M.I.T. Fluid Dynamics Research
Laboratory Report No. 67-3

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ABSTRACT

This report describes a computer code written in FORTRAN language code-named UNFLAVOR I. It computes the unsteady flow field around a body of revolution performing lateral oscillation by the method of small perturbation and method of characteristics. The nonlinear steady flow field upon which the present computation is derived is also computed by the method of characteristics.

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I. INTRODUCTION

This report describes a program code written in FORTRAN language for computing the unsteady supersonic flow field by the method of small perturbation. The theoretical development has been reported in Ref. 1. The steady flow field from which the unsteady flow is computed is furnished by another computer program reported in Ref. 2. At the starting line, the unsteady flow data must be supplied. These quantities can be obtained from the solution of an oscillating cone, which is reported in Ref. 3.

II. EQUATIONS FOR UNSTEADY PERTURBATIONS

The unknown quantities to be computed at a field point or at a body point are the following:

$$M_2^* \ , \ \theta_2 \ , \ M_{w_2}^* \ , \ \frac{S_2}{R} \ , \quad \text{and} \quad \left(\frac{\dot{h}_2}{\dot{h}_1}\right) \ .$$

There are five equations F1 through F5 or B1 through B5 from which the unknowns can be calculated. At a shock point, either primary or secondary, there is an additional unknown namely the amplitude of the shock motion y_2 to be determined and an additional equation is provided. The shock point equations are S1 through S6.

These equations listed in the following pages are written in the form suitable for the final iterations. The first approximation can be made by replacing the quantities at m,n at the right hand side by either quantities at m,n-1 or at m-1,n whichever is appropriate. The subscript 1 refers to the steady quantities which are already known from the steady flow solution. The subscript 2 refers to the unsteady quantities.

In the shock point equations, the subscript f refers to conditions before the shock and the subscript a refers to conditions behind the shock.

The point E is an upstream point from m,n. It is an intersection of the streamline from m,n and a characteristic line either from m,n-1 or from m-1,n. Values at point E are obtained by interpolations. Auxiliary quantities appeared in these equations are listed in separate sheets following these equations.

The unknowns in unsteady flow are all complex quantities. In actual computations, the subroutines should be written in complex operations, or the equations be separated into real and imaginary ones. The subroutines in the present program are written according to the latter procedure.

Field Point Equations:

$$M^*_{2mn} = \frac{1}{\left[\left(\frac{\cot\mu_1}{M_1^*}\right)_{m,n-\frac{1}{2}} + \left(\frac{\cot\mu_1}{M_1^*}\right)_{m-\frac{1}{2},n}\right]} \left\{ M^*_{2\,m,n-1}\left(\frac{\cot\mu_1}{M_1^*}\right)_{m,n-\frac{1}{2}} \right.$$

$$+ M^*_{2\,m-1,n}\left(\frac{\cot\mu_1}{M_1^*}\right)_{m-\frac{1}{2},n} + \theta_{2\,m-1,n} - \theta_{2\,m,n-1}$$

$$- \left[\cot\mu_1 A_1 \theta_2 + \frac{\cot\mu_1}{M_1^*} P_3 M_2^* + \frac{\cos\mu_1 \sin^2\mu_1}{\cos(\theta_1+\mu_1)} \frac{1}{\gamma R} \frac{dS_2}{dn_1}\right.$$

$$- \frac{\sin\mu_1}{\cos(\theta_1+\mu_1)} \frac{1}{y} \frac{M^*_{\omega_2}}{M_1^*} - \frac{\cos\mu_1}{\cos(\theta_1+\mu_1)} \frac{h_1^\circ}{V_1^2} \frac{d\left(\frac{h_2}{h_1^\circ}\right)}{dn_1} + \cot\mu_1 B_3 \frac{h_1^\circ}{V_1^2}\left(\frac{h_2^\circ}{h_1^\circ}\right)$$

$$\left. + \frac{\sin\mu_1}{\cos(\theta_1+\mu_1)} \frac{1}{M_1^*} \frac{i\omega}{\gamma a^*} \frac{S_2}{R}\right]_{m,n-\frac{1}{2}} \left(X_{m,n} - X_{m,n-1}\right)$$

$$+ \left[\cot\mu_1 A_2 \theta_2 - \frac{\cot\mu_1}{M_1^*} P_4 M_2^* + \frac{\cos\mu_1 \sin^2\mu_1}{\cos(\theta_1-\mu_1)} \frac{1}{\gamma R} \frac{dS_2}{dn_1}\right.$$

$$+ \frac{\sin\mu_1}{\cos(\theta_1-\mu_1)} \frac{1}{y} \frac{M^*_{\omega_2}}{M_1^*} - \frac{\cos\mu_1}{\cos(\theta_1-\mu_1)} \frac{h_1^\circ}{V_1^2} \frac{d}{dn_1}\left(\frac{h_2^\circ}{h_1^\circ}\right) - \cot\mu_1 B_4 \frac{h_1^\circ}{V_1^2}\left(\frac{h_2^\circ}{h_1^\circ}\right)$$

$$\left.\left. - \frac{\sin\mu_1}{\cos(\theta_1-\mu_1)} \frac{1}{M_1^*} \frac{i\omega}{\gamma a^*} \frac{S_2}{R}\right]_{m-\frac{1}{2},n} \left(X_{m,n} - X_{m-1,n}\right) \right\}$$

(F - 1)

$$\theta_{2\,m,n} = \theta_{2\,m-1,n} - \left(\frac{\cot\mu_1}{M_1^*}\right)_{m-\frac{1}{2},n} \left[M^*_{2\,m,n} - M^*_{2\,m-1,n}\right] + \left[\cot\mu_1 A_2 \theta_2\right.$$

$$- \frac{\cot\mu_1}{M_1^*} P_4 M_2^* + \frac{\cos\mu_1 \sin^2\mu_1}{\cos(\theta_1-\mu_1)} \frac{1}{\gamma R} \frac{dS_2}{dn_1} + \frac{\sin\mu_1}{\cos(\theta_1-\mu_1)} \frac{1}{y} \frac{M^*_{w_2}}{M_1^*}$$

$$- \frac{\cos\mu_1}{\cos(\theta_1-\mu_1)} \frac{h_1^\circ}{V_1^2} \frac{d}{dn_1}\left(\frac{h_2^\circ}{h_1^\circ}\right) - \cot\mu_1 B_4 \frac{h_1^\circ}{V_1^2}\left(\frac{h_2^\circ}{h_1^\circ}\right)$$

$$\left. - \frac{\sin\mu_1}{\cos(\theta_1-\mu_1)} \frac{1}{M_1^*} \frac{i\omega}{\gamma a^*} \frac{S_2}{R}\right]_{m-\frac{1}{2},n} (X_{m,n} - X_{m-1,n})$$

(F - 2)

Along the streamline:

$$M^*_{w_2\,m,n} = M^*_{w_{2}E} + \left\{ -\frac{1}{y}\left[M_2^* + \sin\theta_1 M^*_{w_2}\right] - \frac{i\omega}{a^*} \frac{M^*_{w_2}}{M_1^*} \right.$$

$$\left. + \frac{1}{y}\left[\frac{h_1^\circ}{a^{*2} M_1^*}\left(\frac{h_2^\circ}{h_1^\circ}\right) - \frac{M_1^* \sin\mu_1}{\gamma} \frac{S_2}{R}\right]\right\}_{\frac{1}{2}(E;\,m,n)} \times \Delta s$$

(F - 3)

$$\frac{S_{2\,m,n}}{R} = \frac{S_{2\,E}}{R} + \left\{ - \frac{i\omega}{a^* M_1^*} \frac{S_2}{R} - \theta_2 \frac{d}{dn_1}\left(\frac{S_1}{R}\right)\right\}_{\frac{1}{2}(E;\,m,n)} \times \Delta s$$

(F - 4)

$$\left(\frac{h_2^\circ}{h_1^\circ}\right)_{m,n} = \left(\frac{h_2^\circ}{h_1^\circ}\right)_E + \left\{ \frac{1}{\frac{h_1^\circ}{a^{*2}}} \left[- \frac{i\omega}{a^*}\left(M_2^* + \frac{M_1^* \sin^2\mu_1}{\gamma} \frac{S_2}{R}\right)\right]\right\}_{\frac{1}{2}(E;\,m,n)} \times \Delta s$$

