Flow Inclination Measurements in Hypersonic Tunnels

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This note comments on the characteristics of four types of null flow direction indicators The comments are based upon measurements that were made in three Aerospace Research Laboratories (ARL) hypersonic tunnels at Mach numbers ranging from M = 11 5 to M = 17

Nomenclature

C_p = pressure coefficient at $\alpha = 0°$
M = Mach number in freestream
$\bar{P}$ = pressure differential between ports symmetrically located on either side of the body in the pitch plane
P_r = claw tube impact pressures for recovery cone at $\alpha = 0°$
P_{t_2} = impact pressures behind normal shock in freestream
q = dynamic pressure in freestream
R_D = Reynolds number in freestream based on diameter of circle inscribing body cross section at pressure ports
$S\alpha$ = sensitivity of flow direction indicator to small changes in α
T_0 = stagnation temperature
T_s = temperature on cone surface or within spiked cylinder
α = pitch angle ~ zero yaw deg
θ = cone total angle

Cones

THE use of cone surface pressures in determining flow direction in supersonic tunnels is discussed in numerous references [1] However, in many hypersonic tunnels and in some supersonic tunnels, it is difficult to use cone surface pressures to determine mean flow inclinations with high precision (better than ± 0 05°) The pressure differentials ($\bar{P}$) across the surfaces of cones, at low angles of attack, may be so small that it is difficult to measure them accurately Furthermore, low cone surface pressures sometimes require excessive lag times before the pressures stabilize in the tubing

The sensitivities (S_α) of the surface pressure on various right circular cones are available from Ref 1 and inviscid theory [2] These are shown in Fig 1 as a function of M Since the pressures measured by most null-flow direction indicators vary linearly with α near $\alpha = 0°$, $S\alpha$ is defined as

$$S_\alpha = (1/q)(\partial\bar{P}/\partial\alpha)_{\alpha=0}$$

Figure 1 and Table 1 also shows measured values of $S\alpha$ for two cones (Figs 2a and 2b) Scaggs of Ohio State University found that with the 90° cone he could determine the flow angularity in the ARL 30-in tunnel to within ± 0 1° at M = 17(1000-psia stagnation pressure)

Cobra Probe

Fusfeld[3] indicated that flow angularity can be determined in supersonic tunnels by using a null indicator that is sometimes called a cobra probe or a Conrad probe (in England) His data show that the cobra probe is about as sensitive as the surface pressures on a 45° cone at M = 1 8 and a 60° cone at M = 2 8 Experimental measurements at M = 14 (Table 1) were obtained for a similar cobra probe (Fig 2c) This cobra probe had about the same sensitivity at M = 14 as Fusfeld's probe displayed at M = 2 8

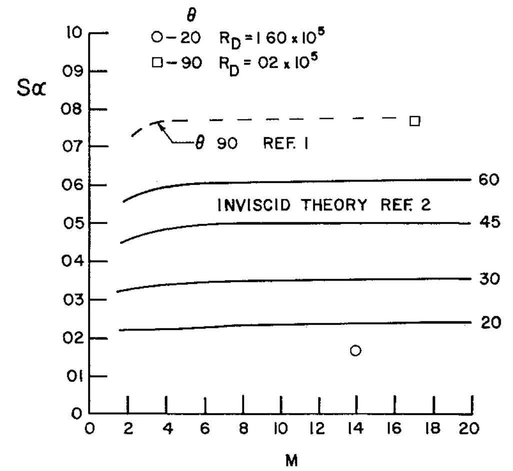

Fig 1 Sensitivity of cone surface pressures to flow inclination

Spiked Cylinder

While attempting to position a spiked cylinder[4] (Fig 2d) at $\alpha = 0°$ with an M = 12 flow, it was found that a pitch angle of α = 0 1° would change the face edge pressures by as much as 10% of the $\alpha = 0°$ value Table 1 shows the flow-sensing characteristics of one spiked cylinder (Fig 2d) at M = 12, and another spiked cylinder (Fig 2e) at M = 14 At M = 14 the measured C_p values were strongly influenced by body temperature as predicted by Wood [5] However, Wood's theory predicts reattachment pressures for this spiked body at M = 12 which are about five times higher than the measured C_p shown in Table 1 This may be because this flow direction indicator had a relatively large pressure port at the edge

Recovery Cone

Sivells[6] reported the use of a highly sensitive flow direction probe, termed a recovery cone in this note At M = 5, this 20° recovery cone was reportedly 20 times more sensitive to flow angularity than the surface pressures of a 20° cone [1] A 30° recovery cone (Fig 2f) was designed using this same concept Knowledge of the flow characteristics in the ARL 3-in hypersonic tunnel permitted zero alignment in yaw by geometric means As may be seen in Table 1, the 30° recovery cone was exceptionally sensitive to flow direction at M = 12 and at M = 14 Furthermore, P_r was measured quite easily since it was even higher than P_{t_2}

Although a detailed study was not attempted, Fig 3 roughly shows the variation of P_r/P_{t_2} with R_D and M chang-

Table 1 Measured characteristics of probes

Flow angle indicator	M = 12				M = 14			
	$R_D \times 10^{-5}$	T_S ~ °F	C_P	$S\alpha$	$R_D \times 10^{-5}$	T_S ~ °F	C_P	$S\alpha$
20° cone					0 16[a]	920	0 07	0 017
Cobra probe					0 50		1 02	0 065
Spiked cylinder [a]	0 34	550	0 11	0 168	1 60	150–550	0 16–0 10	0 276
Recovery cone[a]	0 15	800	5 72	2 05	0 07[a]	660	2 40	1 14

[a] Data using conical flow nozzles $\Delta M \approx$ 0 4/in along centerline in test section

