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DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

ARLSUPER VERSION 1.0, PROGRAM USERS GUIDE (U)

by

I. H. Grundy

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SUMMARY

The computer program ARLSUPER calculates linearised steady and oscillatory supersonic flow around a coplanar wing and tail, vertical fin configuration using an explicit finite difference scheme. In this version, surface and mode shapes may be entered in functional form or as a collection of data points. Generalised forces are calculated and are written out in a form compatible with available flutter solvers.

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1. INTRODUCTION

ARLSUPER V1.0 is a computer program for the calculation of linearised steady and oscillatory supersonic flow. This program supersedes SUPER, which was written by Dr. John Gear [1] of RMIT Mathematics Department and later modified at ARL by the present author [15].

The program computes flow over a configuration consisting of a coplanar wing and tail in association with a vertical fin. With care, a fuselage can also be accounted for if all its parts can be idealised to lie in either the plane of the wing and tail or the plane of the vertical fin.

ARLSUPER implements an explicit finite difference scheme based on that of Sullivan [2], in which the velocity potential is calculated on a characteristic grid, by stepping in a streamwise direction through the flow field. Both the potential and pressure are calculated on the lifting surfaces.

Component and mode shapes can be specified either in terms of FORTRAN subroutines or as collections of data points. In the latter case bivariate interpolation is used to generate input into the program where required.

For unsteady flow, generalised forces are calculated from the potential for each required Mach number, reduced frequency and mode case (multiple cases are possible in one run). The generalised force output is similar to that generated by the doublet lattice program DOULAT, Waldman [14], and can be used directly by a flutter solver compatible with that program.

2. REVIEW OF FINITE DIFFERENCE FORMULATION

Governing Equation

ARLSUPER is based on the linearised supersonic equation, namely

$$(M^2-1)\phi_{xx} - \phi_{yy} - \phi_{zz} + 2M^2\phi_{xt} + M^2\phi_{tt} = 0.$$

The space variables x,y and z (where positive z is up) have been scaled by L, a suitable length scale. Time t has been scaled by L/U_∞ where U_∞ is the undisturbed free stream velocity. The velocity potential ϕ has been scaled by $U_\infty L$. M is the free stream Mach number.

The potential ϕ can be written as

$$\phi = \phi_s + \phi_u e^{i\omega t}$$

where ϕ_s is the steady part, ϕ_u is the oscillatory part and ω is the reduced frequency. Substitution into the governing equation gives two equations to solve, one steady and the other oscillatory, which are uncoupled. It can be seen that the steady problem (apart from the thickness boundary conditions - the oscillatory problem is analogous to the camber problem - see [1]) is just a special case of the unsteady problem with $\omega = 0$, so attention will be restricted here to the unsteady problem alone.

The unsteady potential ϕ_u satisfies

$$(M^2-1)\phi_{uxx} - \phi_{uyy} - \phi_{uzz} + 2i\omega M^2\phi_{ux} - M^2\omega^2\phi_u = 0.$$

The following substitution and (Prandtl-Glauert) change of variables, namely

$$\phi_u = \Phi_u e^{-i\Omega MX}$$

where

$$X = x,\ Y = \alpha y,\ Z = \alpha z,\ T = t,\ \Omega = \omega M/\alpha^2$$

and

$$\alpha^2 = M^2 - 1$$

gives an equation for Φ_u in the form

$$\Phi_{uXX} - \Phi_{uYY} - \Phi_{uZZ} + \Omega^2\Phi_u = 0.$$

Symmetry Arguments

As is usual in linearised theory, all lifting surfaces are assumed to be thin. Thus, the boundary conditions for each surface can be applied on a flat plate, either $Y = 0$ or $Z = 0$, representing the "mean" steady surface position. All configurations under consideration are assumed to be symmetric in Y. Thus, by classifying all modes of oscillation as either symmetric or antisymmetric in Y we can reduce the computational domain to $Y \geq 0$ (with appropriate symmetry boundary conditions on $Y = 0$).

For unsteady motion of a wing and tail plane only, the potential Φ_u is antisymmetric in Z, thus allowing the computational domain to be easily restricted to $Z \geq 0$. However, the presence of a vertical fin means that in general the configuration is no longer symmetric in Z. As a result, the potential is no longer antisymmetric in Z. In order to reduce the computational domain as before, Φ_u must now be written as the sum of an antisymmetric part Φ^A and a symmetric part Φ^S. Both Φ^A and Φ^S satisfy the same governing equation as Φ_u, so they can be calculated simultaneously.

Boundary Conditions

The boundary of flow domain consists of three types of region as shown in Figure 1 below. Of the first type are the aerodynamic surfaces, the horizontal wing and tail and the vertical fin, on which a tangential flow condition (i.e. a specified normal perturbation velocity condition) holds. Of the second type are the wing, tail and fin wakes across which there is a jump in potential but no jump in pressure. Of the third type are the diaphragm regions, including regions of undisturbed flow, across which there is no jump in potential or pressure.

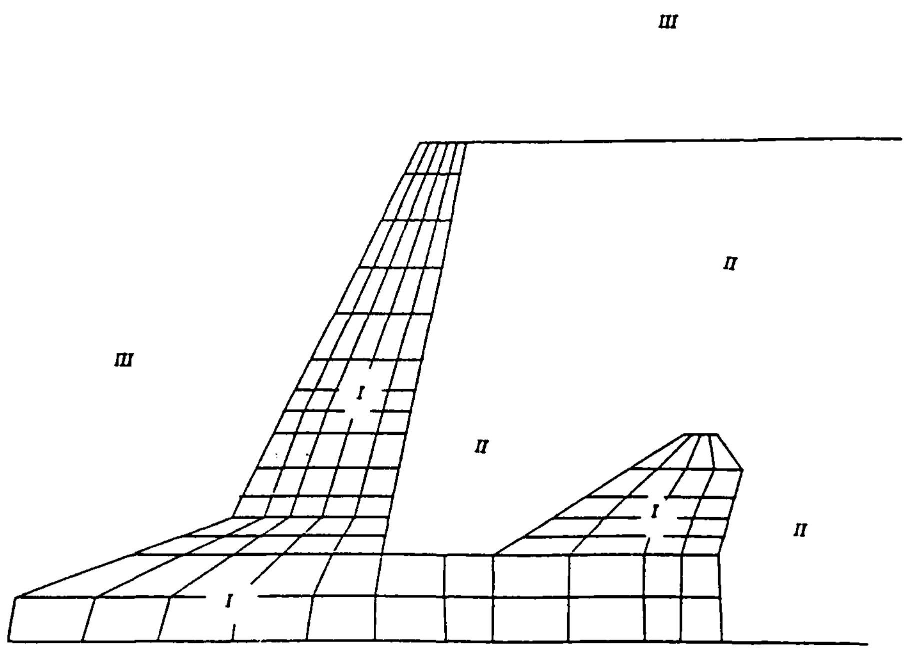

Figure 1. *Boundary regions: Types I, II and III*

In the following we assume that the wing mode shape is $Z = h(X,Y)$, the tail mode shape is $Z = g(X,Y)$ and the fin mode shape is $Y = f(X,Z)$.

The boundary conditions in the plane of the wing and tail are quite straightforward and are uncoupled. Φ^A must satisfy the tangential flow conditions

$$\Phi^A_Z|_{Z=0} = \frac{e^{i\Omega MX}}{\alpha}(\frac{\partial}{\partial X}h + i\omega h) \quad \text{on the wing}$$

and

$$\Phi^A_Z|_{Z=0} = \frac{e^{i\Omega MX}}{\alpha}(\frac{\partial}{\partial X}g + i\omega g) \quad \text{on the tail.}$$

On the wing and tail wakes Φ^A must satisfy the pressure continuity condition

$$\Phi^A_X - i(\Omega/M)\Phi^A = 0$$

which can be rewritten as

$$\Phi^A(X,Y,0) = e^{i\Omega\Delta/M}\Phi^A(X-\Delta,Y,0).$$

On the wing and tail diaphragm regions Φ^A must satisfy

$$\Phi^A|_{Z=0} = 0.$$

The symmetric part Φ^S meanwhile must satisfy

$$\Phi^S_Z = 0$$

everywhere on $Z = 0$.

