8654
2.45	-1.7310	-1.1851	4.9005	3.7299	1.1566	1.5681	-1.8433	-1.0672
2.64	0.9199	-1.2954	6.9913	4.1339	0.7553	1.7019	-1.7623	-1.2910
2.83	3.8360	-1.3971	5.4614	4.5449	0.4975	1.8255	-1.5568	-1.5236
ε_{ij}	ε_{21} =		0.1392574E+01		ε_{22} =		0.1551113E+01	

J = 0.2626275E+01

Table D-14 - Unsteady Aerodynamic Data - Experimental and approximations

D.9. Profile G

G									
k	H2 *(-1)	H3 *(-1)	A2	A3	k	H1 *(-1)	H4 *(-1)	A1	A4
0.1882	-0.8200	9.8600	-0.7960	1.2410	0.1879	3.7690	0.6510	0.6300	0.2580
0.2825	-0.3590	4.2110	-0.5340	0.5170	0.2818	2.4040	0.3730	0.3950	0.2120
0.3767	-0.1480	2.3190	-0.3860	0.2640	0.3756	1.7340	0.2820	0.2630	0.1920
0.4707	-0.0610	1.4860	-0.3040	0.1420	0.4697	1.3700	0.1860	0.1850	0.1720
0.5651	-0.0230	1.0360	-0.2440	0.0770	0.5637	1.1440	0.1370	0.1310	0.1560
0.6590	-0.0130	0.7800	-0.2020	0.0390	0.6582	0.9870	0.1070	0.0950	0.1400
0.7534	-0.0120	0.6190	-0.1690	0.0140	0.7534	0.8760	0.0830	0.0650	0.1280
0.8475	-0.0160	0.5040	-0.1410	-0.0010	0.8466	0.7930	0.0770	0.0440	0.1150
0.9414	-0.0250	0.4220	-0.1190	-0.0100	0.9403	0.7270	0.0790	0.0260	0.1040
1.0355	-0.0350	0.3570	-0.1000	-0.0150	1.0344	0.6710	0.0830	0.0120	0.0910
1.1293	-0.0450	0.3020	-0.0840	-0.0170	1.1284	0.6210	0.0900	0.0020	0.0790
1.2234	-0.0500	0.2570	-0.0700	-0.0170	1.2224	0.5720	0.1030	-0.0060	0.0680
1.3172	-0.0580	0.2160	-0.0590	-0.0160	1.3178	0.5290	0.1140	-0.0120	0.0560
1.4120	-0.0580	0.1830	-0.0500	-0.0130	1.4107	0.4860	0.1250	-0.0140	0.0460

Table D-15 - G derivatives

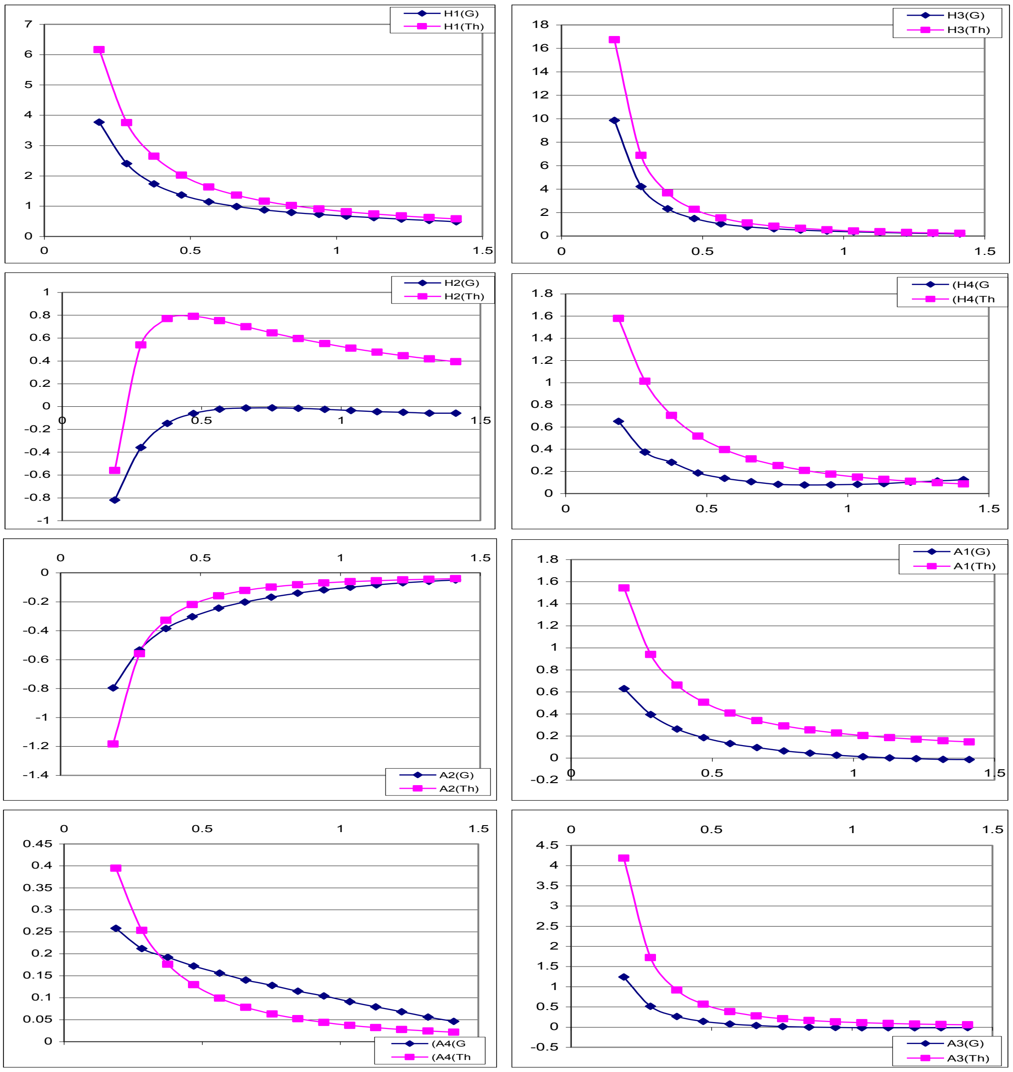

Figure D-9 - Plots of G and Theodorsen derivatives

$$A0 = \begin{vmatrix} 0.1428823E+02 & -0.1354282E+01 \\ -0.9541573E+00 & 0.2429820E+00 \end{vmatrix}$$