(F - 5)

where

$$\Delta s = \left[(X_{m,n} - X_E)^2 + (y_{m,n} - y_E)^2\right]^{\frac{1}{2}}$$

Body Point Equations:

Along the characteristic line λ_{1b} :

$$M^*_{2\,m,n} = M^*_{2\,m-1,n} + \frac{1}{\left(\frac{\cot\mu_1}{M_1^*}\right)_{m-\frac{1}{2},n}} \Bigg\{ \theta_{2\,m-1,n} - \theta_{2\,m,n}$$

$$+ \Bigg[\cot\mu_1 A_2 \theta_2 - \cot\mu_1 P_4 \frac{M_2^*}{M_1^*} + \frac{\cos\mu_1 \sin^2\mu_1}{\cos(\theta_1-\mu_1)} \frac{1}{\gamma R} \frac{dS_2}{dn_1}$$

$$+ \frac{\sin\mu_1}{\cos(\theta_1-\mu_1)} \frac{1}{y} \frac{M^*_{w_2}}{M_1^*} - \frac{\cos\mu_1}{\cos(\theta_1-\mu_1)} \frac{h_1^\circ}{V_1^2} \frac{d}{dn_1}\left(\frac{h_2^\circ}{h_1^\circ}\right)$$

$$- \cot\mu_1 B_4 \frac{h_1^\circ}{V_1^2}\left(\frac{h_2^\circ}{h_1^\circ}\right) - \frac{\sin\mu_1}{\cos(\theta_1-\mu_1)} \frac{1}{M_1^*} \frac{i\omega}{\gamma a^*} \frac{S_2}{R} \Bigg]_{m-\frac{1}{2},n} \times$$

$$\left(X_{m,n} - X_{m-1,n}\right) \Bigg\} \qquad (B-1)$$

Along the body surface:

$$\theta_2 = \cos^2\theta_{1b}\, y'_{1b}\, \delta_{2b} + \frac{i\omega\,\delta_{2b}}{M_1^* a^*} \cos\theta_{1b} - \delta_{2b} \frac{\partial\theta_1}{\partial y} \qquad (B-2)$$

$$M^*_{w_2\,m,n} = M^*_{w_2\,m-1,n-1} + \Bigg\{ -\frac{1}{y}\left[M_2^* + \sin\theta_1 M^*_{w_2}\right] - \frac{i\omega}{a^*} \frac{M^*_{w_2}}{M_1^*}$$

$$+ \frac{1}{y}\left[\frac{h_1^\circ}{a^{*2} M_1^*}\left(\frac{h_2^\circ}{h_1^\circ}\right) - \frac{M_1^* \sin\mu_1}{\gamma} \frac{S_2}{R}\right] \Bigg\}_{m-\frac{1}{2},\, n-\frac{1}{2}} \times \Delta s$$

$$(B-3)$$

$$\frac{S_{2\,m,n}}{R} = \frac{S_{2\,m-1,n-1}}{R} + \left\{ -\frac{i\omega}{a^* M_1^*}\frac{S_2}{R} - \theta_2 \frac{d}{dn_1}\left(\frac{S_2}{R}\right)\right\}_{m-\frac{1}{2},n-\frac{1}{2}} \times \Delta s$$

(B - 4)

$$\left(\frac{\dot{h}_2}{\dot{h}_1}\right)_{m,n} = \left(\frac{\dot{h}_2}{\dot{h}_1}\right)_{m-1,n-1} + \left\{\frac{1}{\frac{\dot{h}_1}{a^{*2}}}\left[-\frac{i\omega}{a^*}\left(M_2^* + \frac{M_1^* \sin^2\mu_1}{\gamma}\frac{S_2}{R}\right)\right]\right\}_{m-\frac{1}{2},n-\frac{1}{2}} \times \Delta s$$

(B - 5)

where

$$\Delta s = \left[(x_{m,n} - x_{m-1,n-1})^2 + (y_{m,n} - y_{m-1,n-1})^2 \right]^{\frac{1}{2}}$$

Shock Point Equations:

Along the characteristic line λ_{1a}:

$$M^*_{2_{m,n}} = M^*_{2_{m,n-1}} + \frac{1}{\left(\frac{\cot\mu_1}{M^*_1}\right)_{m,n-\frac{1}{2}}} \Bigg\{ \theta_{2_{m,n}} - \theta_{2_{m,n-1}}$$

$$- \Bigg[\cot\mu_1 A_1 \theta_2 + \cot\mu_1 P_3 \frac{M^*_2}{M^*_1} + \frac{\cos\mu_1 \sin^2\mu_1}{\cos(\theta_1+\mu_1)} \frac{1}{\gamma R} \frac{dS_2}{dn_1}$$

$$- \frac{\sin\mu_1}{\cos(\theta_1+\mu_1)} \frac{1}{y} \frac{M^*_{w_2}}{M^*_1} - \frac{\cos\mu_1}{\cos(\theta_1+\mu_1)} \frac{h^\circ_1}{V_1^2} \frac{d}{dn_1}\left(\frac{h^\circ_2}{h^\circ_1}\right)$$

$$+ \cot\mu_1 B_3 \frac{h^\circ_1}{V_1^2}\left(\frac{h^\circ_2}{h^\circ_1}\right) + \frac{\sin\mu_1}{\cos(\theta_1+\mu_1)} \frac{1}{M^*_1} \frac{i\omega}{\gamma a^*} \frac{S_2}{R} \Bigg]_{m,n-\frac{1}{2}} \times$$

$$\left(X_{m,n} - X_{m,n-1}\right) \Bigg\} \qquad (S-1)$$

Conditions across the shock at point m,n:

$$M^*_{w_2} = M_{w_{2f}} + \left[M^*_{1a} \sin\theta_{1a} - M^*_{1f} \sin\theta_{1f} \right] \frac{y_2}{y_1}$$

$$(S-2)$$

$$M_{2a}^* = M_{2f}^* \cos(\theta_{1a} - \theta_{1f}) + \theta_{2f} M_{1f}^* \sin(\theta_{1a} - \theta_{1f})$$

$$+ y_2 \left[\frac{\partial M_{1f}^*}{\partial y} \cos(\theta_{1a} - \theta_{1f}) + M_{1f}^* \frac{\partial \theta_{1f}}{\partial y} \sin(\theta_{1a} - \theta_{1f}) \right]$$

$$+ \frac{2}{\gamma+1} \left[1 + \frac{1}{M_{1fn}^2} \right] \Big\{ \sin(\epsilon - \theta_{1a}) \left[- M_{2f}^* \sin(\epsilon - \theta_{1f}) + \theta_{2f} M_{1f}^* \cos(\epsilon - \theta_{1f}) \right]$$

$$+ \sin(\epsilon - \theta_{1a})\, y_2 \left[- \frac{\partial M_{1f}^*}{\partial y} \sin(\epsilon - \theta_{1f}) + M_{1f}^* \frac{\partial \theta_{1f}}{\partial y} \cos(\epsilon - \theta_{1f}) \right]$$

$$+ \cos^2 \epsilon \sin(\theta_{1a} - \theta_{1f}) M_{1f}^* y_2' - \cos\epsilon \sin(\epsilon - \theta_{1a}) \frac{i\omega}{a^*} y_2 \Big\}$$

$$- \frac{4}{\gamma+1} \cos^2\epsilon \cos(\epsilon - \theta_{1a}) \sin(\epsilon - \theta_{1f}) M_{1f}^* y_2'$$

$$- \frac{4}{\gamma+1} \frac{\left(\frac{a_{1f}}{a^*}\right)^2 \frac{a_{2f}}{a_{1f}}}{M_{1f}^* \sin(\epsilon - \theta_{1f})} \sin(\epsilon - \theta_{1a}) - y_2 \frac{\partial M_{1a}^*}{\partial y}$$

$$+ \frac{2(\gamma-1)}{\gamma+1} \frac{1}{M_{1f}^* \sin(\epsilon - \theta_{1f})} \sin(\epsilon - \theta_{1a})\, y_2\, M_{1f}^* \frac{\partial M_{1f}^*}{\partial y} \qquad (S-3)$$

