



Full-potential method for three-dimensional wings and wing-body combinations

Part 5: Pre-processor to represent effect of fore- and aft-body shape on wing flow

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FULL-POTENTIAL METHOD FOR THREE-DIMENSIONAL WINGS AND WING-BODY COMBINATIONS

PART 5: PRE-PROCESSOR TO REPRESENT EFFECT OF FORE- AND AFT-BODY SHAPE ON WING FLOW

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FULL-POTENTIAL METHOD FOR THREE-DIMENSIONAL WINGS AND WING-BODY COMBINATIONS

PART 5: PRE-PROCESSOR TO REPRESENT EFFECT OF FORE- AND AFT-BODY SHAPE ON WING FLOW

1. INTRODUCTION

This is the fifth part of the series of Data Items^{1,2,3,4} dealing with the Full-Potential (FP) method for three-dimensional wings and wing-body combinations. There is a facility in FP for using an indirect (albeit approximate) method of including the effects on the wing due to the fore and aft shaping of the fuselage. Using this approach, the fuselage is specified in the geometry file as an infinite circular cylinder with a radius which closely represents the fuselage cross section profile at the wing-body junction, but the effective flow speed at each wing spanwise grid position differs from the actual free stream Mach number. The speed differences that are applied in FP are derived from input values of increments to the free stream Mach number. The Mach number increments are specified in the flow input file at a number of lateral locations to give a spanwise variation. The FP program then utilises linear interpolation (and, if necessary, linear extrapolation) to generate the corresponding increment at each of the wing grid sections.

Alternatively, as described in ESDU 02013 (Reference 1), the Mach number increments may be determined by a body-alone method such as slender-body theory or a panel method. This Data Item describes a simple procedure for implementing the effects of body shaping at zero incidence by means of the 'source-sink' representation to provide a pre-processor to FP to routinely calculate the effects of body shaping based solely on body length, fore-body length, aft-body length, body radius of the parallel portion and wing position.

A detailed description of the use of the pre-processor programs is given in Section 3 followed in Section 4 by a process to output data in a format giving contours of constant Mach number. The principles of the method are given in Section 5. Comments on the accuracy and limitations are in Section 6. The derivation of body shape process and validation of the method is given in Appendix A.

1.1 Program Access

The files required to run FP and all related programs on a PC are to be found in the folder (or directory) name FPV20. Executable forms of the programs are included, so no Fortran compiler is required. (Source code is available for some programs, such as FPCON and CONTOUR, but not for FP and MAPONLY.)

To run FP or FPIBE, and the pre- and post-processing programs, carry out the following steps.

- 1) Open a 'C:\Command Prompt' window or 'box'. (In some Windows versions the C:\Command Prompt is an Accessory, in others it is a Program.)
- 2) Within the C:\Command Prompt window, create a working directory.
- 3) Copy all the files in the directory FPV20 to this working directory.
- 4) Read the contents of the file README20.dat (which is one of the files copied), using an editor or other suitable application.
- 5) Proceed according to the directions given in that file.

It is recommended that the PC used should have at least 128 Mbytes of RAM, a hard-disk drive with at least 500 Mbytes of free space, and a processor speed of 1.5GHz or more.

Although obtaining results using FP is comparatively easy, care is required in interpreting them in relation to the task in hand. In general, this requires that all the Data Items concerned with FP be consulted in detail.

2. NOTATION AND COORDINATE SYSTEM

In the Notation used for FP and FPIBE, lengths are made non-dimensional by division by c_0 , the centre-line chord. Quantities notionally of length (other than c_0) listed in this Section, such as x and y are thus non-dimensional, having been made so by division of the corresponding length quantities by c_0 .