The boundary conditions on the plane of the vertical fin are considerably more complicated. For modes symmetric in Y the fin does not oscillate. Thus, we have the boundary conditions

$$\Phi^S_Y = \Phi^A_Y = 0 \quad \text{on Y} = 0.$$

For modes antisymmetric in Y the boundary conditions for Φ^A and Φ^S are coupled. We have

$$\frac{\partial}{\partial Y}(\Phi^S(X,Y,Z) + \Phi^A(X,Y,Z))|_{Y=0} = \frac{e^{i\Omega MX}}{\alpha}\{\frac{\partial}{\partial X}f(X,Z) + i\omega f(X,Z)\}$$

if $(X,0,Z)$ is on the fin,

$$\Phi^S(X,0,Z) + \Phi^A(X,0,Z) = e^{i\Omega\Delta/M}\{\Phi^S(X-\Delta,0,Z) + \Phi^A(X-\Delta,0,Z)\}$$

if $(X,0,Z)$ is on the fin wake, and

$$\Phi^S(X,0,Z) + \Phi^A(X,0,Z) = 0$$

if $(X,0,Z)$ is on the fin diaphragm.

To uncouple Φ^A and Φ^S in the above equations we need one more equation for each $(X,0,Z)$, $X,Z \geq 0$. This we obtain by considering the boundary conditions at the reflection of $(X,0,Z)$ in the $X-Y$ plane (i.e. at $(X,0,-Z)$) Then symmetry (or antisymmetry) is used to relate the potentials below the plane to those above. We obtain

$$\frac{\partial}{\partial Y}(\Phi^S(X,Y,Z) - \Phi^A(X,Y,Z))|_{Y=0} = \frac{e^{i\Omega MX}}{\alpha}\{\frac{\partial}{\partial X}f(X,-Z) + i\omega f(X,-Z)\}$$

if $(X, 0, -Z)$ is on the fin,

$$\Phi^S(X,0,Z) - \Phi^A(X,0,Z) = e^{i\Omega\Delta/M}\{\Phi^S(X-\Delta,0,Z) - \Phi^A(X-\Delta,0,Z)\}$$

if $(X, 0, -Z)$ is on the fin wake, and

$$\Phi^S(X,0,Z) - \Phi^A(X,0,Z) = 0$$

if $(X, 0, -Z)$ is on the fin diaphragm.

After expressing all derivatives in finite difference form (see next section) we have two equations (the forms of which depend on the position of $(X, 0, Z)$ and $(X, 0, -Z)$) with which to uncouple the fin boundary conditions for Φ^A and Φ^S.

Finite Difference Discretisation

The finite difference scheme proposed by Sullivan [2] and used here is an explicit second order consistent finite difference scheme with rotational symmetry about the X-axis, which reduces to the method of characteristics for two-dimensional flow in the $X-Y$ or $X-Z$ planes. The grid points form a cubic lattice $(X, Y, Z) = (i, j, k)\Delta$ where Δ is the grid step size. Note that since X, Y and Z are Prandtl-Glauert variables the grid is Mach number dependent. When discretised, the governing equation becomes

$$\Phi(i+1,j,k) = -\Phi(i-1,j,k) + \frac{1}{2+\Omega^2\Delta^2}C(i,j,k)$$

where

$$\begin{aligned} C(i,j,k) =& \Phi(i,j-1,k-1) + \Phi(i,j-1,k+1) \\ &+ \Phi(i,j+1,k-1) + \Phi(i,j+1,k+1) \end{aligned}$$

and $\Phi(i, j, k)$ has the obvious interpretation. Φ here represents Φ^S or Φ^A.

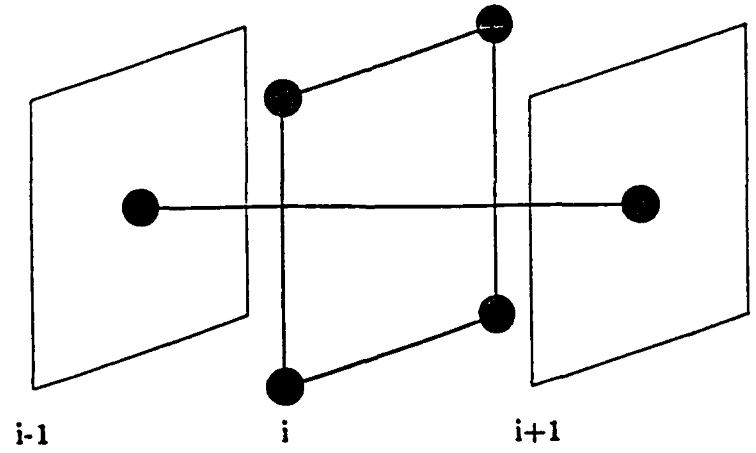

Figure 2. *Finite difference scheme*

From Figure 2 it can be seen that only every second grid point is needed as the scheme steps downstream, *meaning that this scheme is particularly suitable for fast numerical computations.*

Normal derivative boundary conditions are implemented by the use of dummy potentials at fictional grid points. For example, writing

$$\Phi_Z|_{Z=0} = \frac{\{\Phi(i,j,2) - \Phi(i,j,0)\}}{2\Delta}$$

at the boundary level $k = 1$, gives

$$\Phi(i+1,j,1) + \Phi(i-1,j,1) = \frac{2}{2+\Omega^2\Delta^2}\{\Phi(i,j-1,2) + \Phi(i,j-1,2)$$
$$-\Delta\Phi_Z(i,j-1) - \Delta\Phi_Z(i,j+1)\}$$

on substitution into the governing equation, thus allowing the scheme to step forward in X at the boundary. Normal derivative boundary conditions on the $Y = 0$ plane are handled similarly.

3. CALCULATION OF GENERALISED FORCES

The generalised force Q_{ij} in the ith mode of oscillation resulting from harmonic oscillation in the jth mode is given by

$$Q_{ij} = -\frac{1}{2}\int_S\int \Delta C_{pj} f_i \, dS.$$

In this equation, S includes all aerodynamic surfaces, and

$$\Delta C_{pj} = -2(\Delta\phi_{ujx} + i\omega\Delta\phi_{uj}),$$

is the difference in pressure coefficient between the lower and upper sides of each surface resulting from oscillation in mode j (the jth "forcing mode"), f_i is the ith "displacement mode" and ω is the reduced frequency, based on length L and velocity U_∞. The above formula is equivalent to that given in [14]. It is also equivalent to that given in [4] if the wing semi-span is chosen to be the length scale L. Note that we have returned to the original scaled variables here, as opposed to the Prandtl-Glauert variables of the previous section.

For modes i and j which involve the wing only, the above equation becomes

$$Q_{ij} = -\frac{1}{2}\int_{-\ell}^{\ell}\int_{x_{le}(y)}^{x_{te}(y)} \Delta C_{pj}(x,y) f_i(x,y)\,dx\,dy,$$

where ℓ is the (scaled) wing semi-span.

Unfortunately, this equation is unacceptable for calculation of generalised forces because of oscillations in the potential (caused by Mach lines which emanate from the jagged leading edge) which are magnified by the differentiation involved in calculating ΔC_{pj}.

To avoid this problem, we integrate by parts in the x direction to give

$$Q_{ij} = \int_{-\ell}^{\ell}\Big[\Delta\phi_{uj}(x,y) f_i(x,y)\Big]_{x_{le}(y)}^{x_{te}(y)} dy$$
$$-\int_{-\ell}^{\ell}\int_{x_{le}(y)}^{x_{te}(y)} \Delta\phi_{uj}(x,y)\Big[f_{ix}(x,y) - i\omega f_i(x,y)\Big]dx\,dy,$$

which avoids the streamwise derivative of the potential. Note that this formula involves line integrals at the leading and trailing edges as well as a surface integral.

4. ARLSUPER VERSION 1.0 - AN OVERVIEW

ARLSUPER requires certain input files (where [jobname] is the user-specified job name), namely

[jobname].dat

which contains flow and geometry parameters to be read into the program.