where

$$M_{1fn}^2 = \left(\frac{V_{1fn}}{a_{1f}}\right)^2 = \left[\frac{V_{1f} \sin(\epsilon - \theta_{1f})}{a_{1f}}\right]^2 = \frac{M_{1f}^{*2} \sin^2(\epsilon - \theta_{1f})}{\frac{\gamma+1}{2} - \frac{\gamma-1}{2} M_{1f}^{*2}}$$

$$\left(\frac{a_{1f}}{a^*}\right)^2 = \frac{\gamma+1}{2} - \frac{\gamma-1}{2} M_{1f}^{*2}$$

$$\frac{a_{2f}}{a_{1f}} = \frac{h_{2f}}{2 h_{1f}} = \frac{1}{1 - \frac{\gamma-1}{\gamma+1} M_{1f}^{*2}} \left[\frac{h_{2f}^\circ}{h_{1f}^\circ} - \frac{2(\gamma-1)}{\gamma+1} \frac{M_{2f}^*}{M_{1f}^*} M_{1f}^{*2} \right]$$

$$
\begin{aligned}
M_{1a}^{*}\,\theta_{2a} = & - M_{2f}^{*}\sin(\theta_{1a}-\theta_{1f}) + \theta_{2f}\,M_{1f}^{*}\cos(\theta_{1a}-\theta_{1f}) \\
& + y_2\left[-\frac{\partial M_{1f}^{*}}{\partial y}\sin(\theta_{1a}-\theta_{1f}) + M_{1f}^{*}\frac{\partial \theta_{1f}}{\partial y}\cos(\theta_{1a}-\theta_{1f})\right] \\
& + \frac{2}{\gamma+1}\left[1+\frac{1}{M_{1fn}^{2}}\right]\Big\{\cos(\epsilon-\theta_{1a})\left[M_{2f}^{*}\sin(\epsilon-\theta_{1f}) - \theta_{2f}\,M_{1f}^{*}\cos(\epsilon-\theta_{1f})\right] \\
& + \cos(\epsilon-\theta_{1a})\,y_2\left[\frac{\partial M_{1f}^{*}}{\partial y}\sin(\epsilon-\theta_{1f}) - M_{1f}^{*}\frac{\partial \theta_{1f}}{\partial y}\cos(\epsilon-\theta_{1f})\right] \\
& + \cos^2\epsilon\,\cos(\theta_{1a}-\theta_{1f})\,M_{1f}^{*}\,y_2' + \cos\epsilon\,\cos(\epsilon-\theta_{1a})\,\frac{i\omega}{a^*}\,y_2\Big\} \\
& - \frac{4}{\gamma+1}M_{1f}^{*}\,y_2'\cos^2\epsilon\,\sin(\epsilon-\theta_{1f})\sin(\epsilon-\theta_{1a}) \\
& - \frac{4}{\gamma+1}\,\frac{\left(\frac{a_{1f}}{a^*}\right)^2\frac{a_{2f}}{a_{1f}}}{M_{1f}^{*}\sin(\epsilon-\theta_{1f})}\cos(\epsilon-\theta_{1a}) - y_2\,M_{1a}^{*}\frac{\partial \theta_{1a}}{\partial y} \\
& + \frac{2(\gamma-1)}{\gamma+1}\,\frac{1}{M_{1f}^{*}\sin(\epsilon-\theta_{1f})}\cos(\epsilon-\theta_{1a})\,y_2\,M_{1f}^{*}\frac{\partial M_{1f}^{*}}{\partial y}
\end{aligned}
$$

(S - 4)

$$\frac{S_{2a}}{R} = \frac{1}{\gamma-1}\left[\frac{\left(\frac{p_a}{p_f}\right)_2}{\left(\frac{p_a}{p_f}\right)_1}\right]_{(ip)} - \frac{\gamma}{\gamma-1}\left[\frac{\left(\frac{\rho_a}{\rho_f}\right)_2}{\left(\frac{\rho_a}{\rho_f}\right)_1}\right]_{(ip)} + \frac{S_{2f}}{R}$$

$$+ y_2 \frac{1}{R}\left[\frac{\partial S_{1f}}{\partial y} - \frac{\partial S_{1a}}{\partial y}\right] \qquad (S-5)$$

where

$$\left[\frac{\left(\frac{p_a}{p_f}\right)_2}{\left(\frac{p_a}{p_f}\right)_1}\right]_{(ip)} = \left[\frac{2\gamma}{\gamma+1}\,\frac{2M_{1f}^{*2}}{\gamma+1-(\gamma-1)M_{1f}^{*2}}\sin^2(\epsilon-\theta_{1f}) - \frac{\gamma-1}{\gamma+1}\right]^{-1} \times$$

$$\times \frac{4\gamma}{\gamma+1}\,\frac{2M_{1f}^{*2}}{\gamma+1-(\gamma-1)M_{1f}^{*2}}\sin^2(\epsilon-\theta_{1f})\left\{\cos^2\epsilon\cot(\epsilon-\theta_{1f})\,y_2'\right.$$

$$+ \frac{M_{2f}^*}{M_{1f}^*} - \theta_{2f}\cot(\epsilon-\theta_{1f}) + \frac{\cos\epsilon}{M_{1f}^*\sin(\epsilon-\theta_{1f})}\,\frac{i\omega}{a^*}\,y_2$$

$$\left. - \frac{a_{2f}}{a_{1f}} + y_2\left(\frac{a_*}{a_{1f}}\right)^2\frac{\gamma-1}{2}\,M_{1f}^*\,\frac{\partial M_{1f}^*}{\partial y}\right\}$$

$$\left[\frac{\left(\frac{\rho_a}{\rho_f}\right)_2}{\left(\frac{\rho_a}{\rho_f}\right)_1}\right]_{(ip)} = -\,\frac{2\left(1-\frac{\gamma-1}{\gamma+1}M_{1f}^{*2}\right)}{1-\frac{\gamma-1}{\gamma+1}M_{1f}^{*2}\cos^2(\epsilon-\theta_{1f})} \times$$

$$\times\left\{\frac{M_{2f}^*}{M_{1f}^*} - \theta_{2f}\cot(\epsilon-\theta_{1f}) - \frac{\cos\theta_{1f}}{\sin(\epsilon-\theta_{1f})}\,y_2'\right.$$

$$- \frac{\cos\epsilon}{M_{1f}^*\sin(\epsilon-\theta_{1f})}\,\frac{i\omega\,y_2}{a^*} + \frac{a_{2f}}{a_{1f}} - y_2\left(\frac{a^*}{a_{1f}}\right)^2\frac{\gamma-1}{2}\,M_{1f}^*\,\frac{\partial M_{1f}^*}{\partial y}$$

$$\left. + \cos\epsilon\,\sin\epsilon\; y_2'\right\}$$

$$\left(\frac{h^{\circ}_{2a}}{h^{\circ}_{1a}}\right) = \left(1 - \frac{\gamma-1}{\gamma+1} M^{*2}_{1a}\right)\left\{ \left[\frac{\left(\frac{p_a}{p_f}\right)_2}{\left(\frac{p_a}{p_f}\right)_1}\right]_{(ip)} - \left[\frac{\left(\frac{\rho_a}{\rho_f}\right)_2}{\left(\frac{\rho_a}{\rho_f}\right)_1}\right]_{(ip)} \right\}$$

$$+ \frac{1 - \frac{\gamma-1}{\gamma+1} M^{*2}_{1a}}{1 - \frac{\gamma-1}{\gamma+1} M^{*2}_{1f}} \left[\left(\frac{h^{\circ}_{2f}}{h^{\circ}_{1f}} - \frac{2(\gamma-1)}{(\gamma+1)} M^{*}_{1f} M^{*}_{2f} \right]$$

$$+ \frac{2(\gamma-1)}{\gamma+1} y_2 \left[\frac{1 - \frac{\gamma-1}{\gamma+1} M^{*2}_{1a}}{1 - \frac{\gamma-1}{\gamma+1} M^{*2}_{1f}} M^{*}_{1f} \frac{\partial M^{*}_{1f}}{\partial y} - M^{*}_{1a} \frac{\partial M^{*}_{1a}}{\partial y} \right]$$

$$+ \frac{2(\gamma-1)}{(\gamma+1)} M^{*}_{1a} M^{*}_{2a} \qquad \text{(S - 6)}$$

Definitions of Auxiliary Quantities:

