Technical Comments

Comments on "Flow Separation over Axisymmetric Afterbody Models"

F. R. Goldschmied*
Westinghouse Electric Corporation, Pittsburgh, Pa.

EXTENSIVE experimental data have been presented by Presz and Pitkin[1] for subsonic axisymmetric aftbodies, with unseparated, partially separated, and totally separated flow. The paper is based on the doctoral thesis of Presz.[2] At the bottom of p. 680, Presz and Pitkin[1] dismiss the Goldschmied[3] separation criterion with the simple statement that it predicts no separation for the experimental cases shown in Figs. 9 and 10 (Ref. 1). This statement has been found to lack factual foundation, as shown below, both regarding direct experimental verification of the criterion and regarding use of the criterion in a separation location prediction method.

The Goldschmied criterion[3] was derived for incompressible two-dimensional flow. It is a relationship between the turbulent skin-friction coefficient at the start of the adverse pressure gradient and the maximum allowable pressure recovery (as limited by flow separation):

$$C_{p_s} = 1 - (U_s/U_M) \cong 200 C_{f0}$$

The static-pressure coefficient at separation C_P^* is given by

$$C_P^* = 1 - (1 - C_{p_s})(1 - C_{P\min})$$

where

$$C_{f0} = \frac{\tau_0}{\frac{1}{2}\rho U_M{}^2}$$

$$C_P^* = 1 - (U_s/U_\infty)^2$$

$$C_{P\min} = 1 - (U_M/U_\infty)^2$$

U_s = velocity at boundary-layer's edge at separation
U_M = velocity at boundary-layer's edge at the minimum-pressure point
U_∞ = freestream velocity
ρ = fluid mass density
τ_0 = skin-friction at minimum-pressure point

The criterion is not a prediction method as such, since C_{f0} must be provided either experimentally or analytically by some method such as the Cebeci and Smith[4] program. In Ref. 2, the skin-friction coefficient C_F is given in the upstream vicinity of the minimum-pressure point, as determined from the experimental local velocity profile; thus a direct verification of the Goldschmied criterion can be achieved for the cases of Figs. 9 and 10 (Ref. 1), since both experimental C_{f0} and experimental C_{p_s} are available. The conversion from C_F to C_{f0} is given below:

$$C_{f0} = C_F/(1 - C_{P\min})$$

The computations for Fig. 9 of Ref. 1 are as follows:

$$C_F = 0.0027 \text{ (from Table 4, p. 58, Ref. 2)} = \frac{\tau_0}{\frac{1}{2}\rho U_\infty^2}$$

$$C_{P\min} = -0.54 \text{ (experimental)}$$

$$C_{f0} = 0.0027/1.54 = 0.001753$$

$$C_{p_s} = 200 \times 0.001753 = 0.350$$

$$C_P^* = 1 - 0.650 \times 1.54 \cong 0.00$$

From the figure, it is quite evident that the pressure-slope break occurs exactly at $C_p = 0$; thus the Goldschmied[3] criterion is verified directly by the Presz and Pitkin[1] data, as shown in Fig. 1.