Received August 15, 1963 The author wishes to express thanks to William D Vann of Systems Research Laboratories Inc , who aided in conducting some of the tests and in preparing a portion of the results

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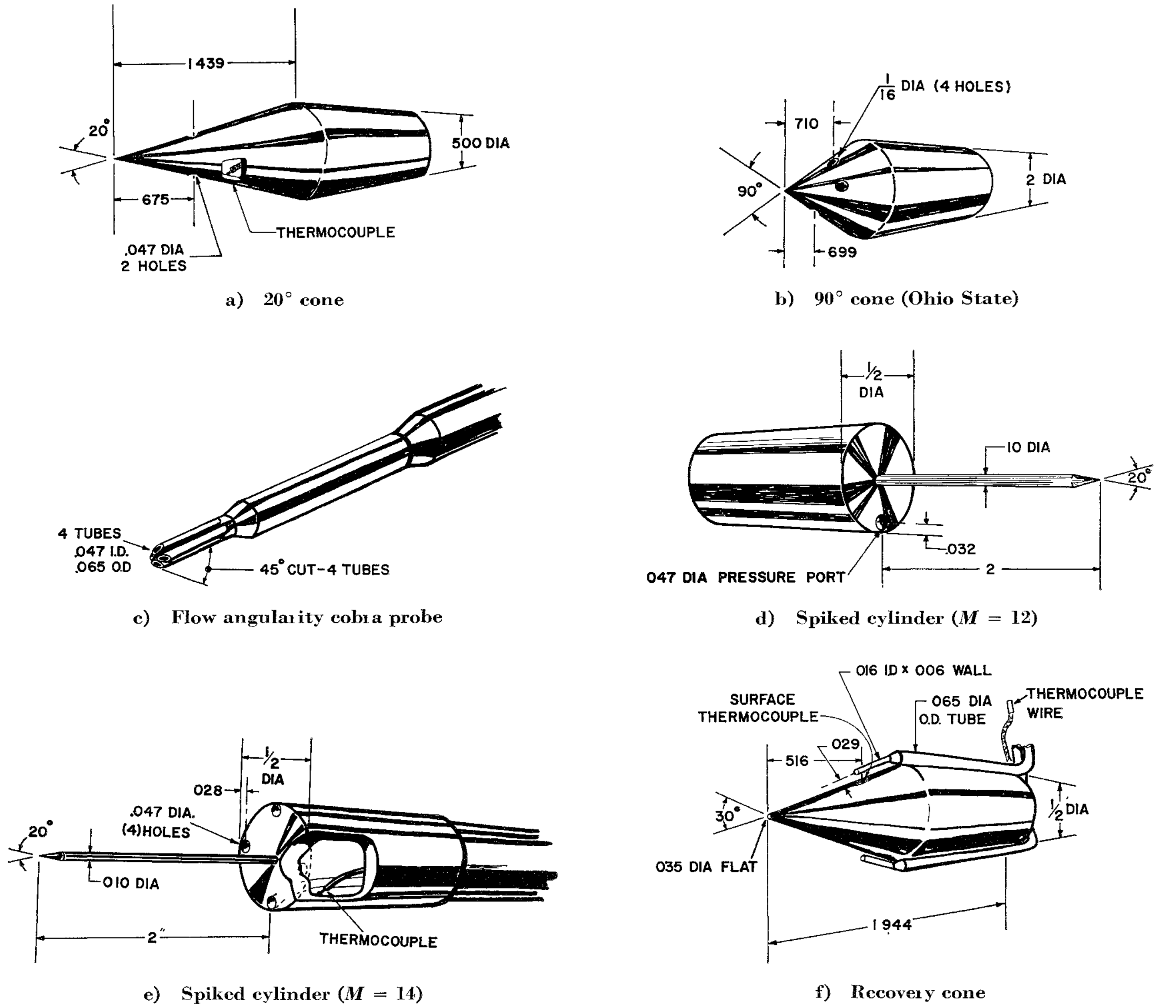

a) 20° cone

b) 90° cone (Ohio State)

c) Flow angularity cobra probe

d) Spiked cylinder (M = 12)

e) Spiked cylinder (M = 14)

f) Recovery cone

Fig 2 Flow direction probes

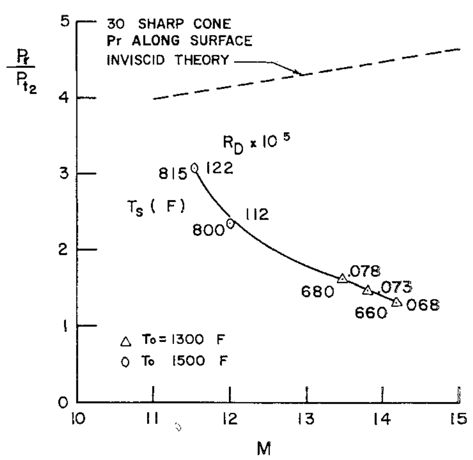

Fig 3 Pressure recovery from claw impact tubes on recovery cone

ing at the same time The variation of the ratio of P_T on the surface of a sharp 30° cone to P_{t_2} was computed using inviscid theory and is also shown as a function of M Figure 3 and the change in S_α between M = 12 and M = 14 (Table 1) imply that anyone contemplating constructing such a probe should give serious thought to the location of the claw impact pressure tubes within the entropy-viscous layer, since this will most likely have a pronounced effect upon S_α and C_p Furthermore, experiments at these Mach numbers involving the use of a pressure probe near the surface of a cone may well require very precise positioning of the model relative to the flow, judging from the extreme sensitivities shown in Table 1 for this particular case

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