$$A_1 = \tan\mu_1 \frac{\cos(\theta_1-\mu_1)}{\cos(\theta_1+\mu_1)} \frac{1}{y_1} + \frac{\sin^4\mu_1}{\cos\mu_1 \cos(\theta_1+\mu_1)} \frac{1}{\gamma R} \frac{dS_1}{dn_1}$$

$$- \frac{\sin\mu_1}{\cos(\theta_1+\mu_1)} \frac{i\omega}{M_1^* a^*} - \frac{\cos(\theta_1-\mu_1)}{\cos\mu_1 \sin\mu_1 \cos(\theta_1+\mu_1)} \frac{1}{M_1^*} \left(\frac{dM_1^*}{dx}\right)_{\lambda 1b}$$

$$- \frac{\sin^2\mu_1}{\cos\mu_1 \cos(\theta_1+\mu_1)} \frac{1}{V_1^2} \frac{dh_1^\circ}{dn_1}$$

$$P_1 = \frac{1}{M_1^*}\left(\frac{dM_1^*}{dx}\right)_{\lambda 1a}\left(\frac{T}{\cos^2\mu_1} - 1\right) - T \frac{2\sin^3\mu_1}{\cos(\theta_1+\mu_1)} \frac{1}{\gamma R} \frac{dS_1}{dn_1}$$

$$+ \frac{2\sin\mu_1}{\cos(\theta_1+\mu_1)} \frac{1}{V_1^2} \frac{dh_1^\circ}{dn_1} + T \frac{\cos(\theta_1-\mu_1)}{\cos^2\mu_1 \cos(\theta_1+\mu_1)} \frac{1}{M_1^*}\left(\frac{dM_1^*}{dx}\right)_{\lambda 1b}$$

$$+ \frac{1}{\cos\mu_1 \cos(\theta_1+\mu_1)} \frac{i\omega}{M_1^* a^*}$$

$$A_2 = \tan\mu_1 \frac{\cos(\theta_1+\mu_1)}{\cos(\theta_1-\mu_1)} \frac{1}{y_1} - \frac{\sin^4\mu_1}{\cos\mu_1 \cos(\theta_1-\mu_1)} \frac{1}{\gamma R} \frac{dS_1}{dn_1}$$

$$+ \frac{\sin\mu_1}{\cos(\theta_1-\mu_1)} \frac{i\omega}{M_1^* a^*} - \frac{\cos(\theta_1+\mu_1)}{\cos\mu_1 \sin\mu_1 \cos(\theta_1-\mu_1)} \frac{1}{M_1^*}\left(\frac{dM_1^*}{dy}\right)_{\lambda 1a}$$

$$+ \frac{\sin^2\mu_1}{\cos\mu_1 \cos(\theta_1-\mu_1)} \frac{1}{V_1^2} \frac{dh_1^\circ}{dn_1}$$

$$P_2 = \frac{1}{M_1^*}\left(\frac{dM_1^*}{dx}\right)_{\lambda 1b}\left[\frac{T}{\cos^2\mu_1} - 1\right] + T\,\frac{2\sin^3\mu_1}{\cos(\theta_1-\mu_1)}\,\frac{1}{\gamma R}\,\frac{ds_1}{dn_1}$$

$$- \frac{2\sin\mu_1}{\cos(\theta_1-\mu_1)}\,\frac{1}{V_1^2}\,\frac{dh_1^\circ}{dn_1} + T\,\frac{\cos(\theta_1+\mu_1)}{\cos^2\mu_1\cos(\theta_1-\mu_1)}\,\frac{1}{M_1^*}\left(\frac{dM_1^*}{dx}\right)_{\lambda 1a}$$

$$+ \frac{1}{\cos\mu_1\cos(\theta_1-\mu_1)}\,\frac{i\omega}{M_1^* a^*}$$

$$T = 1 + \frac{\gamma-1}{2\sin^2\mu_1} = \frac{h_1^\circ}{h_1}$$

$$B_1 = -\frac{\gamma-1}{\gamma R}\,\frac{\sin\mu_1}{\cos(\theta_1+\mu_1)}\,\frac{ds_1}{dn_1} + \frac{\gamma-1}{2\sin^2\mu_1\cos^2\mu_1}\,\frac{1}{M_1^*}\left(\frac{dM_1^*}{dx}\right)_{\lambda 1a}$$

$$+ \frac{\gamma-1}{2\sin^2\mu_1\cos^2\mu_1}\,\frac{\cos(\theta_1-\mu_1)}{\cos(\theta_1+\mu_1)}\,\frac{1}{M_1^*}\left(\frac{dM_1^*}{dx}\right)_{\lambda 1b}$$

$$B_2 = \frac{\gamma-1}{\gamma R}\,\frac{\sin\mu_1}{\cos(\theta_1-\mu_1)}\,\frac{ds_1}{dn_1} + \frac{\gamma-1}{2\sin^2\mu_1\cos^2\mu_1}\,\frac{1}{M_1^*}\left(\frac{dM_1^*}{dx}\right)_{\lambda 1b}$$

$$+ \frac{\gamma-1}{2\sin^2\mu_1\cos^2\mu_1}\,\frac{\cos(\theta_1+\mu_1)}{\cos(\theta_1-\mu_1)}\,\frac{1}{M_1^*}\left(\frac{dM_1^*}{dx}\right)_{\lambda 1a}$$

$$P_3 = P_1 + \frac{1}{\cos\mu_1\cos(\theta_1+\mu_1)}\,\frac{i\omega}{M_1^* a^*}$$

$$P_4 = P_2 + \frac{1}{\cos\mu_1\cos(\theta_1-\mu_1)}\,\frac{i\omega}{M_1^* a^*}$$

$$B_3 = B_1 - \frac{1}{\cos\mu_1\cos(\theta_1+\mu_1)}\,\frac{i\omega}{M_1^* a^*}$$

$$B_4 = B_2 - \frac{1}{\cos\mu_1\cos(\theta_1-\mu_1)}\,\frac{i\omega}{M_1^* a^*}$$

$$\frac{h_1^0}{V_1^2} = \frac{1}{2} + \frac{\sin^2\mu_1}{\gamma - 1}$$

$$\frac{h_1}{V_1^2} = \frac{a_1^2}{\gamma - 1}\frac{1}{V_1^2} = \frac{\sin^2\mu_1}{\gamma - 1}$$

III. DESCRIPTION OF THE COMPUTER PROGRAM

The computer program consists of a main program and six subroutines. The function of each program is described below.

1) Main program

The main program controls the process of computation. The logical order of this program follows that of the steady state program. The points are computed in the same order as the steady case. When a point is to be computed, the identification code is first tested. According to the code, it is identified as a field point, body point or a shock point. The appropriate subroutines are then called when they are needed.

2) Subroutine FIELD

This subroutine computes the unsteady unknown quantities at a field point.

3) Subroutine BODY

This subroutine computes the unsteady unknowns at a body point.

4) Subroutine OUSHOK

This subroutine computes the unsteady unknowns at a outer shock point. The unsteady shock slope is also computed.

5) Subroutine STAR

This subroutine computes the coefficients $A_1, A_2, B_3, B_4, P_3, P_4$.

6) Subroutine PRESSD

This subroutine calculates and prints the pressure ratio and the density ratio.

