Engineering Notes

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Three-Dimensional Numerical and Experimental Flowfield Comparisons for Sphere-Cones

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RECENTLY, a unified three-dimensional flowfield code[1] was developed for Sandia Laboratory, Albuquerque, N.Mex., by General Applied Science Laboratories (GASL), Westbury, N.Y. This code and two others (one developed by GASL[2] for the Redstone Arsenal, Huntsville, Ala., and one developed at the NASA Ames Research Center[3]) have been used to compute flowfields around sphere-cones at nonzero angles of attack. This Note presents numerical results obtained with these three codes and compares them to available experimental data.

The Redstone[2] and NASA Ames[3] codes calculate the subsonic portion of the flow using an axisymmetric (zero angle of attack) coordinate system.† Thus, the calculation can be made using only one meridional plane. For the nose region, the Redstone code uses a Lax-Wendroff type finite-differencing scheme, and the NASA Ames code uses the inverse method, which limits its use to flows with Mach numbers $M > 4$. Both use a 3-dimensional method of characteristics for the afterbody flow, and compute the flowfield over a sphere-cone at angle of attack, α, by rotating the axisymmetric nose region flow α degrees before the 3-dimensional afterbody calculations are started.

The GASL-Sandia code is fully 3-dimensional and calculates both the subsonic nose region and the afterbody flow using a Lax-Wendroff type finite-difference scheme. The forebody solution equations are unsteady with respect to time. The afterbody solution uses a set of steady-state equations, and the solution marches along lines originating from the virtual tip of the cone. This code is useful to lower Mach numbers and is not restricted to spherical nose configurations as are the Redstone and NASA Ames codes. However, the latter two codes consume less computing time, since their nose region calculations can be completed using only one meridional plane. They can handle real equilibrium air, while the GASL-Sandia code is restricted to an ideal-gas model. The Redstone code (which is actually four codes run in series) can also include a simple uncoupled boundary layer.

Table 1 Comparison of codes

	GASL-Sandia[1]	Redstone[2]	NASA Ames[3]
Forebody calculations	3-dimensional unsteady, second-order scheme	Axisymmetric unsteady, second-order scheme	Axisymmetric inverse method
Afterbody calculations	Second-order numerical scheme, steady-state; marches in "R" direction	Method of characteristics	Method of characteristics
Type of gas	Ideal	Ideal and real equilibrium	Ideal and real equilibrium
Mesh points			
Forebody			
Meridional planes	6	1	1
Body to shock	5	5	11
Along body surface	10	10	27
Afterbody			
Meridional planes	7	11	7
Body to shock	11	13	15
Mach number lower limit	1.7	3	4
Time to run sample case on IBM 7094, minutes	60	42	40

Comparisons, Numerical and Experimental

Table 1 compares the three codes, and Fig. 1 compares results from them with experimental data from Ref. 4 for a sphere-cone with a cone half-angle of 15° at $M = 5.25$, $\alpha = 10°$, and a Reynolds number of 1.4×10^6. Parts a, b, and c of Fig. 1 show the surface pressure results for the windward, 90° and leeward meridional planes, respectively. Also obtained (but not displayed herein) were pressure distributions for $M = 10.6$ and shock shapes for both Mach numbers.

The largest percentage variation from the experimental data occurs in the surface pressures calculated on the leeward side. This should be expected, since none of the analyses include viscous effects.

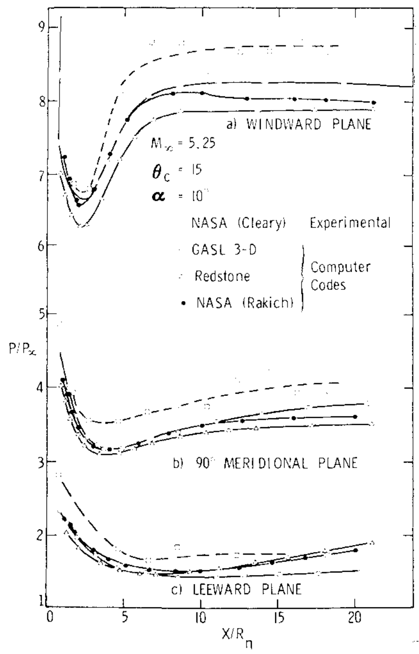

Fig. 1 Comparison of surface pressure distributions computed by the three codes with experimental results from Ref. 4.

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† Computations using the Redstone code[2] were done by B. Z. Jenkins of Redstone. Computations using the NASA Ames code[3] were done by J. V. Rakich.

The maximum error in surface pressure with respect to a mean drawn through Cleary's experimental data is less than 12%, and the computed shock shapes differ from one another by less than 5%.

References

[1] Moretti, G. et al., "Three-Dimensional Inviscid Flow About Supersonic Blunt Cones at Angle of Attack," SC-CR-68-3728, Sept. 1968, Sandia Corp., Albuquerque, N. Mex.

[2] Sanlorenzo, E. A. et al., "Flow Field Analysis of Reentry Configurations by a General Three-Dimensional Method of Characteristics," GASL-TR-247, Vol. III, April 1962, General Applied Science Lab., Westbury, N. Y.

