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# Comment on "Rational Design of an Airfoil for a High-Performance Jet Trainer"

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IN a recent paper, Drs. Powers and Sattler[1] present an astonishing claim of exhibiting a rational design procedure for an airfoil for a high-performance trainer on the basis of some two-dimensional inviscid flow calculations combined with the strictly two-dimensional Stratford criterion for boundary layer separation. Since the paper offers no suggestions for relating such results to swept wings of aspect ratio 3-4 which are typical of fighter or trainer aircraft, it appears that Drs. Powers and Sattler are unaware of the strong three-dimensional flow effects on such wings which render all two-dimensional results not only useless, but actually misleading.

Attempts to use the computationally convenient two-dimensional calculations to derive characteristics of low aspect ratio wings defy an established body of evidence which demonstrates clearly the existence of significant differences in loading levels and distributions. The authors, and interested readers, might wish to consult an excellent exposition of this subject given by Kuchemann.[2] As an example of the wide discrepancies between two- and three-dimensional results, it is interesting to compare the values and chordwise locations of peak loadings of RAE 101 airfoils which are given by Kuchemann in Figs. 4.29 and 4.32 for two-dimensional and 45 deg sweep, aspect ratio 3 wings, respectively. Examples are shown in Table 1.

Discrepancies in peak loading are greater than they appear here because of the applied correction for the chordwise location, $X/c$. Corrections for sweep do not adjust the data even for peak loadings, and would be of no value because of the differences in loading distributions. Further evidence is presented by Kuchemann[2] in Fig. 4.34 which indicates the appearance of strong three-dimensional effects at 63% semispan of an aspect ratio 6 wing.

In terms of using two-dimensional separation criteria to design airfoils for real aircraft, Drs. Powers and Sattler are in even greater error because of the strong influence of crossflow. Detailed calculations of three-dimensional laminar and turbulent boundary layers on an F-8 experimental wing were presented in Ref. 3 which used numerical solutions of the complete governing equations. An example of the calculated surface shear stress directions which matched oil streak data is reproduced in Fig. 1. The chordwise variations of transverse and longitudinal shear stresses, $\tau_l$ and $\tau_2$ respectively, at 31% semispan are shown in Fig. 2 which is also taken from Ref. 3. The demonstrated large magnitudes of three-dimensional flow phenomena indicates that the existence of any generally valid relations between two- and three-dimensional wing flows is not obvious. A study specifically aimed at determining the effects of crossflow on pressure gradients corresponding to turbulent boundary layer separation was made in Ref. 4. The relation between the dimensionless transverse and longitudinal velocity gradients, $\hat{\alpha}$ and $\beta$, respectively, which corresponded to the disappearance of the longitudinal shear stress was obtained in an inverse calculation and was found to be as shown in Table 2.

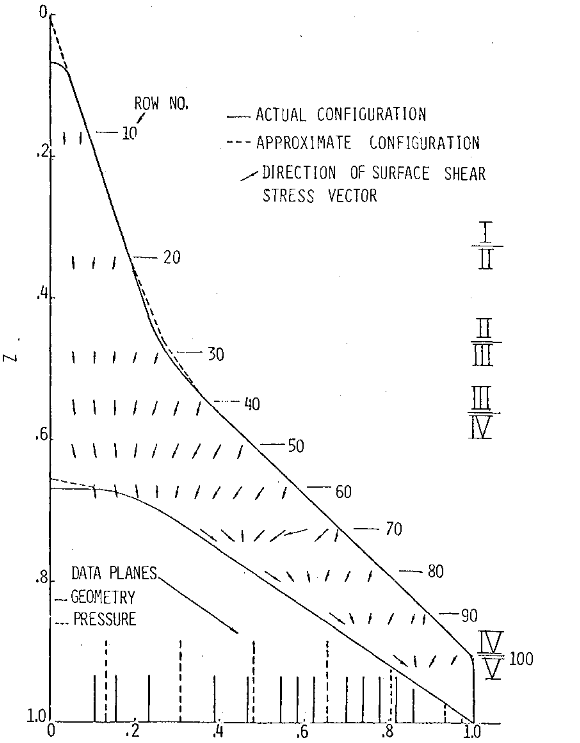


**Fig. 1 Planform of the wing showing surface shear stress directions and divisions into computing regions.**

**Table 1 Two-and three-dimensional wing loadings, RAE 101 section**

| | Maximum $-\Delta C_P (X/c)^{1/2}$ | Location, $(X/C)^{1/2}$ |
|---|---|---|
| Two dimensional | 0.61 | 0.27 |
| Aspect ratio 3, 45 deg sweep wing at 40% Semispan | 0.45 | 0.40 |