a	interval length
C_L	lift coefficient
C_p	pressure coefficient
c	chord
c_0	centre-line chord
DMle	program output designation for ΔM at leading-edge
DMte	program output designation for ΔM at trailing-edge
DMmid	program output designation for ΔM at mid-chord
DMmean	program output designation for mean value of ΔM
d	fuselage diameter
l	fuselage length
l_a	aft-body length
l_f	fore-body length
l_p	length of fuselage parallel portion
M	Mach number
Q_i	total source-sink strength over interval length a
Re	Reynolds number
Re_c	Reynolds number based on reference chord
r	body radius at location x
s	wing semi-span
U	free stream velocity

u	axial velocity
v	radial velocity
x	fuselage axial location, $x = 0$ at nose
x_i	centre point of source-sink i^{th} interval along body axis
y	spanwise location
y_{span}	program output designation for y
α	incidence in degrees
β	Prandtl-Glauert compressibility relationship
ΔM	disturbance Mach number
Δtwist	increment in twist due to additional cross flow
η	y/s
ψ	stream function

Suffices

$body$	denotes spanwise location of body side
c	denotes compressible except in Re_c
$crank$	denotes spanwise location of crank
i	denotes i^{th} interval along body axis
$local$	denotes local value at specified value of η
vfp	denotes spanwise location output from the Viscous Full Potential method
∞	denotes free stream

3. DESCRIPTION AND USE OF PROGRAM THAT PRODUCES INPUT FILES FOR FP

This section illustrates the use of the pre-processor, using the case of “wing W4” mounted on an axisymmetric fuselage, to produce input files for FP with disturbance Mach number. Prior to running these pre-processor programs the GEO.DAT and FLOW.DAT files were made available using ESDU 02014 described in Reference 2.

Prompts produced by firstly running fusegenv2 and followed by running tvkbodyv8 and the responses for this case follow. (Note that most of the responses, shown in bold are read by ‘free format’ statements, and in such cases spaces and or ‘line feeds’ may be introduced before and/or after any entered parameter value as a matter of choice. The exceptions are the ‘yes’ or ‘no’ responses, the file names, and the title. In these cases no additional spaces or line feeds are permissible.)

Generic fuselage generation program fusegenv2 input example:

```
Generic fuselage program
Prepares data for axisymmetric body program
Obtains free stream Mach number from FPCON FLOW.DAT
Input fuselage length, fore-body length and aft-body length
Lengths relative to centre-line chord
```

4.5 1.6 1.6

Wing root leading edge position aft of fuselage nose

1.896468

Obtains wing planform and fuselage diameter from FPCON GEO.DAT

The output file called fuseout.dat contains the radial distribution of the axisymmetric body and planform coordinates of the wing which is the input file for axisymmetric program tvkbodyv8. There is no need to modify the fuseout.dat file produced by fusegenv2.

Axisymmetric body program tvkbodyv8 reads in the output file produced by fusegenv2. The input information requested is to produce a new set of FLOW.DAT files which includes the spanwise distribution of disturbance Mach number.

Axisymmetric body program tvkbodyv8 input example:

Enter title, maximum 80 characters

Wing W4

Is "CL,CD convergence" required? Enter y(es) or n(o)

n

Enter Mach number, and incidence in deg

0.781 1.0

The axisymmetric program outputs several files which are as follows.