[jobname].f

which contains FORTRAN subroutines defining the configuration geometry, and mode shapes (if available in functional form). [jobname].f must be compiled and bound with the main program. If the mode shapes cannot be specified in simple form they can be specified as a collection of points in another data file, [jobname].modes.

and

[jobname].modes

which is the optional mode data file, containing displacement and slope data at user-selected points on each surface. Bivariate interpolation is used to give displacements and slopes at positions required by the program.

It is important to note that ARLSUPER assumes that all lengths are scaled prior to input (i.e. by the user) by a suitable length scale (L, on which the reduced frequency is based).

ARLSUPER generates two output files, namely

[jobname].out

which contains the output potential and/or pressure on each surface if desired. [jobname].out also echoes the input data and contains error messages if generated.

and

[jobname][Mach number case][frequency case].gf

which are a number of files containing generalised forces calculated from the potential for each required Mach number, reduced frequency and mode case. The generalised force output is compatible with the doublet lattice program DOULAT, [14], and can be used directly by a flutter solver compatible with that program. As an example, the generalised forces in various modes for the second Mach number and third frequency case would appear in [jobname]23.gf. The generalised force output consists firstly of the real part Q'_{ij} followed by the imaginary part Q''_{ij}, where

$$Q_{ij} = Q'_{ij} + i\omega Q''_{ij}$$

followed by Q_{ij} written in modulus and argument form.

Details of the above input files will be given in the next section.

5. INPUT DATA FOR ARLSUPER

[jobname].dat

The input data file [jobname].dat contains the flow and geometry variables, one per line unless otherwise stated and in free format. They are

ISW	which is the switch parameter for unsteady (ISW=1) or steady (ISW=2) flow cases.
IOUT	which determines the type of output printed. IOUT=1 for pressure only, IOUT=2 for potential only, IOUT=3 for both pressure and potential. In all cases generalised forces are calculated and printed. Printing of pressure and potential can be supressed by setting IOUT=4.
IWID	which determines the output width. IWID=1 for screen width output and IWID=2 for line printer width output.
IDIG	which determines the number of decimal places in the output, and must be in the range 4 to 8.
DY	which is the spanwise (and also vertical) grid spacing.
B2	which is the wing semi-span length.
T2	which is the tail semi-span length. To run the program without a tail set T2=0.0
FLO	which is the lowest point of the vertical fin.
FUP	which is the highest point of the vertical fin. To run the program without a vertical fin, set FUP=FLO
NAMS	which is the number of Mach number cases considered. Maximum=20.
AMS(J)	which are the Mach numbers listed in free format on one line.
NOMS	which is the number of reduced frequency cases considered. Maximum=20.
OMS(J)	which are the reduced frequencies listed in free format on one line.
MSW	which is the mode switch parameter. When MSW=1 the program uses mode functions listed in the subroutine file. When MSW=2 the program uses point data from the data file [jobname].modes.
NSM	which is the number of symmetric modes labelled 1 to NSM. Maximum=20.
NAM	which is the number of antisymmetric modes labelled NSM+1 to NSM+NAM. Maximum=20.
NFM	which is the number of forcing modes in this run. Maximum=20.
IFMS(J)	which are the forcing modes (in any order) listed in free format on one line.
NDM	which is the number of displacement modes in this run. Maximum=20.
IDMS(J)	which are the displacement modes (in any order) listed in free format on one line.

Note that in the steady case the mode number is assumed to be zero.

[jobname].f

The input file [jobname].f contains FORTRAN subroutines defining the configuration geometry and mode shapes. There are six functions defining the leading and trailing edges of each component. They are WL(Y), WT(Y), TL(Y), TT(Y), FL(Y) and FT(Y). The function WL(Y) gives the x position of the leading edge as a function of the spanwise co-ordinate y. Similarly WT(Y) gives the trailing edge position of the wing, and so on. PLEASE NOTE: The program carries out the Prandtl-Glauert scaling as described in Section 2 internally. All input to the program is assumed to be in terms of the original *scaled* variables x, y, z and t.

Complicated leading edge geometries etc. described by more than one function can be easily handled by the use of IF-THEN-ELSE statements. In this way it is also possible to model a fuselage by assuming the leading part to be part of the wing leading edge and making some arbitrary changeover (i.e. a cut in the fuselage behind the wing) from the wing trailing edge to the tail leading edge. Similarly, vertical surfaces of the fuselage can be treated as part of the vertical fin.

Mode shapes (if they are all available in functional form) should appear in three subroutines, namely
WING (X,Y,IP,H1,H2,IER)
TAIL (X,Y,IP,H1,H2,IER)
and
FIN (X,Z,IP,H1,H2,IER)

Templates for these subroutines are supplied with ARLSUPER. An example of each of these subroutines appears in Appendix 1, and should be referred to while reading the following paragraphs.

In the subroutines WING, TAIL and FIN the parameters X, Y and Z are the original scaled variables x, y and z. The variable IP refers to the mode number plus one. That is, in each of the three subroutines, IP=1 represents the steady surface shape, IP=2 to IP=NSM+1 represent the NSM symmetric unsteady modes 1 to NSM, and IP=NSM+2 to IP=NSM+NAM+1 represent the NAM antisymmetric unsteady modes NSM+1 to NSM+NAM. The program jumps to label IP via a computed GOTO statement. IMPORTANT: The symmetric and antisymmetric modes should be kept separate at this stage, as described above.

The output variables are H1 and H2. For the steady case, IP=1, H1 is the upper surface shape and H2 is the lower surface shape. For the unsteady modes IP=2 onwards, H1 is the modal displacement, and H2 is the streamwise derivative of H1, i.e the derivative of H1 with respect to x.

Each mode, corresponding to a particular IP, is assumed to consist of a WING, TAIL and FIN component even if that contribution is zero. For example, position IP=2 in WING, TAIL and FIN contains the first unsteady mode, even if say, for the fin, H1 and H2 are zero. Similarly for IP=3 onwards.

The final variable IER is an error parameter. IER=0 if there is no error and IER=1 if IP is out of range, i.e. if IP is greater than NSM+NAM+1, or less than unity.

[jobname].modes

This is the optional mode data file which contains displacement and slope data at user-selected points on each surface. The format required of [jobname].modes is, for each mode in turn including the steady mode 0,

NW0 (number of points for wing component of mode 0)
X(1),Y(1),DI(1),SL(1)

. . . .

X(NW0),Y(NW0),DI(NW0),SL(NW0)
NT0 (number of points for tail component of mode 0)
X(1),Y(1),DI(1),SL(1)

. . . .

X(NT0),Y(NT0),DI(NT0),SL(NT0)
NF0 (number of points for fin component of mode 0)
X(1),Z(1),DI(1),SL(1)

. . . .

X(NF0),Z(NF0),DI(NF0),SL(NF0)
NW1 (number of points for wing component of mode 1 – first unsteady mode)
X(1),Y(1),DI(1),SL(1)

. . . .

X(NW1),Y(NW1),DI(NW1),SL(NW1)
etc.

NW0, NT0 etc. are the number of data points to be read in for each surface and mode. On the wing and tail, the data consist of the positions (X(I),Y(I)) and the z-wise displacements DI(I) and streamwise slopes SL(I) at each of those positions. On the vertical fin, the data consist of the positions (X(I),Z(I)) and the y-wise displacements DI(I) and streamwise slopes SL(I) at each of those positions. All entries are assumed to be in free format.

