Technical Comments

Comment on "Numerical Optimization Design of Advanced Transonic Wing Configurations"

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HAVING read Ref. 1 with great interest, I was surprised to find apparent signs of serious inaccuracy in the tables of numerical results. This can be seen from Tables 1 and 2, in which the numbers are identical with those of the paper, except for the additional lines $C_L^2/\pi A$ and $C_D/(C_L^2/\pi A)$.

From Tables 1 and 2, it will be seen that for both wings, even before optimization, the quoted values of the inviscid drag coefficient C_D are well below the ideal minimum induced drag values for the appropriate values of C_L and aspect ratio A. After optimization, the improved values are only about half the theoretical minimum.

Assuming that these apparent errors are not just the result of some numerical slip, this does cast doubt on the accuracy of the authors' method of calculating their "objective function" (L/D) by integrating the appropriate component of pressure over the wing surface. Earlier in the paper (p. 194, top of second column), they state correctly that "for efficient operation in the transonic regime the wave drag must be minimized ..." In my opinion it is, therefore, better to use a method of drag prediction that deals separately with the wave drag and vortex ("induced") drag components (and, in a real flow, the viscous drag). For this purpose, a method such as those suggested in Refs. 2 or 3 could be used.

In mentioning these doubts about the numerical accuracy of the published results, I do not, of course, intend to detract from the undoubted value of the authors' method as a design tool. It is worth stressing, however, the importance of checking the validity of any purely inviscid method such as this by subsequent calculations by a suitable "viscous" code, to make sure that any reductions in inviscid drag have not been outweighed by corresponding increases in viscous drag.

Table 1 Lockheed model C-141B (aspect ratio = 7.89)

Parameter	Original wing	New wing
C_L	0.585	0.558
$C_L^2/\pi A$	0.0138	0.0126
C_D	0.00967	0.00723
$C_D/(C_L^2/\pi A)$	0.70	0.58

Table 2 Cessna model 650 (aspect ratio = 9.0)

Parameter	Original wing	New wing
C_L	0.565	0.506
$C_L^2/\pi A$	0.0113	0.00905
C_D	0.00909	0.00438
$C_D/(C_L^2/\pi A)$	0.81	0.48

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References

[1]Cosentino, G. B. and Holst, T. L., "Numerical Optimization Design of Advanced Transonic Wing Configurations," *Journal of Aircraft*, Vol. 23, March 1986, pp. 192–199.

[2]Yu, N. J., Chen, H. C., Samant, S. S., and Rubbert, P. E., "Inviscid Drag Calculations for Transonic Flows," AIAA Paper 83-1928, 1983.

[3]Lock, R. C., "Prediction of the Drag of Wings at Subsonic Speeds by Viscous/Inviscid Interaction Techniques," AGARD-R-723, Paper 10, 1985.

Reply by Authors to R. C. Lock

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AS pointed out in the comment by Lock, the inviscid drag values published in Ref. 1 show considerable error. This error is truncation error and behaves in a consistent fashion. That is, the inviscid drag is always too small. The inviscid drag values associated with the analysis code (TWING) always result in a small negative value for subcritical nonlifting calculations or an underprediction of inviscid drag for supercritical lifting cases. This error, as expected with truncation error, can be reduced with grid refinement. However, to keep the computer time requirements for the numerical optimization procedure at a minimum, the results presented in Ref. 1 were obtained on a very coarse grid (89×25×18); thus, the absolute drag errors were larger than desired. However, in numerical optimization, the accurate prediction of absolute drag is not important. The accurate prediction of drag increments is the important quantity and is crucial to the success of numerical optimization. This point will be discussed shortly.