7) Subroutine Print

This subroutine prints the results

IV. LISTING OF THE COMPLETE PROGRAM

The complete program is listed in the following pages.

```
C --- DR. P.T.HSU    H. MC CALLUM    MIT EXT. 2430   ---
C --- AIRLOAD DUE TO SMALL LATERAL OSCILLATIONS OF A BODY OF REVOLUTION-
C ---   IN SUPERSONIC FLIGHT ---
C --- U N F L A V O R  I    UNSTEADY STATE PROGRAM  ---
C --- ALLOWS FOR SMOOTH CORNERS AND EXPANSION CORNERS IN THE BODY ---
C --- PROVIDES FOR CONTINUATION RUN ---
C --- USES LOGICAL TAPE ITAPE AND NTAPE FOR INPUT AND OUTPUT ---
C --- USES TWO USER TAPES - LOGICAL KTAPE AND LTAPE ---
C --- FORTRAN II PROGRAM ---
      DIMENSION BSHAPE(8,21),STARPT(11,100),POINT(37,150),TEMP1(37),
     1  TEMP2(37),SHAPE(3,3),BMTION(21),HALFPT(37),TEXP(37)
     2,FSHOK(28),DML(2)
      COMMON NTAPE
      TPOLTF(Y1,Y2)=FACT*(Y2-Y1)+Y1
      ITAPE= 4
      NTAPE= 2
      KTAPE= 9
      LTAPE=10
      WRITE OUTPUT TAPE NTAPE, 900
B     SHAPE(1,1)=626351213127
B     SHAPE(2,1)=306360433145
B     SHAPE(3,1)=256060606060
B     SHAPE(1,2)=472151212246
B     SHAPE(2,2)=432160606060
B     SHAPE(3,2)=606060606060
B     SHAPE(1,3)=462731652560
B     SHAPE(2,3)=606060606060
B     SHAPE(3,3)=606060606060
      READ INPUT TAPE ITAPE, 901, NSEGS,NSTPTS,NCOEFS,NOP1
      READ INPUT TAPE ITAPE, 902, GAMA,R,EMI,THETAC,OMA
       READ INPUT TAPE ITAPE,902,R2SR,R2SI
      GP=GAMA+1.0
      GM=GAMA-1.0
      GR=1.0/(GAMA*R)
      GROMA=GR*OMA
       GRAT=GM/GP
      WRITE OUTPUT TAPE NTAPE, 903, NSEGS,NSTPTS,GAMA,R,EMI,THETAC,OMA
C --- READ AND PRINT BODY SHAPE INFORMATION ---
      NCORNS=NSEGS+1
      READ INPUT TAPE ITAPE, 904, ((BSHAPE(I,NSEG),I=1,5),NSEG=1,
     1 NCORNS)
      WRITE OUTPUT TAPE NTAPE, 905
      DO 10 NSEG=1,NSEGS
      ID=BSHAPE(1,NSEG)+.5
      WRITE OUTPUT TAPE NTAPE, 906, NSEG,(SHAPE(I,ID),I=1,3),(BSHAPE(I,
     1 NSEG),I=2,5)
 10   CONTINUE
      WRITE OUTPUT TAPE NTAPE, 907, (BSHAPE(I,NCORNS),I=2,3)
C --- READ AND PRINT BODY MOTION INFORMATION ---
      NC=2*NCOEFS
      READ INPUT TAPE ITAPE, 908, (BMTION(I),I=1,NC)
      WRITE OUTPUT TAPE NTAPE, 909, (BMTION(I),I=1,NC)
      READ INPUT TAPE ITAPE, 910, ((STARPT(I,N),I=1,11),N=1,NSTPTS)
      WRITE OUTPUT TAPE NTAPE, 911
       READ INPUT TAPE ITAPE,902,(FSHOK(I),I=4,6),(FSHOK(I),I=9,18)
       SM=FSHOK(4)**2
       TERM=GM*SM
       FSHOK(1)=TERM/GP
       FSHOK(2)=1.-FSHOK(1)
       FSHOK(3)=4.*GAMA*SM/(GP*(GP-TERM))
```

```
      FSHOK(19)=FSHOK(13)/FSHOK(4)
      FSHOK(20)=FSHOK(14)/FSHOK(4)
      FSHOK(21)=.5*(GP-TERM)
      FSHOK(22)=SM/FSHOK(21)
      FSHOK(7)=(FSHOK(17)-2.*FSHOK(1)*FSHOK(19))/FSHOK(2)
      FSHOK(8)=(FSHOK(18)-2.*FSHOK(1)*FSHOK(20))/FSHOK(2)
      FSHOK(23)=FSHOK(4)*FSHOK(9)
      FSHOK(24)=FSHOK(4)*FSHOK(10)
      FSHOK(25)=4.*FSHOK(21)*FSHOK(7)/(GP*FSHOK(4))
      FSHOK(26)=4.*FSHOK(21)*FSHOK(8)/(GP*FSHOK(4))
      FSHOK(27)=FSHOK(4)*SINF(FSHOK(6))
      FSHOK(28)=COSF(FSHOK(6))
      JGO=1
C --- INITIALIZATION ---
      REWIND KTAPE
      REWIND LTAPE
      IEND=0
      N=0
      IH=0
      IF (NOP1) 11,14,11
C --- FOR CONTINUATION RUN ---
 11   READ INPUT TAPE ITAPE, 901, NCONT
 12   READ TAPE KTAPE, (TEMP2(I),I=1,8)
      READ TAPE LTAPE, N,M,(POINT(I,M),I=1,37)
      IF (N-NCONT+1) 12,13,13
 13   ID=POINT(1,M)+.5
      IF (ID-2) 12,14,12
C --- READ NEXT POINT FROM STEADY STATE TAPE ---
 14   READ TAPE KTAPE, (TEMP2(I),I=1,8)
      GO TO (145,140),JGO
  140 JGO=1
      DML(2)=(TEMP2(4)-STARM)/(STARM*(TEMP2(2)-STARM))
      CALL STAR(POINT(1,1),GR,GM,OMA,DML)
  145 CONTINUE
      ID=TEMP2(1)+.5
      IF (ID) 48,45,15
 15   GO TO (22,26,48,33,16,30,38,38,38,48),ID
C --- STARTING POINT ---
 16   N=N+1
      M=1
      IF (ABSF(TEMP2(2)-STARPT(11,N))-1.0E-6) 161,161,50
 161  DO 17 I=1,10
      TEMP2(I+8)=STARPT(I,N)
 17   CONTINUE
      NCC=NCOEFS-1
      DO 1703 I=1,2
      TEMP2(I+18)=BMTION(I)
      IF (NCC) 1703,1703,1700
 1700 K=I
      DO 1702 J=1,NCC
      K=K+2
      TEMP2(I+18)=TEMP2(I+18)+BMTION(K)*TEMP2(2)**J
 1702 CONTINUE
 1703 CONTINUE
      ID=TEMP2(1)+.05
      IF (ID-4) 1705,1704,1705
 1704 TEMP2(19)=R2SR
      TEMP2(20)=R2SI
 1705 CONTINUE
C---TO DEFINE DERIVATIVES FOR STARTING POINT---
```

```
      IF (N-1) 170,170,172
  170 DO 171 J=33,37
  171 TEMP2(J)=0.
      JGO=1
      DML(1)=0.
      DML(2)=0.
      CALL STAR(TEMP2,GR,GM,OMA,DML)
      STARX=TEMP2(2)
      STARS=TEMP2(5)
      STARM=TEMP2(4)
      GO TO 179
  172 DENOM=(TEMP2(2)-STARX)*SINF(TEMP2(7))/COSF(TEMP2(7)+TEMP2(6))
      TEMP2(33)=(TEMP2(5)-STARS)/DENOM
      TEMP2(34)=(TEMP2(11)-STARPT(3,N-1))/DENOM