6. SAMPLE RESULTS AND DISCUSSION

In order to demonstrate the accuracy of ARLSUPER, comparison has been made between the output from the present program and that from a number of other methods, namely
a. the Mach box method, [6] and [7],
b. the potential gradient method, [8] and [9] (improved),
c. the doublet point method, [10],
d. the harmonic gradient method, [11], and
e. the constant pressure method, [13],
for a number of well known interference configurations. In addition, results are also given from [2] in which the present finite difference scheme first appeared.

	x	y	z
a	0	0	0
b	2.25	0	0
c	2.75	1.00	0
d	3.70	1.00	0
e	2.70	0	0
f	4.00	0	0
g	3.90	1.00	0
h	4.25	1.00	0
e'	3.10	0	0.60
f'	4.40	0	0.60
g'	4.30	1.00	0.60
h'	4.65	1.00	0.60
e"	3.55	0	1.20
f"	4.85	0	1.20
g"	4.75	1.00	1.20
h"	5.10	1.00	1.20
e"'	2.70	0	0
f"'	4.00	0.	0
g"'	3.90	1.00	0.30
h"'	4.25	1.00	0.30
i	2.50	0	0
j	4.20	0	0
k	3.70	0	1.20
l	4.60	0	1.20

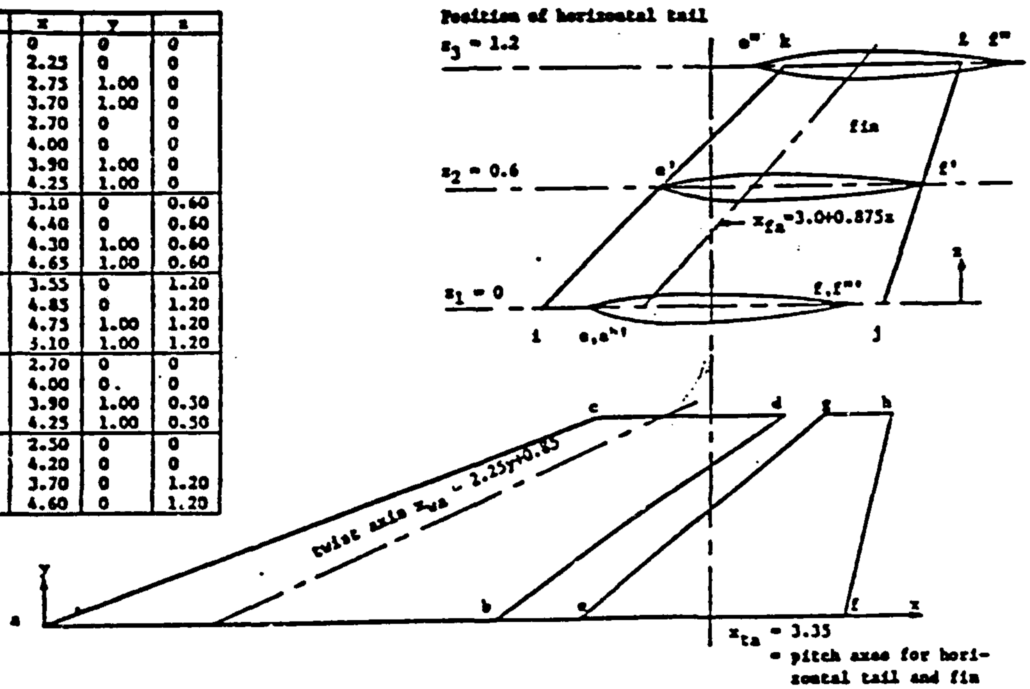

Figure 3. *AGARD horizontal wing, tail and vertical fin interference configuration*

It should be noted here that [4] provides an exhaustive list of generalised force results for a number of wing-only planforms. However, as agreement with those results is quite good, only those results for the more difficult cases of coplanar wing and tail, with and without vertical fin interference are presented here. As mentioned above, the test cases used are largely defined in the AGARD supplement [5] (from which Figure 3 is reproduced), and many of the results quoted here appear in that reference. Forty spanwise grid points were tried as in [2], and gave reasonable results. However, it was decided to generate the present results with sixty spanwise points, as this led (naturally) to better agreement, especially at $M = 3.0$.

Run times are very sensitive to Mach number. For example, for 60 spanwise points, run time per mode at $M = 3.0$ is of the order of one minute, while at $M = 1.2$ run time is of the order of five to ten minutes. This occurs because the streamwise grid spacing is much (around five times) smaller at $M = 1.2$.

Tables 1 to 3b show generalised forces calculated for the coplanar wing and tail configuration shown in Figure 3 at Mach numbers 1.2, 1.356, and 3.0, and reduced frequencies 0.0 and 1.5. The results of the present method are compared with those of [2], [6], [7], [8] and [10]. The mode shapes here are

	1.	Wing Twist	$z = y(x - 2.25\|y\| - 0.85)$,
	2.	Wing Bending	$z = y\|y\|$,
	3.	Tail Roll	$z = y$,
and	4.	Tail Pitch	$z = (x - 3.35)\,\mathrm{sgn}\,(y)$.

There is good agreement here between the various codes, except that the present method tends to underestimate the magnitude of the generalised forces by a small amount.

Table 4 shows generalised forces obtained from the present program for a coplanar wing, tail and vertical fin at Mach number 3.0. Results from the present method for this configuration are compared to results from [8] and [9] for the following modes:

	1.	Wing Twist	$z = y(x - 2.25\|y\| - 0.85)$,
	2.	Tail Pitch	$z = (x - 3.35)\,\mathrm{sgn}\,(y)$,
	3.	Fin Bending	$y = z^2$,
and	4.	Fin Twist	$y = z(x - 0.875z - 3.0)$.

The results of [9] appear (as expected) to be more reliable than those of [8]. Certainly, there is better agreement in the orders of magnitude of the terms between the present method and [9]. Notice, however, that there are some significant differences in sign and magnitude for the modes involving perpendicular surfaces e.g. Q_{31} (fin and wing) and Q_{24} (tail and fin), while the generalised forces for modes involving the same or coplanar surfaces all agree. This suggests a possible error in either the present solution method or that of [9] (as opposed to the post-processing to compute the generalised forces). The present solution method has been checked in a number of ways to ensure consistency between the y and z directions, and for the correct sign of the generalised forces for some simple modes.

Results in Tables 5a and 5b show similar behaviour to that shown in Table 4. Here comparison is made between the present method and the results of [9] [11] and [13] for the T-tail configuration shown in Figure 3. The present program must be set up so that the horizontal tail is in the plane $z = 0$ instead of $z = 1.2$ (i.e. we perform a translation so that the fin lies below the plane $z = 0$). The mode shapes are adjusted accordingly to become

	1.	Fin Bending	$y = (z + 1.2)^2$,
	2.	Fin Twist	$y = (z + 1.2)(x - 0.875(z + 1.2) - 3.0)$,
and	3.	Tail Roll	$z = y$.

Again, there are significant differences between the codes for modes involving perpendicular surfaces, while the modes involving coplanar surfaces are in good agreement. However, [13] and the present method now largely agree regarding magnitudes of all the generalised forces. This strongly suggests that the potential gradient method of [9] and the harmonic gradient method of [11] are in error for perpendicular surfaces. Also, the absence of internal inconsistencies in the present code suggests that the axes directions have effectively been confused in some fashion (eg. positive z axis being taken to be down) in [13].

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TABLE 1

Wing and Horizontal Tail Interference
at $M = 1.2$ and $k = 0.0, 1.5$

	i, j	$k = 0.0$ Ref. 6	$k = 0.0$ Ref. 2	$k = 0.0$ Present	$k = 1.5$ Ref. 6	$k = 1.5$ Ref. 2	$k = 1.5$ Present
Q'_{ij}	1,1	-0.0672	-0.0680	-0.0661	-0.0931	-0.1071	-0.0991
	2,1	0.2868	0.2833	0.2774	0.4040	0.3714	0.3705
	3,1	-0.5037	-0.4940	-0.4829	-0.4149	-0.4038	-0.3937
	4,1	-0.2784	-0.2639	-0.2591	-0.2390	-0.2559	-0.2351
	1,2				-0.1491	-0.1401	-0.1389
	2,2				-0.3009	-0.3135	-0.2876
	3,2				-0.4632	-0.3798	-0.4515
	4,2				-0.3141	-0.2804	-0.3003
	1,3				0.0008	0.0079	0.0010
	2,3				0.0013	0.0117	0.0015
	3,3				-0.0982	-0.1255	-0.1001
	4,3				-0.1467	-0.1702	-0.1515
	1,4	0.0028	0.0044	0.0039	-0.0007	-0.0085	-0.0026
	2,4	0.0049	0.0073	0.0058	-0.0020	-0.0097	-0.0038
	3,4	0.7838	0.7519	0.7724	1.0239	0.9330	1.0025
	4,4	0.3163	0.2832	0.2955	0.5005	0.4345	0.4935
Q''_{ij}	1,1				0.2675	0.2331	0.2367
	2,1				0.4221	0.3957	0.3927
	3,1				0.3175	0.2514	0.3108
	4,1				0.2017	0.1919	0.1926
	1,2				0.0044	-0.0227	-0.0071
	2,2				0.2772	0.2401	0.2556
	3,2				0.0015	-0.0533	-0.0053
	4,2				-0.0046	-0.0359	-0.0134
	1,3				-0.0002	-0.0002	-0.0002
	2,3				-0.0003	-0.0019	-0.0004
	3,3				0.4828	0.4771	0.4757
	4,3				0.2911	0.2856	0.2872
	1,4				-0.0024	-0.0003	-0.0017
	2,4				-0.0038	0.0023	-0.0025
	3,4				0.5650	0.5816	0.5622
	4,4				0.6388	0.6372	0.6275