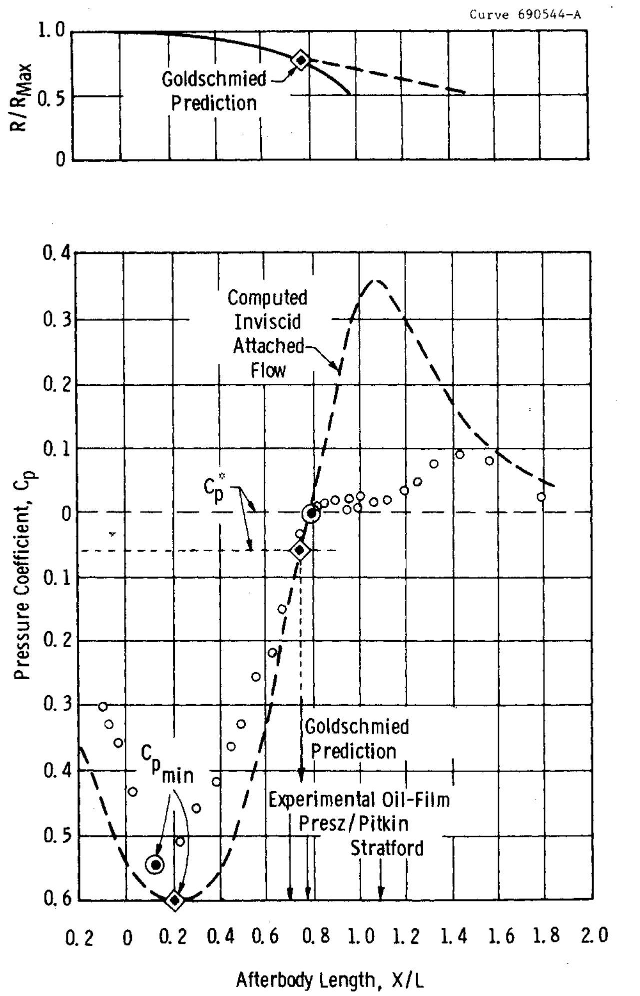

Fig. 1 Eperimental verification of Goldschmied criterion and of prediction method (Fig. 9 of Ref. 1).

Received Feb. 7, 1977.
Index categories: Aerodynamics; Jets, Wakes, and Viscid-Inviscid Flow Interactions; Airbreathing Propulsion.

*Advisory Scientist, Research and Development Center. Associate Fellow AIAA.

Table 1 Test configurations

Ref.	Figure	Aftbody	Mach number	Run
1	9	16° circular arc	0.50	14
1	10	24° elliptical	0.25	7
2	56	8° elliptical	0.50	2
2	57	16° elliptical	0.50	5
2	58	24° elliptical	0.50	8
2	59	8° circular arc	0.25	10
2	60	16° circular arc	0.25	13
2	61	24° circular arc	0.25	22
2	62	24° conical	0.70	33

Table 2 Separation pressure prediction

Run	Experimental C_F	C_{f0}	$C_{P_{min}}$ inviscid	C_{p_s}	C_P^* inviscid
14	0.0027	0.00168	−0.60	0.330	−0.06
7	0.0029	0.00168	−0.73	0.336	−0.15
2	0.0027	0.00198	−0.36	0.397	0.179
5	0.0028	0.00182	−0.54	0.364	0.020
8	0.0027	0.00153	−0.76	0.306	−0.219
10	0.0030	0.00227	−0.32	0.454	0.279
13	0.0029	0.00188	−0.54	0.376	0.04
22	0.0029	0.00170	−0.70	0.340	−0.122
33	0.0027	0.00140	−0.93	0.280	−0.389

Table 3 Separation location

Run	Oil-film separation	Pressure-slope separation	Goldschmied prediction	Figure (Ref.)
14	0.70	0.80	0.74	9(1)
7	0.47	0.82	0.70	10(1)
2	10.0″	10.0″	10.0″	56(2)
5	8.05″	8.20″	8.20″	57(2)
8	7.50″	7.55″	7.40″	58(2)
10	9.55″	9.55″	no separation	59(2)
13	7.95″	8.05″	8.00″	60(2)
22	7.30″	7.50″	7.40″	16(2)
33	6.80″	6.80″	6.95″	62(2)

The computations for Fig. 10 of Ref. 1 are as follows:

$$C_F = 0.0028 \text{ (from Table 4, p. 58, Ref. 2)} = \frac{\tau_0}{\frac{1}{2}\rho U_\infty^2}$$

$$C_{P_{min}} = -0.65 \text{ (experimental)}$$

$$C_{f0} = 0.0029/1.65 = 0.001757$$

$$C_{p_s} = 200 \times 0.001757 = 0.351$$

$$C_P^* = 1 - 0.649 \times 1.65 = -0.071$$

From the figure it is quite evident that the pressure-slope break occurs exactly at $C_P = -0.07$; thus the criterion is again verified directly by the Presz and Pitkin[1] data.