      TEMP2(35)=(TEMP2(12)-STARPT(4,N-1))/DENOM
      TEMP2(36)=(TEMP2(17)-STARPT(9,N-1))/DENOM
      TEMP2(37)=(TEMP2(18)-STARPT(10,N-1))/DENOM
      DML(1)=(TEMP2(4)-STARM)/(TEMP2(4)*(TEMP2(2)-STARX))
      STARX=TEMP2(2)
      STARM=TEMP2(4)
      STARS=TEMP2(5)
      JGO=2
  179 CONTINUE
      CALL PRINT (N,M,TEMP2)
      WRITE TAPE LTAPE, N,M,(TEMP2(I),I=1,37)
      IF (N-1) 18,18,20
 18   DO 19 I=1,37
      POINT(I,1)=TEMP2(I)
 19   CONTINUE
      CALL PRESSD (GM,GP,GAMA,R,EMI,TEMP2)
      GO TO 14
C --- UPDATE MEMORY ---
 20   DO 21 I=1,37
      TEMP1(I)=TEMP2(I)
 21   CONTINUE
      MP=1
      GO TO 14
C --- FIELD POINT ---
 22   M=M+1
      IF (M-150) 23,23,49
 23   MP=MP+1
      ID=POINT(1,MP)+.5
      IF (ID-7) 24,41,231
 231  IF (ID-9) 43,43,48
 24   CALL FIELD (POINT(1,MP),TEMP1,POINT(1,MP-1),TEMP2,GM,GR,OMA,
     1  GROMA)
C --- UPDATE MEMORY ---
      DO 25 I=1,37
      POINT(I,M-1)=TEMP1(I)
      TEMP1(I)=TEMP2(I)
 25   CONTINUE
      CALL PRINT (N,M,TEMP2)
      WRITE TAPE LTAPE, N,M,(TEMP2(I),I=1,37)
      GO TO 14
C --- BODY POINT ---
 26   IF (N) 16,16,27
 27   M=M+1
      IF (M-150) 28,28,49
 28   MP=MP+1
      CALL BODY (TEMP1,POINT(1,MP-1),TEMP2,BMTION,GR,GM,OMA,GROMA,
```

```
      1  NCOEFS)
C --- UPDATE MEMORY ---
      DO 29 I=1,37
      POINT(I,M-1)=TEMP1(I)
      POINT(I,M)=TEMP2(I)
 29   CONTINUE
 291  CALL PRINT (N,M,TEMP2)
      WRITE TAPE LTAPE, N,M,(TEMP2(I),I=1,37)
      IH=0
      CALL PRESSD (GM,GP,GAMA,R,EMI,TEMP2)
      IF (IEND) 47,14,47
C --- HALFWAY POINT ---
 30   IH=1
      MP=1
      DO 31 I=1,8
      HALFPT(I)=TEMP2(I)
 31   CONTINUE
      FACT=(HALFPT(2)-POINT(2,1))/(POINT(2,2)-POINT(2,1))
       DO 32 I=9,37
      HALFPT(I)=TPOLTF(POINT(I,1),POINT(I,2))
 32   CONTINUE
      CALL PRINT (N,M,HALFPT)
      WRITE TAPE LTAPE, N,M,(HALFPT(I),I=1,37)
      GO TO 14
C --- OUTER SHOCK POINT ---
 33   N=N+1
      M=1
      IF (IH) 34,34,36
 34   MP=2
      DO 35 I=1,8
      HALFPT(I)=POINT(I,2)
 35   CONTINUE
 36   DO 37 I=1,8
      TEMP1(I)=TEMP2(I)
 37   CONTINUE
       CALL OUSHOK(HALFPT,POINT(1,MP-1),TEMP1,R,GR,GRAT,GM,OMA,GP,FSHOK)
      CALL PRINT (N,M,TEMP1)
      WRITE TAPE LTAPE, N,M,(TEMP1(I),I=1,37)
      GO TO 14
C --- EXPANSION POINTS ---
 38   M=M+1
      IF (M-150) 39,39,49
 39   DO 40 I=1,8
      POINT(I,M)=TEMP2(I)
 40   CONTINUE
       WRITE TAPE LTAPE, N,M,(TEMP2(I),I=1,37)
      GO TO 14
C --- FIRST EXPANSION POINT - COMPUTE UNSTEADY VALUES ---
 41   TANP=TANF(POINT(6,MP-1)+POINT(7,MP-1))
      TANM=TANF(POINT(6,MP)-POINT(7,MP))
      TEXP(2)=(POINT(3,MP-1)-POINT(2,MP-1)*TANP-POINT(3,MP)+POINT(2,MP)
     1 *TANM)/(TANM-TANP)
      TEXP(3)=POINT(3,MP)+TANM*(TEXP(2)-POINT(2,MP))
      FACT=(TEXP(2)-POINT(2,MP-1))/(TEMP1(2)-POINT(2,MP-1))
      DO 42 I=4,37
      TEXP(I)=TPOLTF(POINT(I,MP-1),TEMP1(I))
 42   CONTINUE
      CALL BODY (TEXP,POINT(1,MP-1),POINT(1,MP),BMTION,GR,GM,OMA,GROMA,
     1 NCOEFS)
      CALL PRINT (N,M,POINT(1,MP))
```

```
      CALL PRESSD (GM,GP,GAMA,R,EMI,POINT(1,MP))
      GO TO 24
C --- SUBSEQUENT EXPANSION POINTS ---
 43   DO 44 I=9,37
      POINT(I,MP)=POINT(I,MP-1)
 44   CONTINUE
      GO TO 24
C --- END OF BODY ---
 45   TANP=TANF(POINT(6,MP-1)+POINT(7,MP-1))
      TANM=TANF(TEMP2(6)-TEMP2(7))
      TEXP(2)=(POINT(3,MP-1)-POINT(2,MP-1)*TANP-TEMP2(3)+TEMP2(2)
     1 *TANM)/(TANM-TANP)
      TEXP(3)=TEMP2(3)+TANM*(TEXP(2)-TEMP2(2))
      FACT=(TEXP(2)-POINT(2,MP-1))/(TEMP1(2)-POINT(2,MP-1))
      DO 46 I=4,37
      TEXP(I)=TPOLTF(POINT(I,MP-1),TEMP1(I))
 46   CONTINUE
      CALL BODY (TEMP1,POINT(1,MP-1),TEMP2,BMTION,GR,GM,OMA,GROMA,
     1 NCOEFS)
      IEND=1
      GO TO 291
C --- NORMAL EXIT ---
 47   END FILE LTAPE
      CALL EXIT
C --- IMPOSSIBLE ID NUMBER ---
 48   WRITE OUTPUT TAPE NTAPE, 912, N,M,MP,ID
      CALL EXIT
C --- M EXCEEDS 150 ---
 49   WRITE OUTPUT TAPE NTAPE, 913
      CALL EXIT
C --- X OF UNSTEADY STATE STARTING POINT AND X OF STEADY STATE STARTING
C ---  POINT FROM TAPE DO NOT AGREE ---
  50   WRITE OUTPUT TAPE NTAPE,914,STARPT(11,N),TEMP2(2)
      CALL EXIT
 900  FORMAT (29H0  HELEN MC CALLUM   EXT.2430/1H1//40X,48HUNSTEADY AIRL
     1OAD ON A LATERALLY OSCILLATING BODY/1H0,58X,10HUNFLAVOR I)
 901  FORMAT (4I4)
 902  FORMAT (5E14.8)
 903  FORMAT (18H3  INPUT   NSEGS =I3,6X,8HNSTPTS =I4/1H0,10X,7HGAMMA =
     1 F5.2,4X,3HR =F9.3,4X,7HM I 2 =E14.8,4X,9HTHETA C =E14.8,4X,
     2 10HOMEGA/A* =E14.8)
 904  FORMAT (F2.0,4E13.7)
 905  FORMAT (1H2,40X,16HBODY INFORMATION/20H0SEG.NO.  BODY SHAPE,13X,
     1 1HX,16X,1HR,14X,5HTHETA,10X,11HDELTA THETA/)
 906  FORMAT (I5,5X,2A6,A1,4E17.7)
 907  FORMAT (1H0,9X,11HEND OF BODY,2X,2E17.7)