TABLE 2

Wing and Horizontal Tail Interference
at $M = 1.356$ and $k = 0.0, 1.5$

	i,j	$k = 0.0$ Ref. 6	$k = 0.0$ Ref. 7	$k = 0.0$ Present	$k = 1.5$ Ref. 6	$k = 1.5$ Ref. 7	$k = 1.5$ Present
Q'_{ij}	1,1		-0.0541	-0.0587	-0.0484	0.0041	-0.0552
	2,1		0.2910	0.2859	0.4637	0.4986	0.4226
	3,1		-0.5073	-0.4986	-0.3395	-0.4503	-0.3258
	4,1		-0.3218	-0.3023	-0.1742	-0.2507	-0.1672
	1,2				-0.1501	-0.1523	-0.1361
	2,2				-0.2831	-0.2694	-0.2623
	3,2				-0.4369	-0.4341	-0.4083
	4,2				-0.2882	-0.2941	-0.2693
Q''_{ij}	1,1				0.2766	0.2992	0.2461
	2,1				0.3933	0.4168	0.3705
	3,1				0.3261	0.3115	0.3021
	4,1				0.2083	0.2083	0.1924
	1,2				0.0120	0.0299	0.0063
	2,2				0.2329	0.2912	0.2667
	3,2				0.0160	-0.0144	0.0116
	4,2				0.0179	-0.0041	0.0132

TABLE 3a

Wing and Horizontal Tail Interference
at $M = 3.0$ and $k = 0.0$

	i,j	$k = 0.0$ Ref. 6	$k = 0.0$ Ref. 7	$k = 0.0$ Ref. 8	$k = 0.0$ Ref. 10	$k = 0.0$ Present
Q'_{ij}	1,1	-0.0226	-0.0208	-0.0187	-0.0046	-0.0233
	2,1	0.3035	0.3020	0.3287	0.3062	0.3049
	3,1	-0.2152	-0.2137	-0.1075	-0.2091	-0.2174
	4,1	-0.1550	-0.1516	-0.0843	-0.1476	-0.1395
	1,2					
	2,2					
	3,2					
	4,2					
	1,3					
	2,3					
	3,3					
	4,3					
	1,4					
	2,4					
	3,4	0.4665		0.4756	0.4635	0.4634
	4,4	0.2882		0.2904	0.2875	0.2673

TABLE 3b

Wing and Horizontal Tail Interference
at $M = 3.0$ and $k = 1.5$

	i,j	$k = 1.5$				
		Ref. 6	Ref. 7	Ref. 8	Ref. 10	Present
Q'_{ij}	1,1	0.0966	0.1002	0.0901	0.0771	0.0941
	2,1	0.3846	0.3740	0.3895	0.3616	0.3743
	3,1	-0.0394	-0.0463	-0.0695	-0.0492	-0.0527
	4,1	-0.0147	-0.0171	-0.0360	-0.0201	-0.0095
	1,2	-0.0700	-0.0720	-0.0819	-0.0688	-0.0648
	2,2	-0.0759	-0.0730	-0.0888	-0.0969	-0.0683
	3,2	-0.1531	-0.1477	-0.0400	-0.1541	-0.1434
	4,2	-0.1033	-0.0988	-0.0179	-0.1029	-0.0885
	1,3					
	2,3					
	3,3	0.0168		0.0140	-0.0094	0.0193
	4,3	0.0050		0.0032	-0.0137	0.0065
	1,4					
	2,4					
	3,4	0.4517		0.4541	0.4307	0.4449
	4,4	0.2965		0.2903	0.2680	0.2731
Q''_{ij}	1,1	0.1486	0.1463	0.1593	0.1449	0.1384
	2,1	0.0890	0.0890	0.1083	0.1189	0.0804
	3,1	0.0769	0.0696	0.0007	0.0761	0.0620
	4,1	0.0559	0.0517	0.0008	0.0552	0.0457
	1,2	0.0309	0.0327	0.0300	0.0319	0.0269
	2,2	0.2363	0.2335	0.2498	0.2309	0.2337
	3,2	0.0239	0.0160	-0.0003	0.0151	0.0075
	4,2	0.0197	0.0167	0.0030	0.0155	0.0164
	1,3					
	2,3					
	3,3	0.2560		0.2635	0.2552	0.2510
	4,3	0.1786		0.1820	0.1766	0.1657
	1,4					
	2,4					
	3,4	0.1632		0.1820	0.1945	0.1577
	4,4	0.2188		0.2300	0.2327	0.2042

TABLE 4

Wing, Tail and Fin Interference
at $M = 3.0$ and $k = 0.0, 1.5$

	i,j	$k = 0.0$			$k = 1.5$		
		Ref. 8	Ref. 9	Present	Ref. 8	Ref. 9	Present
Q'_{ij}	1,1	-0.0202	-0.0285	-0.0233	0.0839	0.0918	0.0941
	2,1	-0.1333	-0.1360	-0.1285	-0.1779	0.0073	-0.0187
	3,1	-0.0980	-0.1000	0.0434	0.0492	0.0490	-0.0192
	4,1	-0.0460	-0.0459	0.0223	0.0240	0.0253	-0.0115
	1,2						
	2,2	0.3420	0.3366	0.2922	0.3137	0.3096	0.2813
	3,2	-0.0176	-0.0183	0.0112	0.0042	0.0058	-0.0029
	4,2	-0.0414	-0.0422	0.0261	-0.0059	-0.0003	0.0026
	1,3						
	2,3				-0.0046	-0.0044	0.0028
	3,3				-0.0420	-0.0400	-0.0405
	4,3				-0.0217	-0.0215	-0.0209
	1,4						
	2,4	-0.0144	-0.0137	0.0088	-0.0017	-0.0008	0.0005
	3,4	0.3400	0.3396	0.3113	0.3314	0.3345	0.3095
	4,4	0.0545	0.0534	0.0412	0.0551	0.0564	0.0477
Q''_{ij}	1,1				0.1641	0.1559	0.1384
	2,1				0.1444	0.0409	0.0429
	3,1				0.0066	0.0048	0.0009
	4,1				0.0185	0.0098	-0.0033
	1,2						
	2,2				0.2160	0.2127	0.1968
	3,2				0.0084	0.0087	-0.0055
	4,2				0.0170	0.0179	-0.0113
	1,3						
	2,3				-0.0006	-0.0005	0.0003
	3,3				0.2918	0.2930	0.2640
	4,3				0.0361	0.0364	0.0277
	1,4						
	2,4				0.0059	0.0057	-0.0038
	3,4				0.0780	0.0762	0.0675
	4,4				0.0711	0.0703	0.0667

TABLE 5a

Tail and Fin Interference
at $M = 1.6$, $Z = 1.2$ and $k = 0.0$

	i,j	$k = 0.0$			
		Ref. 9	Ref. 11	Ref. 13	Present
Q'_{ij}	1,1				
	2,1				
	3,1				
	1,2	0.7948		0.7845	0.7956
	2,2	0.0807		0.0978	0.0824
	3,2	0.1828		0.4370	-0.4470
	1,3				
	2,3				
	3,3				

