# Reply by Authors to P.R. Payne

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## Introduction

As suggested by Payne in his Comment, we have checked our analysis for Fig. 13 in Ref. 1 and found no error.

The correctness of that analysis may be checked by examining a special case of $\theta = 30$ deg, in which the cross section becomes an equilateral triangle whose apparent mass coefficient $m_{\parallel}$ can be found in Ref. 2, which reads

$$m_{\parallel} = 0.654\pi\rho a^2 \tag{1}$$

where $a$ is the radius of the circumscribed circle of that triangle. Since the height of the triangle is $h = 1.5a$, Eq. (1) can be rewritten as

$$\frac{m_{\parallel}}{\rho\pi(h/2)^2} = 1.1627 \tag{2}$$

which agrees with our curve shown in Fig. 1 of Payne's Comment. Note that this value is not below 1, as expected by Payne based on his assumption that the curve for an isosceles triangle is similar to Taylor's curve for a rhomboid. Nevertheless, these two curves do agree at $\theta = 0$ deg when both bodies reduce to a flat plate.

Although additional published results cannot be found by us to check the validity of our curve at other $\theta$ values, we believe that the agreement at $\theta = 30$ deg with the formula in Ref. 2 is not a coincidence, and the analysis based on which our curve was plotted is not in error. Analyses reveal that the added mass of an isosceles triangle behaves differently from that of a rhomboid, which is in contradiction to intuition.

Figure 3 in Payne's Comment shows the behavior of a cavitating flat plate and a penetrating wedge having one and two wetted surfaces, respectively. Flows around them are not similar in nature to those around a triangle or a rhomboid having wetted surfaces all around. The close agreement of the two curves shown in Payne's Fig. 3 does not necessarily mean that the two curves in his Fig. 1 should also be in close agreement.

We would like to thank Payne for his interest in our paper and his thorough review of literature concerning added mass theory, which corrects and complements our sketchy historical description on the related literature in aerodynamics only.

## References

[1]Huang, M-K. and Chow, C-Y., "Apparent-Mass Coefficients for Isosceles Triangles and Cross Sections Formed by Two Circles," *Journal of Aircraft*, Vol. 20, Sept. 1983, pp. 810-816.

[2]Nielsen, J.N., *Missile Aerodynamics*, McGraw-Hill Book Co., New York, 1960, p. 373.

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# Comment on "Application of Computational Aerodynamics to Airplane Design"

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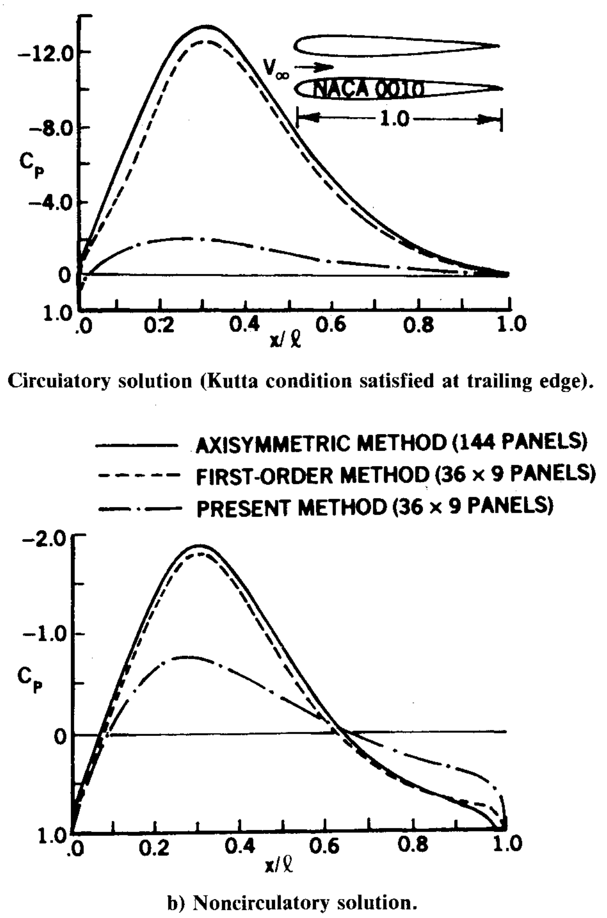
In the June 1984 issue of the *Journal of Aircraft*, Mr. Miranda published a review article on computational aerodynamics.[1] In Fig. 14 of that article, he presents some highly unsatisfactory calculational results, which he erroneously states were produced by Hess' higher order three-dimensional panel method. In fact, the results in question were produced by a first-order panel method[2] more than a dozen years old, which is known to be inaccurate for internal flows. The higher order method[3] has been applied to Miranda's case in Ref. 4. The results are shown in Fig. 1, which was taken from Ref. 4. As a standard of comparison, a graphically exact solution was obtained by using an axisymmetric method[5] with successively larger number of panels until the results stopped changing. This is also the source of Miranda's exact solution. It is evident from Fig. 1 that, in contrast to the first-order method, the higher order method gives a very satisfactory solution with a moderate number of panels.




a) Circulatory solution (Kutta condition satisfied at trailing edge).

b) Noncirculatory solution.

**Fig. 1 Calculated pressure distributions in the interior of a ring wing.**

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## References

[1]Miranda, L. R., "Application of Computational Aerodynamics to Airplane Design," *Journal of Aircraft*, Vol. 21, June 1984, pp. 355-370.