$$A1 = \begin{vmatrix} 0.4700185E+00 & 0.2530285E+00 \\ 0.8508760E-01 & -0.2557940E+00 \end{vmatrix}$$

$$D = \begin{vmatrix} 0.9727750E+11 & -0.7808196E+07 & 0.9139604E+07 \\ -0.1695936E+11 & 0.1306211E+07 & -0.1565547E+07 \end{vmatrix}$$

$$E = \begin{vmatrix} -0.7014327E-08 & 0.1456413E-03 & 0.1915604E-03 \\ 0.3613225E-08 & -0.8407563E-04 & -0.1075921E-03 \end{vmatrix}$$

$$\lambda 11.\ \lambda 22,\ \lambda 33\ = \begin{vmatrix} 0.2515063E+01 & 0.2012862E+01 & 0.2130107E+01 \end{vmatrix}$$

K	Q11		Q11		Q12		Q12	
	Q11 r (exp)	Q11 r (app)	Q11 i (exp)	Q11 i (app)	Q12 r (exp)	Q12 r (app)	Q12 i (exp)	Q12 i (app)
0.38	0.1838	0.0945	1.0641	1.1367	2.7945	2.7926	-0.2324	-0.1852
0.56	0.2369	0.2150	1.5270	1.5917	2.6893	2.7050	-0.2293	-0.2038
0.75	0.3183	0.3210	1.9571	2.0177	2.6324	2.6427	-0.1680	-0.1745
0.94	0.3282	0.3800	2.4176	2.4227	2.6341	2.6220	-0.1081	-0.1167
1.13	0.3483	0.3933	2.9083	2.8474	2.6470	2.6530	-0.0588	-0.0611
1.32	0.3708	0.3842	3.4208	3.3214	2.7102	2.7253	-0.0452	-0.0334
1.51	0.3769	0.3852	3.9776	3.8555	2.8107	2.8193	-0.0545	-0.0480
1.69	0.4415	0.4231	4.5465	4.4111	2.8958	2.9095	-0.0919	-0.1036
1.88	0.5588	0.5228	5.1425	5.0329	2.9922	2.9892	-0.1773	-0.2011
2.07	0.7105	0.6941	5.7441	5.6685	3.0622	3.0417	-0.3002	-0.3280
2.26	0.9168	0.9380	6.3262	6.2958	3.0809	3.0612	-0.4591	-0.4725
2.44	1.2313	1.2303	6.8378	6.8657	3.0770	3.0467	-0.5986	-0.6234
2.64	1.5837	1.6138	7.3491	7.4566	2.9982	3.0037	-0.8051	-0.7639
2.82	1.9900	2.0004	7.7372	7.9424	2.9186	2.9314	-0.9250	-0.9029
ε_{ij}	ε_{11} =		0.2347324E-02		ε_{12} =		0.1077755E-02	

K	Q21		Q21		Q22		Q22	
	Q21 r (exp)	Q21 r (app)	Q21 i (exp)	Q21 i (app)	Q22 r (exp)	Q22 r (app)	Q22 i (exp)	Q22 i (app)
0.38	0.0728	0.1004	0.1779	0.158595	0.3517	0.3777	-0.2256	-0.2242
0.57	0.1347	0.1438	0.2509	0.2290	0.3302	0.3520	-0.3410	-0.3369
0.75	0.2167	0.2105	0.2968	0.2926	0.2997	0.3143	-0.4382	-0.4402
0.94	0.3035	0.2959	0.3265	0.3371	0.2517	0.2607	-0.5389	-0.5409
1.13	0.3966	0.3932	0.3330	0.3563	0.1967	0.1955	-0.6234	-0.6280
1.32	0.4852	0.4933	0.3293	0.3472	0.1355	0.1238	-0.7019	-0.6985
1.51	0.5812	0.5870	0.2951	0.3111	0.0636	0.0510	-0.7674	-0.7517
1.69	0.6593	0.6631	0.2523	0.2559	-0.0057	-0.0146	-0.8101	-0.7875
1.88	0.7356	0.7255	0.1839	0.1816	-0.0709	-0.0765	-0.8438	-0.8124
2.07	0.7790	0.7675	0.1027	0.0972	-0.1287	-0.1290	-0.8577	-0.8275
2.26	0.8048	0.7890	0.0204	0.0087	-0.1734	-0.1711	-0.8569	-0.8363
2.45	0.8129	0.7921	-0.0717	-0.0743	-0.2035	-0.2030	-0.8381	-0.8416
2.63	0.7780	0.7783	-0.1667	-0.1619	-0.2221	-0.2244	-0.8190	-0.8457
2.82	0.7323	0.7531	-0.2229	-0.2341	-0.2073	-0.2389	-0.7974	-0.8506
ε_{ij}	ε_{21} =		0.4850071E-02		ε_{22} =		0.9551460E-02	

J = 0.1335163E+00

Table D-16 - Unsteady Aerodynamic Data - Experimental and approximations.