TABLE 5b

Tail and Fin Interference
at $M = 1.6$, $Z = 1.2$ and $k = 1.5$

	i,j	$k = 1.5$			
		Ref. 9	Ref. 11	Ref. 13	Present
Q'_{ij}	1,1	0.0093	0.0236	-0.0315	0.0300
	2,1	-0.0553	-0.0516	-0.0688	-0.0495
	3,1	0.0473	0.1931	0.3029	-0.3310
	1,2	0.6926	0.6864	0.6725	0.6783
	2,2	0.1158	0.1250	0.1174	0.1152
	3,2	-0.0458	0.0745	0.1050	-0.0491
	1,3	0.0450	0.0676	0.0261	-0.0317
	2,3	0.0211	0.0277	0.0100	-0.0131
	3,3	0.0192	0.0622	0.0201	0.0266
Q''_{ij}	1,1	0.5457	0.5466	0.5353	0.5360
	2,1	0.0462	0.0620	0.0551	0.0463
	3,1	-0.0627	0.0471	0.0564	-0.0372
	1,2	0.1086	0.1295	0.1518	0.0928
	2,2	0.1552	0.1518	0.1547	0.1485
	3,2	-0.0071	-0.0952	-0.1862	0.2091
	1,3	0.0561	0.0341	0.0292	-0.0261
	2,3	0.0157	0.0074	0.0083	-0.0075
	3,3	0.4783	0.4309	0.4661	0.4188

APPENDIX 1. EXAMPLE PROBLEM

Compute the generalised forces for the AGARD configuration shown in Figure 3 for the following antisymmetric modes at $M = 3.0$ and $k = 1.5$, using 60 spanwise grid points. Use (1) mode shape functions and (2) mode shape point data.

The modes are

	1.	Wing Twist	$z = y(x - 2.25\|y\| - 0.85)$,
	2.	Tail Pitch	$z = (x - 3.35)\,\mathrm{sgn}\,(y)$,
	3.	Fin Bending	$y = z^2$,
and	4.	Fin Twist	$y = z(x - 0.875z - 3.0)$.

(1) Using mode shape functions

The input data file appa.dat takes the form

```
 1                ISW
 4                IOUT
 1                IWID
 6                IDIG
 0.0166666        DY
 1.0              B2
 1.0              T2
 0.0              FLO
 1.2              FUP
 1                NAMS
 3.0              AMS(J)
 1                NOMS
 1.5              OMS(J)
 1                MSW
 0                NSM
 4                NAM
 4                NFM
 1 2 3 4          IFMS(J)
 4                NDM
 1 2 3 4          IDMS(J)
```

Note that IOUT=4 so the potential and pressure output is suppressed. Since the wing semi-span length B2 is one unit, the grid step size DY equals 1/60. The fin is assumed to lie between FLO ($Z = 0$) and FUP ($Z = 1.2$). The modes are generated using functions so MSW=1. The total number of available symmetric modes NSM is zero and the number of antisymmetric modes NAM is four. We are using all the possible forcing modes so NFM=4. Similarly for the displacement modes NDM=4.

The mode and geometry functions file appa.f takes the form

```
C
C=====================================================================
C
      FUNCTION WL(Y)
C     Wing leading edge x = WL(y).
      WL=2.75*Y
      RETURN
      END
C
C=====================================================================
C
      FUNCTION WT(Y)
C     Wing trailing edge x = WT(y).
      WT=2.25+1.45*Y
      RETURN
      END
C
C=====================================================================
```

```
C
      FUNCTION TL(Y)
C     Tail leading edge x = TL(y).
      TL=2.7+1.2*Y
      RETURN
      END
C
C=====================================================================
C
      FUNCTION TT(Y)
C     Tail trailing edge x = TT(y).
      TT=4.0+0.25*Y
      RETURN
      END
C
C=====================================================================
C
      FUNCTION FL(Z)
C     Fin leading edge x = FL(z).
      FL=2.5+ABS(Z)
      RETURN
      END
C
C=====================================================================
C
      FUNCTION FT(Z)
C     Fin trailing edge x = FT(z).
      FT=4.2+ABS(Z)/3.0
      RETURN
      END
C
C=====================================================================
C
      SUBROUTINE WING(X,Y,IP,H1,H2,IER)
C
C=====================================================================
C
      IER=0
      GO TO (1,2,3,4,5) IP
      IER=1
      RETURN
 1    CONTINUE
      H1=-1.0
      H2=-1.0
      RETURN
 2    CONTINUE
      H1=Y*(X-2.25*ABS(Y)-0.85)
      H2=Y
      RETURN
 3    CONTINUE
      H1=0.0
      H2=0.0
      RETURN
 4    CONTINUE
      H1=0.0
      H2=0.0
      RETURN
 5    CONTINUE
      H1=0.0
      H2=0.0
      RETURN
      END
C
C=====================================================================
C
      SUBROUTINE TAIL(X,Y,IP,H1,H2,IER)
C
C=====================================================================
```

```
C
      IER=0
      GO TO (1,2,3,4,5) IP
      IER=1
      RETURN
 1    CONTINUE
      H1=-1.0
      H2=-1.0
      RETURN
 2    CONTINUE
      H1=0.0
      H2=0.0
      RETURN
 3    CONTINUE
      H1=(X-3.35)*SIGN(1.0,Y)
      H2=SIGN(1.0,Y)
      RETURN
 4    CONTINUE
      H1=0.0
      H2=0.0
      RETURN
 5    CONTINUE
      H1=0.0
      H2=0.0
      RETURN
      END
C
C======================================================================
C
      SUBROUTINE FIN(X,Z,IP,H1,H2,IER)
C
C======================================================================
C
      IER=0
      GO TO (1,2,3,4,5) IP
      IER=1
      RETURN
 1    CONTINUE
      H1=-1.0
      H2=-1.0
      RETURN
 2    CONTINUE
      H1=0.0
      H2=0.0
      RETURN
 3    CONTINUE
      H1=0.0
      H2=0.0
      RETURN
 4    CONTINUE
      H1=Z*Z
      H2=0.0
      RETURN
 5    CONTINUE
      H1=ABS(Z)*(X-0.875*ABS(Z)-3.0)
      H2=ABS(Z)
      RETURN
      END
C
C======================================================================
C
```

The leading and trailing edge geometry functions precede the mode shape subroutines WING, TAIL and FIN. Notice that mode 1 corresponds to IP=2. Note also that although the WING contributions to the remaining modes, IP=3,4 and 5 are zero, they must still appear. Similarly for the subroutines TAIL and FIN.

The generalised force output appears in appa.gf

```
 ARLSUPER V1.0

 Mach number = 3.00000  Frequency = 1.50000
 Antisymmetric displacement modes:  1   2   3   4
 Antisymmetric forcing modes:  1   2   3   4
1
 GENERALISED FORCES

 REAL PART

         1             2             3             4

     .094091       .000000       .000000       .000000
    -.018697       .281293       .002820       .000511
    -.019244      -.002924      -.040485       .309534
    -.011493       .002608      -.020878       .047716

 IMAGINARY PART

         1             2             3             4

     .138390       .000000       .000000       .000000
     .042867       .196830       .000281      -.003816
     .000925      -.005476       .264004       .067520
    -.003293      -.011264       .027696       .066716


 MODULUS

         1             2             3             4

     .227914       .000000       .000000       .000000
     .066963       .407793       .002851       .005747
     .019294       .008720       .398070       .325682
     .012510       .017095       .046495       .110868

 ARGUMENT

         1             2             3             4

   65.616798       .000000       .000000       .000000
  106.213478     46.386326      8.502292    275.101104
  175.878372    250.404327     95.837280     18.118195
  203.255706    278.773498    116.681755     64.507668
```

If we were to set IOUT=2 we would obtain the following output in appa.out

---

```
(1) Unsteady supersonic.
(2) Output = reduced potential only.
(1) Input = mode functions.
Printout width parameter =  1 for 80  ch. wide paper
Number of digits printed in output is 6.
Grid step size = .16667E-01 in Y direction
Wing semi span length = 1.0000
Tail semi span length = 1.0000
Tail fin lies between z =    .0000 and z =  1.2000
Forcing mode numbers ( 4) =  1  2  3  4
Displacement mode numbers ( 4) =  1  2  3  4
Mach numbers ( 1) = 3.000
Reduced Frequencies ( 1) = 1.500
```

```
Execution for wing and tail plane with fin.
```

Max. spanwise points on wing = 60
Max. spanwise points on tail = 60
Max. vertical points on fin = 72
Mach no. = 3.00000
Frequency = 1.50000
Mode (1) antisymmetric (in Y).