Since the results appearing in Ref. 1 were completed, a new version of TWING with improved truncation error characteristics has been developed and is described in Ref. 3. (This new version is used in the TWING/QNM design pro-

Table 1 Comparison of drag coefficients computed for an ONERA M6 wing at $M_\infty = 0.2$ and $\alpha = 0$ deg

Code description	Inviscid drag
Ref. 2 result	0.0005
TWING (CY = 3) (89×25×18)	−0.0018
TWING (CY = 4) (89×25×18)	−0.0004
TWING (CY = 4) (89×25×31)	0.0001

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Table 2 Comparison of computed lift and drag coefficient values for the Lockheed C141B wing of Ref. 1, $M_\infty = 0.77$, $\alpha = 0$ deg

Code description	Original wing C_l	Original wing C_d	Optimized wing C_l	Optimized wing C_d	Change in C_d
Ref. 1 result	0.585	0.0097	0.558	0.0072	0.0025
TWING (CY = 4) (89 × 25 × 18)	0.604	0.0143	0.581	0.0116	0.0027
TWING (CY = 4) (109 × 31 × 41)	0.614	0.0157	0.590	0.0130	0.0027

gram.) The absolute level of the drag error can be determined by looking at a nonlifting subcritical case where the correct inviscid drag should be zero. Table 1 can be constructed using the example of Ref. 2 (ONERA M6 wing, with a freestream Mach number of 0.2 and zero angle of attack). The old version of TWING is referred to as CY = 3 and the new version as CY = 4. All results have been tightly converged. As can be seen from Table 1, the CY = 3 version of TWING is not very accurate. Even larger drag errors can be produced for wings with twist and dramatic spanwise section variation, which is certainly the case for the wing geometries presented in Ref. 1. However, the new version of TWING, especially when the normal grid direction is refined, solves the drag accuracy problem.

In numerical optimization where the drag-to-lift ratio is minimized, the ability of an analysis code to predict absolute drag levels is not important. Instead, an analysis code must be able to predict drag changes or increments accurately as the wing configuration is perturbed from one configuration to another. This is an extremely important point and cannot be emphasized enough! Because of the consistency of the drag error associated with TWING (CY = 3 and CY = 4), the incremental changes in drag are relatively accurate, even on coarse grids. This is demonstrated in Table 2 where three sets of results are displayed for the original and optimized C141B wing. The original and optimized wing coordinates for these results were obtained from the Ref. 1 study; that is, no new design computations were made. The results of a coarse grid (CY = 3) were taken directly from Ref. 1. The CY = 4 (coarse grid) results were obtained on the same grid, but with the improved version of TWING. The CY = 4 (fine grid) results in Table 2 were obtained from the improved version of TWING on a fine grid. Note that the values of drag for the improved version of TWING, especially on the fine grid, are much closer to, or even above, the theoretical minimum induced drag level. Finally, despite the large error in the absolute levels of drag associated with the old version of TWING using the coarse grid, the incremental values of drag vary by only 0.0002! Thus, the numerical optimization results presented in Ref. 1 are accurate and do indicate that this method represents an effective technique for minimizing wave drag.

A suggestion by Prof. Lock to use the wave drag to construct the objective function instead of the total inviscid drag seems to be a good one and should be investigated. However, for cases in which the lift can be constrained to be a constant, such a study is unnecessary. This lift constraint can be imposed by adding a large penalty to the objective function for any values of lift away from the desired value. The resulting designs will be effective at constant lift. Wave drag-to-lift minimization, as suggested by Lock, will not necessarily force a design at constant lift.

The last comment made by Prof. Lock is very appropriate—that is, to check the final design to make sure that the viscous drag has not increased while the wave drag is minimized. In the future, after the computer hardware has improved in speed by perhaps an order of magnitude and after certain needed numerical optimization advances are obtained, it might be appropriate to do numerical optimization calculations where the total drag is minimized. Thus, the wave drag and skin-friction drag could be minimized simultaneously.

References

[1]Cosentino, G. B. and Holst, T. L., "Numerical Optimization Design of Advanced Transonic Wing Configurations," *Journal of Aircraft*, Vol. 23, March 1986, pp. 192–199.

[2]Yu, N. J., Chen, H. C., Samant, S. S., and Rubbert, P. E., "Inviscid Drag Calculations for Transonic Flows," AIAA Paper 83-1928, 1983.

[3]Thomas, S. D. and Holst, T. L., "A Consistent Spatial Differencing Scheme for the Transonic Full-Potential Equation in Three Dimensions," NASA TM 86716, Dec. 1985.