cpdmach.dat

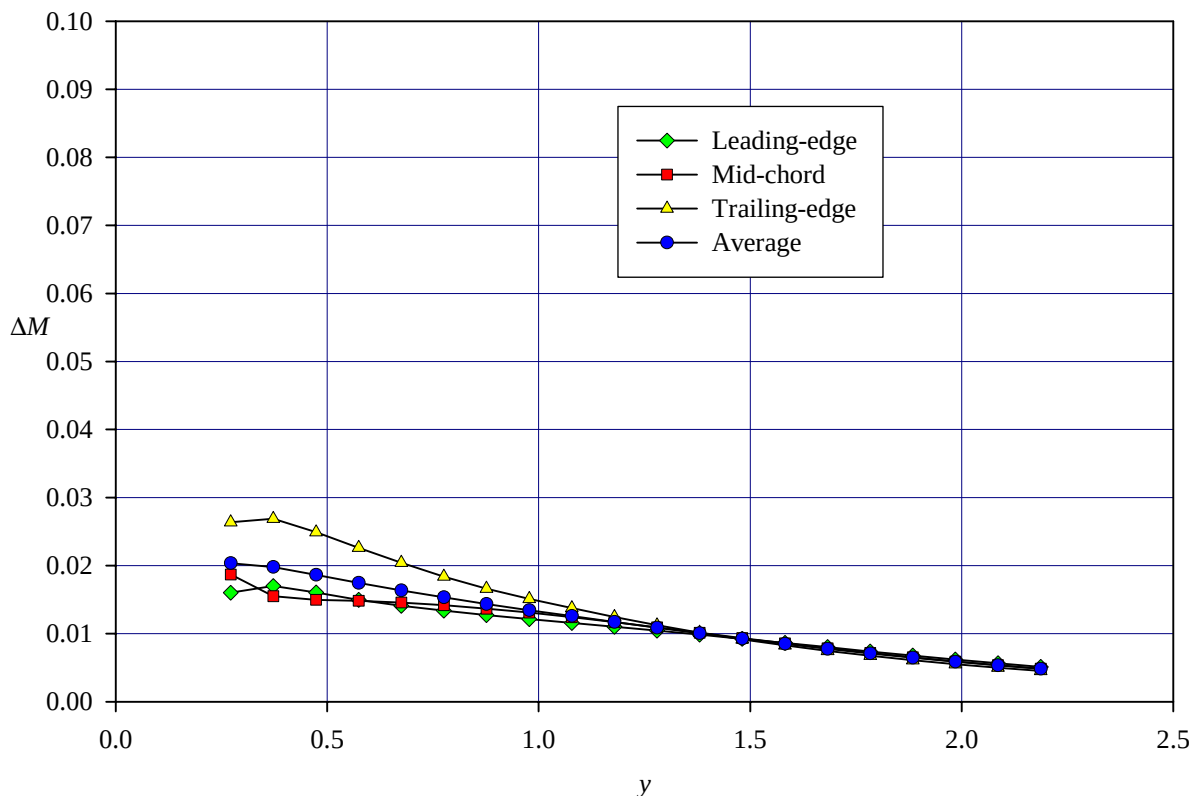
This file contains pressure coefficients and disturbance Mach numbers on the body and twenty spanwise stations from root to tip.

delmach.dat

Table 3.1 contains twenty spanwise values of disturbance Mach number, ΔM , along the wing leading-edge, mid-chord, trailing-edge and mean values and can be plotted using Microsoft Excel as shown in Sketch 3.1.

TABLE 3.1 Disturbance Mach number data

yspan	DMle	DMmid	DMte	DMmean
0.272021	0.016008	0.018686	0.026371	0.020355
0.372791	0.017016	0.015520	0.026872	0.019803
0.473562	0.016036	0.014975	0.024922	0.018644
0.574333	0.014969	0.014819	0.022613	0.017467
0.675104	0.014112	0.014585	0.020407	0.016368
0.775875	0.013383	0.014195	0.018401	0.015326
0.876646	0.012735	0.013673	0.016607	0.014339
0.977417	0.012144	0.013098	0.015126	0.013456
1.078188	0.011584	0.012442	0.013749	0.012592
1.178958	0.011026	0.011712	0.012454	0.011731
1.279729	0.010450	0.010934	0.011253	0.010879
1.380500	0.009854	0.010136	0.010157	0.010049
1.481271	0.009251	0.009356	0.009168	0.009258
1.582042	0.008639	0.008599	0.008276	0.008504
1.682813	0.008017	0.007872	0.007473	0.007787
1.783584	0.007394	0.007180	0.006752	0.007109
1.884355	0.006790	0.006529	0.006105	0.006475
1.985126	0.006208	0.005924	0.005524	0.005886
2.085896	0.005651	0.005369	0.005005	0.005341
2.186667	0.005121	0.004859	0.004540	0.004840



Sketch 3.1 Spanwise variation of disturbance Mach number for W4 wing on axisymmetric fuselage, $M_\infty = 0.78$