While calculations of turbulent separation are admittedly somewhat speculative, the results are certainly indicative of the magnitudes involved. In the case of aircraft wings, the ratio of velocity gradients may be expressed as

$$\hat{\alpha}/\beta = \frac{V}{U}\frac{(\mathrm{d}U/\mathrm{d}y)}{(\mathrm{d}U/\mathrm{d}x)} \tag{1}$$

with $U, V$ being the longitudinal and transverse velocities and $x,y$ the corresponding coordinates. The ratio varies with the location on the wing, but reaches, or exceeds the values of unity near the trailing edge, particularly in the outboard regions of the wing. The longitudinal pressure gradient

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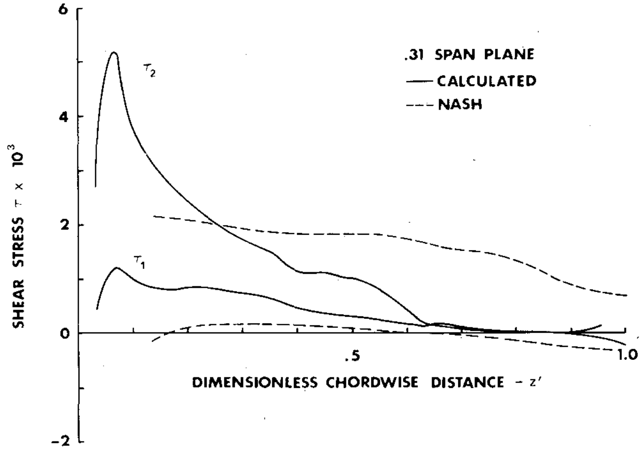


Fig. 2 Transverse and longitudinal shear stresses, $\tau_1$ and $\tau_2$ at the 0.31 semispan plane.

Table 2 Transverse and longitudinal velocity gradients at longitudinal separation

| | | | | |
|---|---|---|---|---|
| $\bar{\alpha}$ | 0.0 | 0.1 | 0.3 | 0.5 |
| $-\beta$ | 0.2 | 0.28 | 0.4 | 0.51 |

corresponding to separation would be about twice the magnitude of the two-dimensional value and the use of Stratford's criterion would lead to entirely misleading results.

An excellent demonstration of the potential pitfalls in simplified calculations was given by Goethert[5] who used the data of Thomas and Redeker[6] for an F-86A aircraft with an aspect ratio of 4.8 to point out that the buffet boundary at $C_L = 0.5$ was calculated on the basis of cosine law correction to be at $M \approx 0.91$ while flight test at the same Reynolds number indicated $M = 0.87$. An alternate way of looking at this result is that for $M = 0.9$, calculations with the cosine correction showed buffet at $C_L \approx 0.51$ while flight test yielded a value of $C_L \approx 0.38$.

The work of Drs. Powers and Sattler does not exhibit a rational procedure for design of jet trainer airfoils and both the title and contents of the paper are misrepresentations with no basis in fact.

The undeniable success of correlations of flows on wings of different sweep angles and aspect ratios might lead to the expectation of the general validity of such an approach. When little or no boundary layer separation is encountered, inviscid similitude may be invoked to justify correlations. Wings designed to a separation criterion introduce the additional difficulty of correlation of separation in three-dimensional flows. On the basis of the cited references and extensive numerical parametric studies of three-dimensional boundary layers, it does not appear likely that a general relation can be developed. In order to justify the title of the paper, the authors should demonstrate their technique for extending two-dimensional airfoil results to three-dimensional fighter or trainer wings.

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# Reply by Authors to A. Wortman

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We appreciate Dr. Wortman's analysis of our paper, delivered in the same spirit as that of Ref. 1. Dr. Wortman has missed the point of our paper, which is the determination of a two-dimensional airfoil section to satisfy the local conditions on a three-dimensional straight wing. The subjects of low aspect ratio and high sweep were not discussed because the target aircraft was to have a straight wing of aspect ratio 5.3. Once the discussions in Dr. Wortman's paper pertaining to high sweep and low aspect ratio are removed, nothing is left.

The experimental and theoretical analysis which Dr. Wortman has brought to bear to support his spurious criticisms merely reflect the current state of aerodynamic configuration development; analysis is easy, design is difficult.

We wish to thank our colleague, R.R. Johnson[2] for stimulating and supporting discussions of the issues raised by Dr. Wortman.

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