Reduced potential on wing.

y = .008333 Points = 48

x	.0229168	.0700571	.1171973	.1643376	.2114778
Phi'+	-.131409E-03	-.738572E-04	-.273148E-03	-.146588E-03	-.391632E-03
Phi"+	.190390E-03	.804451E-04	.421135E-03	.128752E-03	.647869E-03
Phi'-	.131409E-03	.738572E-04	.273148E-03	.146588E-03	.391632E-03
Phi"-	-.190390E-03	-.804451E-04	-.421135E-03	-.128752E-03	-.647869E-03
x	.2586181	.3057584	.3528986	.4000389	.4471792
Phi'+	-.227394E-03	-.485580E-03	-.318378E-03	-.555402E-03	-.420787E-03
Phi"+	.158240E-03	.865664E-03	.172113E-03	.107120E-02	.172809E-03
Phi'-	.227394E-03	.485580E-03	.318378E-03	.555402E-03	.420787E-03
Phi"-	-.158240E-03	-.865664E-03	-.172113E-03	-.107120E-02	-.172809E-03
x	.4943194	.5414597	.5885999	.6357402	.6828805
Phi'+	-.602095E-03	-.535436E-03	-.627073E-03	-.662796E-03	-.632104E-03
Phi"+	.126147E-02	.162629E-03	.143370E-02	.143822E-03	.158527E-02
Phi'-	.602095E-03	.535436E-03	.627073E-03	.662796E-03	.632104E-03
Phi"-	-.126147E-02	-.162629E-03	-.143370E-02	-.143822E-03	-.158527E-02
x	.7300208	.7771610	.8243012	.8714415	.9185818
Phi'+	-.803013E-03	-.619280E-03	-.955948E-03	-.590978E-03	-.112117E-02
Phi"+	.118571E-03	.171382E-02	.889973E-04	.181720E-02	.570948E-04
Phi'-	.803013E-03	.619280E-03	.955948E-03	.590978E-03	.112117E-02
Phi"-	-.118571E-03	-.171382E-02	-.889973E-04	-.181720E-02	-.570948E-04
x	.9657221	1.0128623	1.0600026	1.1071428	1.1542830
Phi'+	-.549826E-03	-.129800E-02	-.498674E-03	-.148552E-02	-.440538E-03
Phi"+	.189358E-02	.247225E-04	.194143E-02	-.643023E-05	.195954E-02
Phi'-	.549826E-03	.129800E-02	.498674E-03	.148552E-02	.440538E-03
Phi"-	-.189358E-02	-.247225E-04	-.194143E-02	.643023E-05	-.195954E-02
x	1.2014234	1.2485636	1.2957039	1.3428441	1.3899844
Phi'+	-.168263E-02	-.378567E-03	-.188804E-02	-.315990E-03	-.210032E-02
Phi"+	-.348802E-04	.194707E-02	-.593414E-04	.190357E-02	-.787845E-04
Phi'-	.168263E-02	.378567E-03	.188804E-02	.315990E-03	.210032E-02
Phi"-	.348802E-04	-.194707E-02	.593414E-04	-.190357E-02	.787845E-04
x	1.4371247	1.4842650	1.5314052	1.5785455	1.6256857
Phi'+	-.256[illegible]E-03	-.231796E-02	-.202184E-03	-.253938E-02	-.157419E-03
Phi"+	.182[illegible]E-02	-.924112E-04	.172339E-02	-.997176E-04	.158763E-02
Phi'-	.256110E-03	.231796E-02	.202184E-03	.253938E-02	.157419E-03
Phi"-	-.182891E-02	.924112E-04	-.172339E-02	.997176E-04	-.158763E-02
x	1.6728261	1.7199663	1.7671065	1.8142468	1.8613870
Phi'+	-.276296E-02	-.124954E-03	-.298711E-02	-.107803E-03	-.321026E-02
Phi"+	-.100394E-03	.142266E-02	-.944467E-04	.122980E-02	-.820599E-04
Phi'-	.276296E-02	.124954E-03	.298711E-02	.107803E-03	.321026E-02
Phi"-	.100394E-03	-.142266E-02	.944467E-04	-.122980E-02	.820599E-04
x	1.9085274	1.9556676	2.0028079	2.0499482	2.0970883
Phi'+	-.108751E-03	-.343095E-02	-.130398E-03	-.364779E-02	-.175137E-03
Phi"+	.101072E-02	-.637621E-04	.767427E-03	-.402103E-04	.502117E-03
Phi'-	.108751E-03	.343095E-02	.130398E-03	.364779E-02	.175137E-03
Phi"-	-.101072E-02	.637621E-04	-.767427E-03	.402103E-04	-.502117E-03
x	2.1442287	2.1913688	2.2385092		
Phi'+	-.385960E-02	-.245020E-03	-.406526E-02		
Phi"+	-.123102E-04	.217290E-03	.189182E-04		
Phi'-	.385960E-02	.245020E-03	.406526E-02		
Phi"-	.123102E-04	-.217290E-03	-.189182E-04		

```
y =      .025000         Points =    48
x           .0700571        .1171973        .1643376        .2114778        .2586181
Phi'+   -.452698E-03   -.417035E-03   -.800589E-03   -.717409E-03   -.109936E-02
Phi"+    .657443E-03    .544699E-03    .119033E-02    .892778E-03    .167686E-02
Phi'-    .452698E-03    .417035E-03    .800589E-03    .717409E-03    .109936E-02
Phi"-   -.657443E-03   -.544699E-03   -.119033E-02   -.892778E-03   -.167686E-02
```