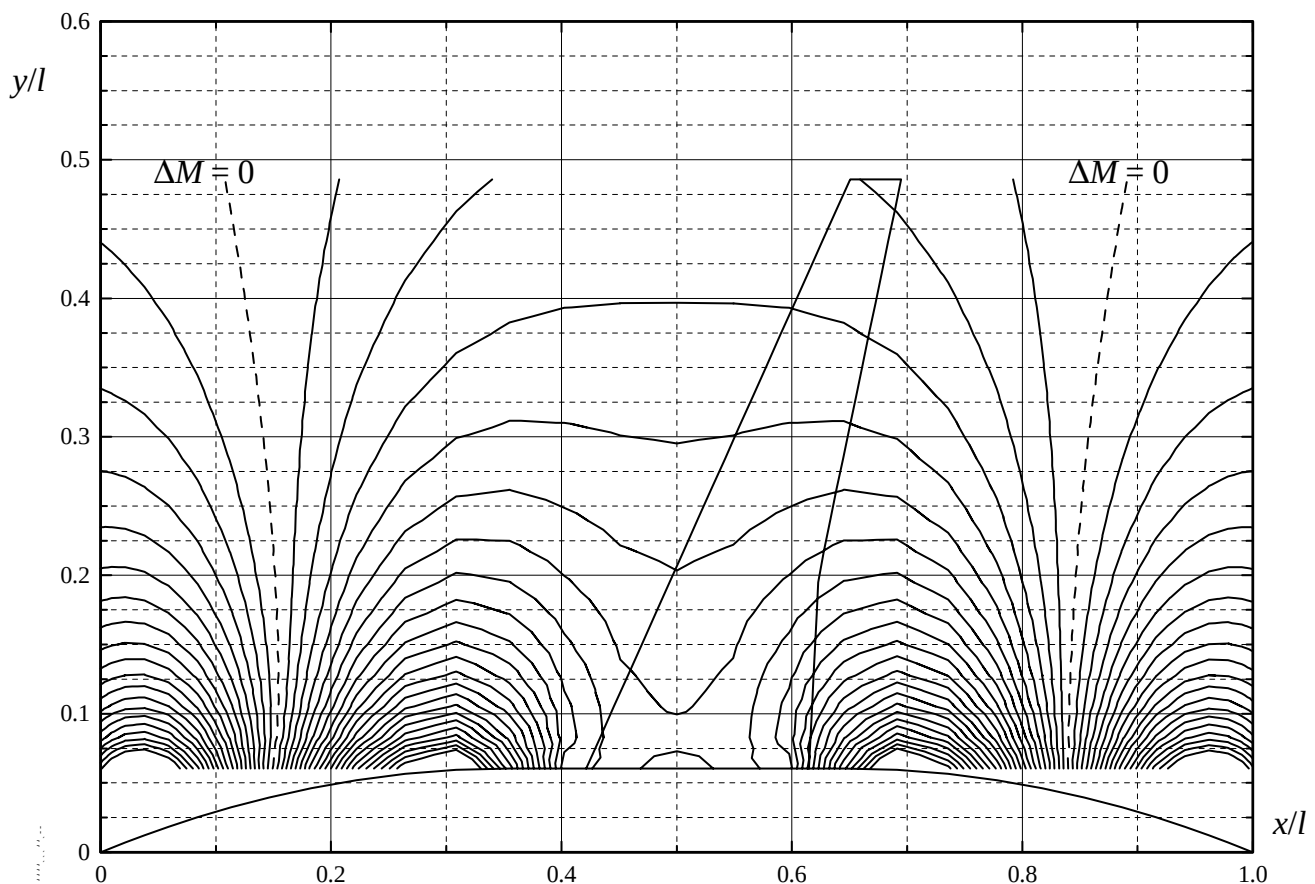
4. OBTAINING GRAPHS OF CONSTANT MACH NUMBER CONTOURS

The program *contourbody* reads in the output file *cpnew* and a file called *zintbody.dat*. A run of *contourbody* produces a file of off-body lines of constant Mach number.

The file *zintbody.dat* contains four numbers, which are the values of:

- the interval, in terms of ΔM , between lines of constant Mach number of different levels. It is recommended that a value of 0.0025 is used,
- the minimum gap, in terms of distance measured in the lines of constant Mach number plane, between two successive points on any lines of constant Mach number,
- the number of streamwise lines across the span at which ΔM values are available, from which the line of constant Mach number contours are to be obtained. This is always set to 20,
- the number of streamwise points at which ΔM values are available. This is always set to 33.