 908  FORMAT (2E14.8)
 909  FORMAT (1H1//4X,36HCOEFFICIENTS IN BODY MOTION EQUATION/1H0,10X,
     1 4HREAL,12X,9HIMAGINARY//(2E19.8))
  910  FORMAT(4E13.8/4E13.8/3E13.8)
 911  FORMAT (4H1  N,5X,1HM,3X,2HID,43X,4HREAL,10X,9HIMAGINARY,20X,
     1 4HREAL,10X,9HIMAGINARY)
 912  FORMAT (20H0  IMPOSSIBLE ID NO.,4X,3HN =I4,4X,3HM =I4,4X,4HMP =I4,
     1 4X,4HID =I5)
 913  FORMAT (16H0  M EXCEEDS 150)
 914  FORMAT (39H0  X OF UNSTEADY STATE STARTING POINT =E14.8,6X,
     1 44HX OF STEADY STATE STARTING POINT FROM TAPE =E14.8/19H0 THEY SH
     2OULD AGREE)
      END
```

```
      SUBROUTINE FIELD(POINT1,POINT2,POINT3,POINT4,GM,GR,OMA,GROMA)
C---FOR UNSTEADY FLOW---
C---COMPUTES FIELD POINT M,N GIVEN POINTS M-1,N   ,M-1,N-1   ,AND---
C---M,N-1  AND GIVEN STEADY STATE VALUES FOR ALL POINTS          ---
      DIMENSION GIVEN(37,5),ACOMP(12,2,2),C4(2),COMP(3,2),AV(2),AVA(2),
     1AVB(2),AVC(2),AVD(2),AV1(2),AV2(2),AV3(2),AV4(2),AV5(2),BCOMP(6,2)
     2,SUM(2)
      DIMENSION POINT1(1),POINT2(1),POINT3(1),POINT4(1)
      COMMON NTAPE
C---STORE KNOWN POINTS IN GIVEN---
      DO 7 I=1,37
      GIVEN(I,1)=POINT1(I)
      GIVEN(I,3)=POINT2(I)
      GIVEN(I,4)=POINT3(I)
  7   CONTINUE
      DO 8 I=1,7
  8   GIVEN(I,2)=POINT4(I)
      DO 12 K=1,2
      SIGN=1.
      DO 11 J=1,2
      KJ=K+J-1
      ACOMP(1,J,K)=SINF(GIVEN(7,KJ))
      ACOMP(2,J,K)=COSF(GIVEN(7,KJ))
      ACOMP(3,J,K)=ACOMP(2,J,K)/ACOMP(1,J,K)
      ACOMP(4,J,K)=ACOMP(3,J,K)/GIVEN(4,KJ)
      ACOMP(5,J,K)=.5+ACOMP(1,J,K)**2/GM
      ACOMP(6,J,K)=COSF(GIVEN(6,KJ)+SIGN*GIVEN(7,KJ))
      ACOMP(7,J,K)=GR*(ACOMP(1,J,K)**2)*ACOMP(2,J,K)/ACOMP(6,J,K)
      ACOMP(8,J,K)=ACOMP(1,J,K)/ACOMP(6,J,K)
      ACOMP(9,J,K)=ACOMP(8,J,K)/(GIVEN(3,KJ)*GIVEN(4,KJ))
      ACOMP(10,J,K)=ACOMP(2,J,K)*ACOMP(5,J,K)/ACOMP(6,J,K)
      ACOMP(11,J,K)=ACOMP(3,J,K)*ACOMP(5,J,K)
      ACOMP(12,J,K)=ACOMP(9,J,K)*GIVEN(3,KJ)*GROMA
 11   CONTINUE
      SIGN=-SIGN
 12   CONTINUE
C---COMPARE XE AND XF---
      TTHET=TANF(GIVEN(6,2))
      AMBCB=(GIVEN(3,3)-GIVEN(3,4))/(GIVEN(2,3)-GIVEN(2,4))
      AMBCA=(GIVEN(3,4)-GIVEN(3,1))/(GIVEN(2,4)-GIVEN(2,1))
      XE=(GIVEN(2,4)*AMBCB-GIVEN(3,4)+GIVEN(3,2)-GIVEN(2,2)*TTHET)/
     1(AMBCB-TTHET)
      XF=(GIVEN(2,2)*TTHET-GIVEN(3,2)+GIVEN(3,1)-GIVEN(2,1)*AMBCA)
     1/(TTHET-AMBCA)
      IF (XE-XF) 16,14,14
 14   GIVEN(2,5)=XE
      ME=3
      GO TO 17
 16   ME=1
      GIVEN(2,5)=XF
 17   GIVEN(3,5)=GIVEN(3,2)+TTHET*(GIVEN(2,5)-GIVEN(2,2))
      FRACT=(GIVEN(2,5)-GIVEN(2,4))/(GIVEN(2,ME)-GIVEN(2,4))
C---SET UP VARIABLES AT POINT E---
      DO 20 I=4,18
      GIVEN(I,5)=GIVEN(I,4)+FRACT*(GIVEN(I,ME)-GIVEN(I,4))
 20   CONTINUE
      GIVEN(33,5)=GIVEN(33,4)+FRACT*(GIVEN(33,ME)-GIVEN(33,4))
      DS=SQRTF((GIVEN(2,2)-GIVEN(2,5))**2+(GIVEN(3,2)-GIVEN(3,5))**2)
      DX1=GIVEN(2,2)-GIVEN(2,1)
      DX2=GIVEN(2,2)-GIVEN(2,3)
```

```
      DENOM=DX1*ACOMP(8,1,1)+DX2*ACOMP(8,2,2)
      GIVEN(33,2)=(GIVEN(5,3)-GIVEN(5,1))/DENOM
      DMSA=(GIVEN(4,2)-GIVEN(4,1))/DX1
      DMSB=(GIVEN(4,2)-GIVEN(4,3))/DX2
      AVCOT1=.5*(ACOMP(4,1,2)+ACOMP(4,2,2))
      AVCOT2=.5*(ACOMP(4,1,1)+ACOMP(4,2,1))
      RETAN=1./(AVCOT1+AVCOT2)
      DO 23 J=1,2
      GIVEN(J+33,2)=(GIVEN(J+10,3)-GIVEN(J+10,1))/DENOM
      GIVEN(J+35,2)=(GIVEN(J+16,3)-GIVEN(J+16,1))/DENOM
   23 CONTINUE
      DO 24 J=1,2
      K=J**2+1
      BCOMP(1,J)=SINF(GIVEN(6,K))
      BCOMP(2,J)=SINF(GIVEN(7,K))
      BCOMP(3,J)=OMA/GIVEN(4,K)
      BCOMP(4,J)=GR*BCOMP(2,J)*GIVEN(4,K)
      BCOMP(5,J)=GIVEN(4,K)*(.5+(BCOMP(2,J)**2)/GM)
      BCOMP(6,J)=OMA/(BCOMP(5,J)*GIVEN(4,K))
      SUM(J)=AVCOT2*GIVEN(J+12,1)+AVCOT1*GIVEN(J+12,3)+GIVEN(J+8,3)
     1-GIVEN(J+8,1)
   24 CONTINUE
C---DEFINE A,B,P COEFFICIENTS---
      S2=ACOMP(1,1,2)**2
      C2=ACOMP(2,1,2)**2
      T=1.+.5*GM/S2
      C3=GR*GIVEN(33,2)
      C4(2)=DMSA/GIVEN(4,2)
      C4(1)=DMSB/GIVEN(4,2)
      C5=2.*C2*S2
      COMP(1,1)=ACOMP(6,2,1)
      COMP(1,2)=ACOMP(6,1,2)
      COMP(2,1)=COMP(1,2)/COMP(1,1)
      COMP(2,2)=COMP(1,1)/COMP(1,2)
      COMP(3,1)=ACOMP(2,1,2)*COMP(1,1)
      COMP(3,2)=ACOMP(2,1,2)*COMP(1,2)
      SIGN=1.
      DO 25 J=1,2
      JSIGN=1.5*SIGN
      K=J+JSIGN
C---A1,2R---
      GIVEN(J+20,2)=COMP(2,J)/(ACOMP(3,1,2)*GIVEN(3,2))+(SIGN*C3*S2*S2
     1-C4(J)*COMP(1,K)/ACOMP(1,1,2))/COMP(3,J)
C---A1,2I---
      GIVEN(J+22,2)=-SIGN*ACOMP(12,K,J)/GR
C---P3,4R---
      GIVEN(J+24,2)=(T/C2-1.)*C4(K)+T*(COMP(2,J)*C4(J)/C2-2.*SIGN*S2*C3
     1*ACOMP(8,K,J))
C---B3,4I---
      GIVEN(J+30,2)=-OMA/(GIVEN(4,2)*COMP(3,J))
C---B3,4R---
      GIVEN(J+28,2)=GM*((C4(K)+C4(J)*COMP(2,J))/C5-SIGN*C3*ACOMP(8,K,J)