Such an excellent direct experimental verification is quite gratifying, since the criterion was derived for incompressible two-dimensional flow and the test were obtained on axisymmetric configurations at Mach numbers up to 0.50.

On the other hand, a prediction approach, as against the previous verification objective, would have to be based on the computed inviscid attached pressure distribution and on a computed skin-friction coefficient. The inviscid distribution is shown for a total of nine cases in Refs. 1 and 2; a computed skin-friction is not given, thus making it necessary to use the experimental C_F of Table 4, p. 58 (Ref. 2) (in the absence of laminar/turbulent transition data). Table 1 below lists the figure number, the aftbody type, the Mach number, and the identification run number for the nine test cases.

Table 2 presents a summary of the experimental Presz C_F, of the Goldschmied C_{f0}, of the inviscid $C_{P_{min}}$, of the computed pressure-recovery C_{p_s}, and of the inviscid C_P^* at separation.

Finally, Table 3 presents a summary of the separation locations; the oil-film separation indication is not always in agreement with the pressure-slope break.

The separation location is predicted by the intersection of the inviscid attached pressure-distribution with the line $C_P^* =$ constant as shown in Fig. 1 for the case of Run 14 (Fig. 9 of Ref. 1).

The agreement between predicted location and test data appears quite good for eight cases; for run 10, the method incorrectly predicts no separation.

References

[1] Presz, W. M. Jr. and Pitkin, E. T., "Flow Separation Over Axisymmetric Afterbody Models," *Journal of Aircraft*, Vol. 11, Nov. 1974, pp. 677-682.

[2] Presz, W. M. Jr., "Turbulent Boundary Layer Separation on Axisymmetric Afterbodies," Ph.D. Thesis, School of Engineering, University of Connecticut, Storrs, Conn., 1974.

[3] Goldschmied, F. R., "An Approach to Turbulent Incompressible Separation under Adverse Pressure Gradients," *Journal of Aircraft*, Vol. 2, March-April 1965, pp. 108-115.

[4] Cebeci, T. and Smith, A.M.O., "A Finite-Difference Method for Calculating Compressible Laminar and Turbulent Boundary-Layers," *ASME Journal of Basic Engineering*, Vol. 92, Sept. 1970, pp. 523-535.

Reply by Authors to F.R. Goldschmied

Walter M. Presz Jr.
Pratt & Whitney Aircraft, East Hartford, Conn.
and
Edward T. Pitkin
University of Connecticut, Storrs, Conn.

THE boundary-layer properties measured in the referenced test program were taken at model station 6.35. This location is considerably upstream of the minimum-pressure point. Thus, Goldschmied's separation criteria was applied using a calculated skin friction coefficient at the minimum-pressure point. The measured boundary-layer values and surface static pressures were used as input for a modified Reshotko-Tucker boundary-layer analysis. This analysis was used to obtain the boundary-layer development on the afterbody and thus the skin friction coefficient at the minimum-pressure point. This calculated value can be significantly higher (i.e., $C_F = .0032$ for Fig. 9) than the C_F value used by Goldschmied, which was the measured value at station 6.35. The higher calculated C_F value can be attributed to additional energizing of the boundary layer between the measured station and the minimum-pressure point. We believe this accounts for the apparent discrepancies pointed out by Goldschmied.

Received April 7, 1977.

Index categories: Aerodynamics; Jets, Wakes, and Viscid-Inviscid Flow Interactions; Airbreathing Propulsion.

*Assistant Project Engineer, Propulsion Integration Group. Associate Member AIAA.

†Professor of Mechanical and Aerospace Engineering. Associate Fellow AIAA.