Program *contourbody* produces an output file called *machcont.dat*. Copying file *wingfuse.dat* to the beginning of *machcont.dat* produces a plotting file which is suitable for EasyPlot™ for Microsoft Windows, Reference 5, and produces plots as shown in Sketch 4.1.



Sketch 4.1 Contours of Mach number disturbance in plane through body axis for W4 wing-body geometry, $M_{\infty} = 0.78$

5. AXISYMMETRIC BODY METHOD

In this Data Item and associated pre-processor program the axisymmetric body solver is based on the simple potential flow method described by von Karman⁶. The flow is produced by superimposing the flow arising from a system of sources and sinks on a parallel flow of velocity U . The axis of the given body is subdivided into a finite number of intervals, to each of which a source or sink distribution of constant strength is assigned. Therefore the body is represented by a finite number of axial source-sink lines and the stream function of this arrangement is obtained by summation for each interval and for incompressible flow is

$$\psi = \frac{Ur^2}{2} - \sum_{i=1}^n \frac{Q_i}{4\pi} \left(1 + \frac{(r^2 + (x-x_1)^2)^{1/2} - (r^2 + (x-x_i-a)^2)^{1/2}}{a} \right). \quad (5.1)$$

In Equation (5.1) Q_i is the total source-sink strength over interval length a , x_i is the centre point of source-sink interval and r is the body radius at location x . The lines ψ equal to zero must yield the axis and body envelope. Therefore by setting ψ to zero for just as many points on the body at each x_i as there are unknown line sources, gives a system of linear equations for the determination of Q_i by matrix inversion.

Once the source-sink distribution is known the velocities u and v in the axial (x) and radial (r) directions can be solved as follows

$$u = U - U \frac{a}{2r} \sum_{i=1}^n \frac{Q_i}{2Ua^2\pi} \left(\frac{r}{(r^2 + (x-x_i-a)^2)^{1/2}} - \frac{r}{(r^2 - (x-x_1)^2)^{1/2}} \right), \quad (5.2)$$

$$v = U \frac{a}{2r} \sum_{i=1}^n \frac{Q_i}{2Ua^2\pi} \left(\frac{x-x_i-a}{(r^2 + (x-x_i-a)^2)^{1/2}} - \frac{x-x_1}{(r^2 + (x-x_1)^2)^{1/2}} \right). \quad (5.3)$$

From Equation (5.2) and (5.3) the pressure distribution can be calculated.

For three-dimensional flows the compressibility effects⁷ are applied as follows. The body radius is reduced by the Prandtl-Glauert relationship β , where

$$\beta = \sqrt{1 - M_\infty^2} \quad (5.4)$$

to transform the body to an equivalent inviscid body to calculate incremental velocities in the axial and radial directions. The incremental velocities in the compressible flow field of the original body are then given by the equations