[3] Rakich, J. V. and Cleary, J. W., "Theoretical and Experimental Study of Supersonic Steady Flow Around Inclined Bodies of Revolution," AIAA Paper 69-187, New York, 1969.

[4] Cleary, J. W., "An Experimental and Theoretical Investigation of the Pressure Distribution and Flow Fields of Blunted Cones at Hypersonic Mach Numbers," TN-D-2969, 1965, NASA.

Simulated Low-Gravity Sloshing in Spherical, Ellipsoidal, and Cylindrical Tanks

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Nomenclature

f_1 = first mode slosh natural frequency
g = gravity or equivalent linear axial acceleration
N_{BO} = Bond number, $\rho g R_o^2/\sigma$
R_o = radius of tank
ν,ρ = liquid kinematic viscosity and density
σ = surface tension

Introduction

Since the primary effect of reduced gravity on propellant sloshing is to accentuate the surface tension forces relative to the gravity forces in the body of the liquid, the Bond number, $N_{BO} = \rho g R_o^2/\sigma$, which is a measure of these two forces, is the correct indicator of "low-gravity" simulation. ($N_{BO} = 0$ indicates zero gravity, but $N_{BO} = 40$ is typical for large boosters even when gravity is only 10^{-5} of earth gravity.) Also, for $N_{BO} < 100$ simulations, the correct static contact contact angle of the free surface at the tank walls must be duplicated and contact angle "hysteresis" or "dynamic contact angle" accounted for.

Several methods of simulating low gravity using scale models have been advanced. In a *drop-tower*, the effective gravity acting on the liquid is reduced by allowing the experimental package to fall freely, see Ref. 1. In the *magneto-hydrodynamic* method, body forces generated in an electrically conducting liquid by crossed electric and magnetic fields are used to cancel gravity.[2] The *dielectrophoretic* method uses a strong electric field and a dielectric liquid to create body forces opposed to gravity.[2] The *magnetic fluid* method uses a specially prepared magnetic liquid and an axial magnetic field to cancel the gravitational forces.[2]

Most existing steady-state data have been obtained by using *ultra-small models*, see Ref. 3, since surface tension forces can be increased by decreasing the tank diameter. The two main difficulties of this simulation are 1) the small dynamic slosh force is difficult to measure, and 2) the viscous damping is large compared to the prototype; these difficulties generally limit the simulation to $N_{BO} > 10$, which, however, still includes most low-gravity missions to date. The data presented in this Note were obtained by this technique, which requires an extremely sensitive and accurate dynamometer-excitation system. (Slosh forces as small as 0.0005 lb had to be measured during tests.) In principle, the dynamometer-excitation package was similar to but much more sensitive than that used for much larger tanks. The force-measuring system is shown schematically in Fig. 1. Each sensing ele-

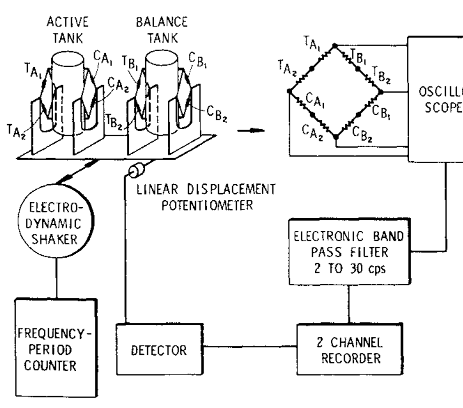

Fig. 1 Schemetic of slosh-force dynamometer.

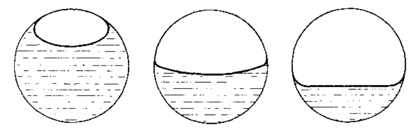

Fig. 2 Change in free-surface curvature with filling level, for equal bond numbers.

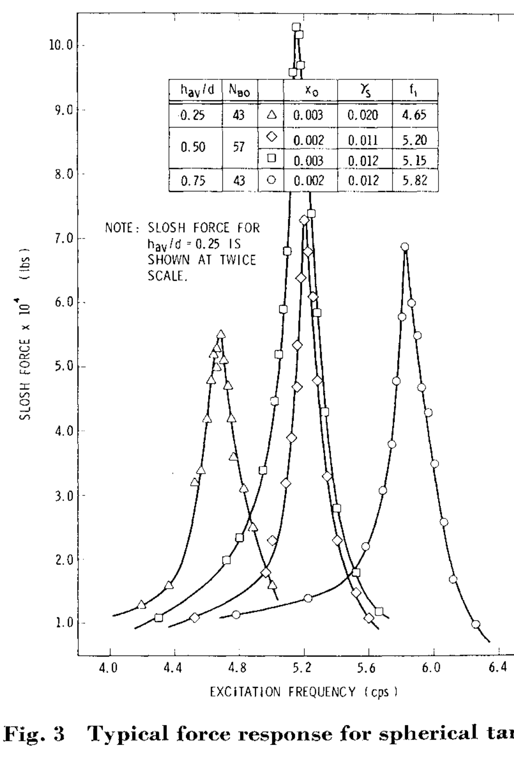

Fig. 3 Typical force response for spherical tanks.

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