(2) Using Mode point data

We set MSW=2 in appa.dat. The input mode data file appa.modes takes the form shown below, where we have 36 data points on each surface in which the contribution to the mode shape is non-trivial and zero data points otherwise. PLEASE NOTE: Beyond about 50 data points the interpolation scheme starts to slow execution time considerably.

```
  0   wing mode 0
  0   tail mode 0
  0   fin mode 0
 36   wing mode 1
   .00000000      .00000000      .00000000      .00000000
   .45000002      .00000000      .00000000      .00000000
   .90000004      .00000000      .00000000      .00000000
  1.35000002      .00000000      .00000000      .00000000
  1.80000007      .00000000      .00000000      .00000000
  2.25000000      .00000000      .00000000      .00000000
   .55000001      .20000000     -.15000001      .20000000
   .94800001      .20000000     -.07040001      .20000000
  1.34599995      .20000000      .00919998      .20000000
  1.74399995      .20000000      .08879998      .20000000
  2.14199995      .20000000      .16839997      .20000000
  2.53999996      .20000000      .24799998      .20000000
  1.10000002      .40000001     -.26000002      .40000001
  1.44599997      .40000001     -.12160003      .40000001
  1.79200005      .40000001      .01680000      .40000001
  2.13800001      .40000001      .15519996      .40000001
  2.48399996      .40000001      .29359993      .40000001
  2.82999992      .40000001      .43199992      .40000001
  1.65000009      .60000002     -.32999998      .60000002
  1.94400012      .60000002     -.15359996      .[illegible]00002
  2.23800015      .60000002      .02280007      .60000002
  2.53200006      .60000002      .19920002      .60000002
  2.82600021      .60000002      .37560013      .60000002
  3.12000012      .60000002      .55200005      .60000002
  2.20000004      .80000001     -.36000004      .80000001
  2.44200015      .80000001     -.16639996      .80000001
  2.68400001      .80000001      .02719994      .80000001
  2.92600011      .80000001      .22080003      .80000001
  3.16800022      .80000001      .41440010      .80000001
  3.41000008      .80000001      .60799998      .80000001
  2.75000000     1.00000000     -.35000002     1.00000000
  2.94000005     1.00000000     -.15999997     1.00000000
  3.13000011     1.00000000      .03000009     1.00000000
  3.32000017     1.00000000      .22000015     1.00000000
  3.50999999     1.00000000      .40999997     1.00000000
  3.70000004     1.00000000      .60000002     1.00000000
  0   tail mode 1
  0   fin mode 1
  0   wing mode 2
 36   tail mode 2
  2.70000004      .00000000     -.64999986     1.00000000
  2.96000003      .00000000     -.38999987     1.00000000
  3.22000002      .00000000     -.12999988     1.00000000
  3.48000001      .00000000      .13000011     1.00000000
  3.74000000      .00000000      .39000010     1.00000000
  4.00000000      .00000000      .65000010     1.00000000
  2.94000005      .20000000     -.40999985     1.00000000
  3.16200017      .20000000     -.18799973     1.00000000
```

```
3.38400006     .20000000     .03400016    1.00000000
3.60600018     .20000000     .25600028    1.00000000
3.82800006     .20000000     .47800016    1.00000000
4.05000019     .20000000     .70000029    1.00000000
3.18000006     .40000001    -.16999984    1.00000000
3.36400008     .40000001     .01400018    1.00000000
3.54800009     .40000001     .19800019    1.00000000
3.73199987     .40000001     .38199997    1.00000000
3.91599988     .40000001     .56599998    1.00000000
4.09999990     .40000001     .75000000    1.00000000
3.42000007     .60000002     .07000017    1.00000000
3.56599998     .60000002     .21600008    1.00000000
3.71200013     .60000002     .36200023    1.00000000
3.85800004     .60000002     .50800014    1.00000000
4.00400018     .60000002     .65400028    1.00000000
4.15000009     .60000002     .80000019    1.00000000
3.66000008     .80000001     .31000018    1.00000000
3.76800012     .80000001     .41800022    1.00000000
3.87599992     .80000001     .52600002    1.00000000
3.98399996     .80000001     .63400006    1.00000000
4.09200000     .80000001     .74200010    1.00000000
4.19999980     .80000001     .84999990    1.00000000
3.90000009    1.00000000     .55000019    1.00000000
3.97000002    1.00000000     .62000012    1.00000000
4.03999996    1.00000000     .69000006    1.00000000
4.11000013    1.00000000     .76000023    1.00000000
4.17999982    1.00000000     .82999992    1.00000000
4.25000000    1.00000000     .90000010    1.00000000
0   fin mode 2
0   wing mode 3
0   tail mode 3
36  fin mode 3
2.50000000     .00000000     .00000000     .00000000
2.83999991     .00000000     .00000000     .00000000
3.17999982     .00000000     .00000000     .00000000
3.51999998     .00000000     .00000000     .00000000
3.85999989     .00000000     .00000000     .00000000
4.19999980     .00000000     .00000000     .00000000
2.74000000     .24000001     .05760000     .00000000
3.04799985     .24000001     .05760000     .00000000
3.35599994     .24000001     .05760000     .00000000
3.66399979     .24000001     .05760000     .00000000
3.97199954     .24000001     .05760000     .00000000
4.27999973     .24000001     .05760000     .00000000
2.98000001     .48000002     .23040001     .00000000
3.25600004     .48000002     .23040001     .00000000
3.53199982     .48000002     .23040001     .00000000
3.80799984     .48000002     .23040001     .00000000
4.08399963     .48000002     .23040001     .00000000
4.35999965     .48000002     .23040001     .00000000
3.22000002     .72000003     .51840001     .00000000
3.46399998     .72000003     .51840001     .00000000
3.70799994     .72000003     .51840001     .00000000
3.95199966     .72000003     .51840001     .00000000
4.19599962     .72000003     .51840001     .00000000
4.43999958     .72000003     .51840001     .00000000
3.46000003     .96000004     .92160004     .00000000
3.67199993     .96000004     .92160004     .00000000
3.88400006     .96000004     .92160004     .00000000
4.09600019     .96000004     .92160004     .00000000
4.30800008     .96000004     .92160004     .00000000
4.51999998     .96000004     .92160004     .00000000
3.70000004    1.20000004    1.44000005     .00000000
3.88000011    1.20000004    1.44000005     .00000000
4.05999994    1.20000004    1.44000005     .00000000
4.23999977    1.20000004    1.44000005     .00000000
4.42000007    1.20000004    1.44000005     .00000000
4.59999990    1.20000004    1.44000005     .00000000
```

```
 0   wing mode 4
 0   tail mode 4
36   fin mode 4
 2.50000000     .00000000     .00000000     .00000000
 2.83999991     .00000000     .00000000     .00000000
 3.17999982     .00000000     .00000000     .00000000
 3.51999998     .00000000     .00000000     .00000000
 3.85999989     .00000000     .00000000     .00000000
 4.19999980     .00000000     .00000000     .00000000
 2.74000000     .24000001    -.11280001     .24000001
 3.04799985     .24000001    -.03888004     .24000001
 3.35599994     .24000001     .03503998     .24000001
 3.66399979     .24000001     .10895994     .24000001
 3.97199964     .24000001     .18287991     .24000001
 4.27999973     .24000001     .25679994     .24000001
 2.98000001     .48000002    -.21120003     .48000002
 3.25600004     .48000002    -.07872002     .48000002
 3.53199982     .48000002     .05375988     .48000002
 3.80799984     .48000002     .18623990     .48000002
 4.08399963     .48000002     .31871980     .48000002
 4.35999965     .48000002     .45119983     .48000002
 3.22000002     .72000003    -.29519990     .72000003
 3.46399998     .72000003    -.11951993     .72000003
 3.70799994     .72000003     .05616005     .72000003
 3.95199966     .72000003     .23183969     .72000003
 4.19599962     .72000003     .40751967     .72000003
 4.43999958     .72000003     .58319962     .72000003
 3.46000003     .96000004    -.36480013     .96000004
 3.67199993     .96000004    -.16128021     .96000004
 3.88400006     .96000004     .04224014     .96000004
 4.09600019     .96000004     .24576005     .96000004
 4.30800008     .96000004     .44927996     .96000004
 4.51999998     .96000004     .65279984     .96000004
 3.70000004    1.20000004    -.41999990    1.20000004
 3.88000011    1.20000004    -.20400010    1.20000004
 4.05999994    1.20000004     .01199970    1.20000004
 4.23999977    1.20000004     .22799951    1.20000004
 4.42000007    1.20000004     .44399989    1.20000004
 4.59999990    1.20000004     .65999967    1.20000004
```

Corresponding to this input, the generalised force output appears as

```
 ARLSUPER V1.0

 Mach number = 3.00000  Frequency = 1.50000
 Antisymmetric displacement modes:  1   2   3   4
 Antisymmetric forcing modes:  1   2   3   4
1

 GENERALISED FORCES

 REAL PART

          1           2           3           4

      .091648     .000000     .000000     .000000
     -.018672     .281293     .002909     .000339
     -.019233    -.001909    -.041069     .310433
     -.011311     .001118    -.020409     .047280

 IMAGINARY PART

          1           2           3           4

      .135578     .000000     .000000     .000000
      .042444     .196830     .000317    -.003911
      .001154    -.005675     .265070     .067157
     -.002779    -.010681     .027410     .066618
```

MODULUS

1	2	3	4
.223064	.000000	.000000	.000000
.066347	.407793	.002947	.005877
.019311	.008723	.399720	.326368
.012055	.016061	.045902	.110548

ARGUMENT

1	2	3	4
65.741226	.000000	.000000	.000000
106.345176	46.386330	9.284918	273.306030
174.858627	257.359222	95.897278	17.978161
200.230545	273.990386	116.399612	64.678986

Comparison of the results of (2) with those of (1) which use the exact mode shapes shows good agreement in all modes.

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16. ABSTRACT
The computer ~~program ARLSUPER~~ calculates linearised steady and oscillatory supersonic flow around a coplanar wing and tail, vertical fin configuration using an explicit finite difference scheme. In this version, surface and mode shapes may be entered in functional form or as a collection of data points. Generalised forces are calculated and are written out in a form compatible with available flutter solvers.

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