[2]Hess, J. L., "Calculation of Potential Flow about Arbitrary Lifting Bodies," McDonnell Douglas Rept. MDC J5679, Oct. 1972; (see also Computer Methods in Applied Mathematics and Engineering, Vol. 4, No. 3, Nov. 1974).

[3]Hess, J. L. and Friedman, D. M., "An Improved Higher Order Panel Method for Three-Dimensional Lifting Potential Flow," NADC-79277-60, Dec. 1981.

[4]Hess, J. L. and Friedman, D. M., "Analysis of Complex Inlet Configurations Using a Higher-Order Panel Method," AIAA Paper 83-1828, July 1983.

[5]Hess, J. L., "Improved Solution for Potential Flow About Arbitrary Axisymmetric Bodies by Use of a Higher-Order Surface Source Method," *Computer Methods in Applied Mechanics and Engineering*, Vol. 5, No. 3, May 1975.


# Reply by Author to J. L. Hess


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DR. Hess is correct in pointing out that the data shown in Fig. 14 of Ref. 1, labeled as Hess Program results, were obtained using the method of Ref. 2 rather than that of Ref. 3. This author appreciates this correction and apologizes for any wrong impression that might have been created about the accuracy of the Hess' higher order method of Ref. 3.

Nevertheless, the basic message of the discussion involving Fig. 14 in Ref. 1 remains unchanged: namely, a properly implemented low-order, constant singularity strength panel method should yield subsonic flow results of an accuracy comparable to that of the higher order panel methods but at a fraction of the computational effort.

The argument of comparable accuracy is clearly demonstrated in Fig. 1, which is the same as Fig. 14 of Ref. 1 but with the results of Hess' higher order method of Ref. 3 included. These latter results were obtained from Fig. 1 of Hess' Technical Comment. Both of Hess' computations, i.e., first order and higher order, used 9 × 36 panels (9 circumferentially and 36 longitudinally), whereas the QUADPAN (Lockheed's advanced low-order panel method) computations were carried out with 8 × 36 panels.

The question of computational effort cannot be directly addressed in this particular case because this author has no cost data for Hess' higher order computations. An examination of the two major contributions to the computational cost of any panel method may help answer this question. One of the major costs stems from the solution to the linear system of equations. Since Hess' higher order method uses only one control point per panel, both it and QUADPAN will generate essentially the same size linear system for the same number of panels. Therefore, assuming comparable solution techniques, the contribution to the cost from the matrix solution should be the same from either method. The second major cost contributor is the generation of the linear system. This includes the calculation of the influence coefficients and the distribution of these coefficients into a matrix. Both of these operations are more complex for Hess' method than for QUADPAN, involving higher order terms in the influence coefficients and local least-squares splines for source continuity. Consequently, other things being equal, a higher computational cost should be incurred when using Hess' higher order panel method.

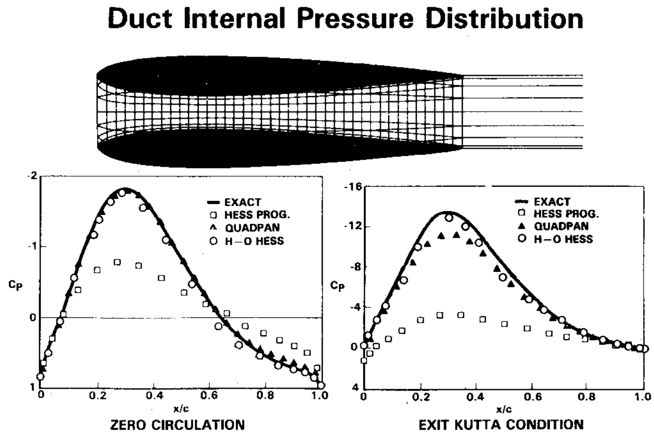


Fig. 1 Comparison of theoretical results for nacelle internal flow.

Other higher order approaches to panel methods, such as PANAIR,[4] generate significantly larger linear systems of equations for the same number of panels. Thus, in addition to a more expensive computation of influence coefficients, there is a much greater effort required to solve for the singularity strengths. This type of panel method will fare much less favorably than Hess' method when compared to an advanced low-order panel method like QUADPAN.

Even though it may be more a matter of semantics rather than substance, it should be pointed out that the older Hess' method of Ref. 2 is, in a sense, a method of higher order than QUADPAN. Although both have the same order source distribution, namely, constant or zeroth-order, the constant vorticity distribution used in Hess' method is equivalent to a linear (first-order) dipole distribution, whereas QUADPAN uses a constant (zeroth-order) dipole distribution.


## References

[1]Miranda, L. R., "Application of Computational Aerodynamics to Airplane Design," *Journal of Aircraft*, Vol. 21, June 1984, pp. 355-370.

[2]Hess, J. L., "Calculation of Potential Flow About Arbitrary Lifting Bodies," McDonnell Douglas Rept. MDC J5679, Oct. 1972.

[3]Hess, J. L. and Friedman, D. M., "An Improved Higher Order Panel Method for Three-Dimensional Lifting Potential Flow," NADC-79277-60, Dec. 1981.

[4]Carmichael, R. L. and Erickson, L. L., "PAN AIR—A Higher Order Panel Method for Predicting Subsonic and Supersonic Linear Potential Flows About Arbitrary Configurations," AIAA Paper 81-0252, 1981.


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