Conclusions

Heterogeneous nucleation is seen to begin at partial pressures of about 10 times the wall partial pressure. Homogeneous nucleation is seen to begin at partial pressures on the order of 10^3 times the wall partial pressure. Initial gas temperature has only a weak effect on the onset of snow as long as the wall temperatures are substantially below this inlet temperature. Snow may be avoided by staying below the onset curves, lowering the inlet partial pressures of the water vapor, or increasing the wall temperatures. These calculations and curves apply to any uniform temperature water cold trap. These curves can even be used to predict the humidity required for the thin natural convection boundary layer flowing down the outside of a glass of ice water to be visible due to small droplet formation (fog) in this boundary layer.

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Engine Power Simulation for Transonic Flow-Through Nacelles

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I. Introduction

EXISTING inlet and nacelle analyses examine either "isolated inlets," i.e., semi-infinite nacelles with prescribed mass flux, or finite length "flow-through" nacelles, where Kutta's condition determines the mass flow. For example, panel methods, finite difference and element solutions, and Euler and Navier-Stokes solvers presently are available for engineering analysis.[1-4] This Note addresses the effect of jet engine power addition. The interaction between the external potential flow past a finite length nacelle and an internal irrotational flow with increased total pressure is discussed in the transonic small disturbance limit (this interaction occurs at the actuator disk, where flow properties change abruptly, and through the trailing-edge slipstream where significant velocity discontinuities are found). A simple, physically ratational and easily implementable numerical model requiring only minor modification to existing airfoil codes is developed for use in preliminary design.

This work expands on the author's earlier research. In Ref. 5, a finite length nacelle is immersed in a uniform, constant density potential flow; a radial parallel shear flow is assumed at the actuator disk, producing a rotational flow which interacts with the external flow through the downstream plume. This rotational flow was solved using a "superpotential" ϕ^*. Extended Cauchy-Riemann conditions for ϕ^* were inferred from a linearized disturbance streamfunction equation cast in conservation form; ϕ^* then satisfies a simple "potential-like" equation. Invariance properties of vorticity were next used to rewrite Bernoulli's equation so that wake pressure continuity could be expressed using jumps in ϕ^*. Finally, tangency conditions, expressed by normal derivatives, result in an easily implementable formulation (the general approach and numerical results for a strong shear appear in Ref. 5). This approach does not handle compressibility. In Ref. 6, a transonic irrotational freestream producing shock waves on the external nacelle surface was assumed; for simplicity, a radially uniform increase in total pressure was prescribed so that the internal flow remains potential. Reference 6 discusses the nontrivial details required to computationally match different potential equations referenced to different thermodynamic conditions and provides results of sample calculations.

When the latter work was completed and satisfactorily evaluated, it was evident that the complexities introduced to ensure thermodynamic consistency were not necessary in view of the small disturbance equation used. The aim then focused on a simple preliminary design tool employing approximations consistent with transonic small disturbance theory. The basic idea is simple. Airfoil analysis, for example, solves the same potential equation fore and aft of any calculated shocks, expanded about the same freestream Mach number, despite a discontinuous change in local Mach number; in our engine-nacelle problem, where the planar equation would be modified by an axisymmetric ϕ_r/r term, we will assume a change in reference Mach number through the actuator disk of, at most, the same order. The mathematical model is discussed next.

II. Analytical and Numerical Approach

Let $\phi_1(x,r)$ be the external disturbance potential, x and r being streamwise and radial coordinates, and, assuming a constant total pressure increase, let $\phi_2(x,r)$ represent the

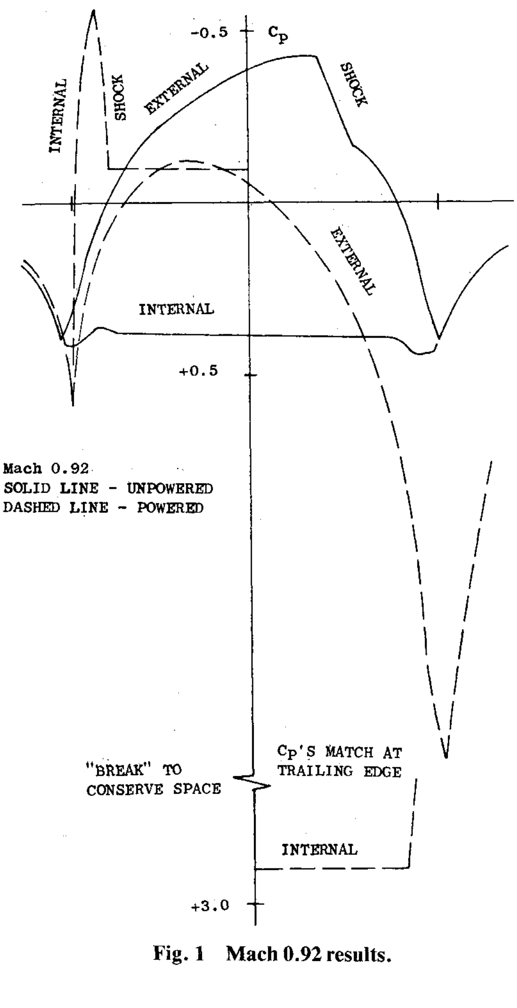

Fig. 1 Mach 0.92 results.