$$u_c = \frac{1}{\beta^2} u \quad (5.5)$$

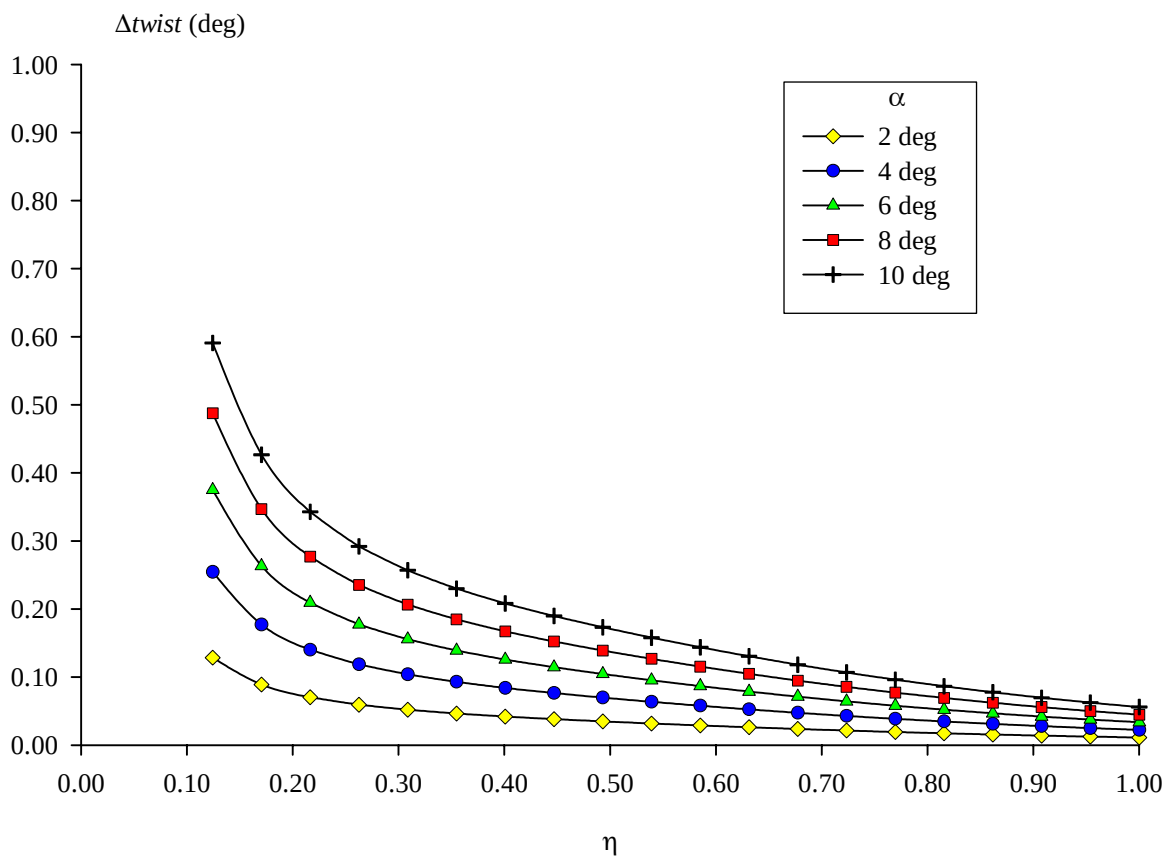
$$v_c = \frac{1}{\beta} v. \quad (5.6)$$

From these, the pressure distribution and local Mach numbers can be calculated.

6. ACCURACY AND LIMITATIONS

The results presented in Appendix A clearly show that using a generic fuselage approach in combination with a 'source-sink' representation to calculate the effects of fore- and aft-body effects can produce disturbance Mach number effects at zero incidence which are comparable with those predicted by a more complicated panel method.

For fuselage incidences up to 2 deg an example using wing W4 low-mounted on an axisymmetric fuselage shows that, over a lift-coefficient range of interest (cruise to shock-induced separation), using the disturbance Mach number approach improves the flow quality towards the body side with improved shock capturing. For incidences above 2 deg the effect of the additional cross-flow due to Mach number increment could be an issue affecting the wing lift. This incorrect cross flow effect will gradually become more pronounced with increasing incidence above 2 deg. An indication of magnitude of the effect of applying the disturbance Mach number approach to non-zero incidence cases on local incidence using the wing W4 example presented in Appendix A is shown in Sketch 6.1.



Sketch 6.1 Local increases in incidence due to disturbance Mach number for wing W4, $M_\infty = 0.78$

The magnitude of change of local incidence varies from 0.15 to 0.6 deg at the body side with $2 \text{ deg} \leq \alpha \leq 10 \text{ deg}$ and quickly reduces away from the body. Applying a wing twist correction to compensate for the incorrect cross-flow effect on wing W4 at $\alpha = 2 \text{ deg}$ produces a very small difference in span-loading and wing pressures at the wing/fuselage junction. The difference in overall lift between the uncorrected and corrected case is 0.7%. The small difference in span-loading and wing pressure will gradually increase with incidence, however, caution needs to be taken for all high incidence cases for high speed cruise Mach number conditions where viscous effects are likely to be important.

For most cases it is recommended that the mean disturbance Mach number is used. However for cases where there is a significant variation of disturbance Mach number over the wing planform due to the proximity of the fore- and aft-body to the wing, it is suggested FP calculations are performed with the range of disturbance Mach numbers to check sensitivity before making a final selection.

7. REFERENCES

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