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internal powered plume flow downstream of the actuator disk. Under the conditions assumed, ϕ_1 and ϕ_2 satisfy the same $(1-M_\infty^2-M_\infty^2(\gamma+1)\phi_x)\phi_{xx}+\phi_{rr}+\phi_r/r=0$. For the external flow, $C_p=-2\phi_x$ is referenced to upstream conditions. For low-power levels, the internal C_p can also be referenced to the upstream dynamic head Q, so that $C_p=-2\phi_x+N$, NQ being the total pressure jump. Our approach assumes that power effects act primarily through slipstream boundary conditions rather than through changes in governing equation. This approach is simple because existing airfoil codes are modified easily. The matrix coefficients related to the differential equation need not be changed; in the difference algorithm used, the wake boundary condition $\phi_1(x,R)-\phi_2(x,R)=\phi_1(x_{te},R)-\phi_2(x_{te},R)-½N(x-x_{te})$ was applied on a mean radius R, x_{te} here referring to the trailing edge. This reduces to the usual relation for $N=0$. The nonlinear correction $N(1-M_\infty^2)(\phi_m(x_{te},R)-\phi_m(x_{te},R))/2$ to the right side, where $\phi_m=½(\phi_1+\phi_2)$, was also tested, and yielded no appreciable changes to results at transonic speeds. The derivatives ϕ_r and ϕ_{rr}, incidentally, were assumed to be continuous through the wake, so that explicit difference formulas are possible; this assumes small slipstream deflection angles consistently with small disturbance theory. The mean radius assumption, finally, is justifiable on one-dimensional grounds, because area (and, hence, radius) changes are only weakly dependent on changes in local Mach number; this and the use of fixed reference conditions in the differential equation place some restrictions on allowable pressure ratios.

III. Numerical Results and Closing Remarks

For simplicity, an external nacelle shape corresponding to a 10%-thick symmetric parabolic arc airfoil and an internal circular cylinder were used, with a chord-to-diameter ratio of 2. A coarse 60×60 constant mesh was taken, and two freestream Mach numbers, 0.92 and 0.98, were considered, in each case, assuming $N=0$ and a powered $N=3$ (large M_∞'s and N's were chosen to test numerical stability). Computed results should agree with this physical observation: engine power addition increases the mass flow passed by the nacelle, moving the inlet stagnation point from the inner toward the outer surface. Thus, the external shock present in the unpowered flow should disappear or reduce in strength in the powered case. This is seen from Figs. 1 and 2. The external shock present in the unpowered flows disappears completely with power addition; in both powered examples, the internal surface shows a localized and rapid inlet expansion peak terminated by a shock wave, indicating a stagnation point on the external surface that the fluid backs away from as it speeds supersonically into the engine face. This simple test problem, and several not reported here, show that the approach adopted here captures the basic feature of powered flows.

While we have considered here axisymmetric nacelles only, the basic ideas apply to three-dimensional flows as well, and may be useful in nacelle and wing interference studies. Again, as we have stressed throughout, our simplified approach applies only to small total pressure increases. Using different thermodynamic reference conditions would require the explicit use of actuator disk Fortran logic, plus additional matching conditions needed for the assumed disk model. Our column relaxation procedure, which "sweeps" through the disk from upstream to downstream without stopping, implicitly yields smooth and continuous ϕ_x's and ϕ_r's, the required pressure discontinuities appearing only when the converged $\phi(x,r)$ field is postprocessed using the respective C_p formulas. It is hoped that these early encouraging results will stimulate further research along these lines.

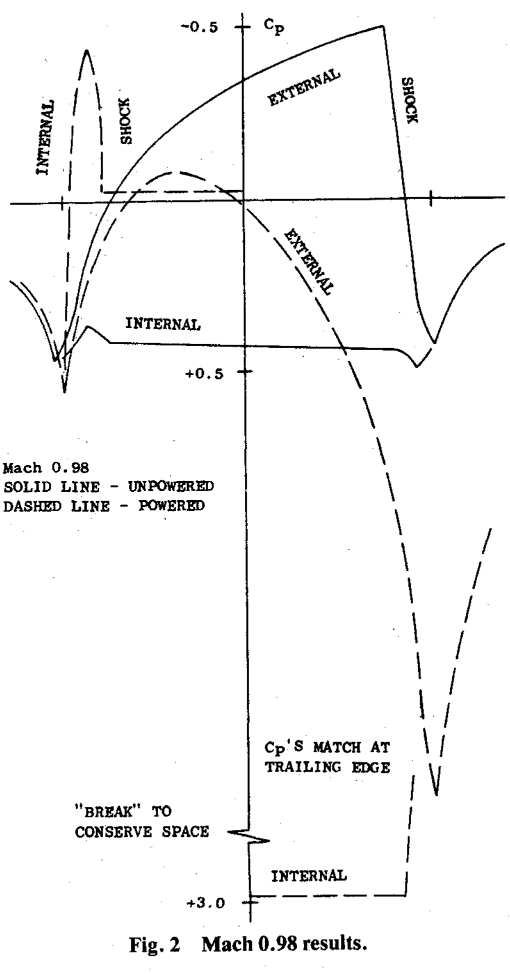

Fig. 2 Mach 0.98 results.

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Vibration of Triangular Plates

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Nomenclature

a,b,h	= fixed length, cantilever length, and thickness of plate
$\|D\|$	= flexural rigidity matrix
D	= flexural rigidity, $Eh^3/\|12(1-\nu^2)\|$

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