     1)
C---P3,4I---
      GIVEN(J+26,2)=-2.*GIVEN(J+30,2)
   25 SIGN=-SIGN
C---START ITERATION---
      NIT=0
      OLDMOD=0.
   28 NIT=NIT+1
```

```
      SIGN=1.
      IF (NIT-2) 29,30,31
   29 I=2
      L=1
      II=I*I+1
      HALF=1.
      AV(1)=0.
      AV(2)=0.
      AVA(1)=0.
      AVA(2)=0.
      AVB(1)=0.
      AVB(2)=0.
      AVC(1)=0.
      AVC(2)=0.
      AVD(1)=0.
      AVD(2)=0.
      GO TO 31
   30 I=1
      L=2
      II=I*I+1
      HALF=.5
      DO 300 J=1,2
      AV(J)=AV1(J)
      AVA(J)=AV2(J)
      AVB(J)=AV3(J)
      AVC(J)=AV4(J)
      AVD(J)=AV5(J)
  300 CONTINUE
   31 DO 32 J=1,2
C---COMPUTE S2---
      JSIGN=1.5*SIGN
      K=J+JSIGN
      AV1(J)=HALF*(AV(J)+SIGN*GIVEN(K+10,II)*BCOMP(3,I)-GIVEN(33,II)
     1*GIVEN(J+8,II))
      GIVEN(J+10,2)=GIVEN(J+10,5)+DS*AV1(J)
   32  SIGN=-SIGN
C---COMPUTE H RATIO---
      DO 34 J=1,2
      JSIGN=1.5*SIGN
      K=J+JSIGN
      AV2(J)=HALF*(AVA(J)+BCOMP(6,I)*SIGN*(GIVEN(K+12,II)+GIVEN(K+10,
     1 II)*BCOMP(2,I)*BCOMP(4,I)))
      GIVEN(J+16,2)=GIVEN(J+16,5)+DS*AV2(J)
   34 SIGN=-SIGN
      DO 36 J=1,2
C---COMPUTE MW2---
      JSIGN=1.5*SIGN
      K=J+JSIGN
      AV3(J)=HALF*(AVB(J)+(BCOMP(5,I)*GIVEN(J+16,II)-BCOMP(4,I)
     1*GIVEN(J+10,II)-GIVEN(J+12,II)-BCOMP(1,I)*GIVEN(J+14,II))/
     2 GIVEN(3,II)+SIGN*BCOMP(3,I)*GIVEN(K+14,II))
      GIVEN(J+14,2)=GIVEN(J+14,5)+DS*AV3(J)
   36 SIGN=-SIGN
      DO 40 J=1,2
C---COMPUTE THETA---
      JSIGN=1.5*SIGN
      K=J+JSIGN
      AV4(J)=HALF*(AVC(J)+ACOMP(3,I,2)*(GIVEN(22,I+1)*GIVEN(J+8,I+1)
     1-SIGN*GIVEN(24,I+1)*GIVEN(K+8,I+1)-(GIVEN(26,I+1)*GIVEN(J+12,I+1)
     2-SIGN*GIVEN(28,I+1)*GIVEN(K+12,I+1))/GIVEN(4,I+1)-ACOMP(5,I,2)*
```

```
     3(GIVEN(30,I+1)*GIVEN(J+16,I+1)-SIGN*GIVEN(32,I+1)*GIVEN(K+16,I+1))
     4)+ACOMP(7,I,2)*GIVEN(J+33,I+1)+ACOMP(9,I,2)*GIVEN(J+14,I+1)
     5-GIVEN(J+35,I+1)*ACOMP(10,I,2)+SIGN*ACOMP(12,I,2)*GIVEN(K+10,I+1))
      GIVEN(J+8,2)=GIVEN(J+8,3)-AVCOT1*(GIVEN(J+12,2)-GIVEN(J+12,3))
     1+AV4(J)*DX2
C---COMPUTE M2---
      AV5(J)=HALF*(AVD(J)+ACOMP(3,L,1)*(GIVEN(21,L)*GIVEN(J+8,L)-SIGN
     1*GIVEN(23,L)*GIVEN(K+8,L)+(GIVEN(25,L)*GIVEN(J+12,L)-SIGN*GIVEN(27
     2,L)*GIVEN(K+12,L))/GIVEN(4,L)+ACOMP(5,L,1)*(GIVEN(29,L)*GIVEN(J
     3+16,L)-SIGN*GIVEN(31,L)*GIVEN(K+16,L)))+GIVEN(J+34,L)*ACOMP(7,L,1)
     4-ACOMP(9,L,1)*GIVEN(J+14,L)-ACOMP(10,L,1)*GIVEN(J+35,L)-SIGN
     5*ACOMP(12,L,1)*GIVEN(K+10,L))
      GIVEN(J+12,2)=RETAN*(SUM(J)-DX1*AV5(J)+DX2*AV4(J))
   40 SIGN=-SIGN
      FMOD=SQRTF(GIVEN(13,2)**2+GIVEN(14,2)**2)
      IF (ABSF(FMOD-OLDMOD)-1.E-7) 61,61,63
C---HAVE CONVERGED---
   61 DO 62 J=9,37
      POINT4(J)=GIVEN(J,2)
   62 CONTINUE
      RETURN
   63 IF (NIT-99) 64,64,66
   64 OLDMOD=FMOD
      GO TO 28
C---ERROR - NO CONVERGENCE---
   66 WRITE OUTPUT TAPE NTAPE,67,OLDMOD,FMOD,GIVEN(13,2),GIVEN(14,2)
   67 FORMAT(48H- ITERATIONS IN COMPUTING FIELD POINT EXCEED 100 /
     137H0 MODULUS OF M * PREVIOUS ITERATION =E14.8/16H0 MODULUS OF M *
     2 20X,1H=E14.8/9H0 M * R =E14.8,6X,7HM * I =E14.8)
      CALL EXIT
      END
```

```
      SUBROUTINE BODY (POINT1,POINT2,POINT3,BMTION,GR,GM,OMA,GROMA,
     1 NCOEFS)
C --- FOR UNSTEADY FLOW ---
C --- COMPUTES BODY POINT M,N GIVEN POINT M-1,N AND POINT M-1,N-1  ---
C --- AND GIVEN STEADY STATE VALUES FOR ALL THREE POINTS ---
      DIMENSION POINT1(1),POINT2(1),POINT3(1),BMTION(1)
      DIMENSION GIVEN(37,3),ACOMP(8,2),BCOMP(13,2),COMP(3,2),C4(2),
     1 AV(2),AVA(2),AV1(2,2),AV2(2,2),AV3(2,2),AV4(2,2)
      COMMON NTAPE
      DO 20 I=1,37
      GIVEN(I,1)=POINT2(I)
      GIVEN(I,3)=POINT1(I)
 20   CONTINUE
      DO 21 I=1,7
      GIVEN(I,2)=POINT3(I)
 21   CONTINUE
      DO 22 J=1,2
      ACOMP(1,J)=SINF(GIVEN(7,J))
      ACOMP(2,J)=(.5+ACOMP(1,J)**2/GM)*GIVEN(4,J)**2
      ACOMP(3,J)=SINF(GIVEN(6,J))/GIVEN(3,J)
      ACOMP(4,J)=OMA/GIVEN(4,J)
      ACOMP(5,J)=GR*GIVEN(4,J)*ACOMP(1,J)/GIVEN(3,J)
      ACOMP(6,J)=ACOMP(2,J)/(GIVEN(3,J)*GIVEN(4,J))
      ACOMP(7,J)=OMA/ACOMP(2,J)
      ACOMP(8,J)=GR*GIVEN(4,J)*ACOMP(1,J)**2/ACOMP(2,J)
      BCOMP(1,J)=SINF(GIVEN(7,J+1))
      BCOMP(2,J)=COSF(GIVEN(7,J+1))
      BCOMP(3,J)=BCOMP(1,J)**2
      BCOMP(4,J)=BCOMP(2,J)/BCOMP(1,J)
      BCOMP(5,J)=BCOMP(4,J)/GIVEN(4,J+1)
      BCOMP(6,J)=COSF(GIVEN(6,J+1)-GIVEN(7,J+1))
      BCOMP(7,J)=.5+BCOMP(3,J)/GM
      BCOMP(8,J)=BCOMP(4,J)*BCOMP(7,J)
      BCOMP(9,J)=BCOMP(1,J)/BCOMP(6,J)
      BCOMP(10,J)=BCOMP(9,J)/(GIVEN(3,J+1)*GIVEN(4,J+1))
      BCOMP(11,J)=GR*BCOMP(2,J)*BCOMP(1,J)*BCOMP(9,J)
      BCOMP(12,J)=BCOMP(7,J)*LCOMP(2,J)/BCOMP(6,J)
      BCOMP(13,J)=GROMA*BCOMP(9,J)/GIVEN(4,J+1)
 22   CONTINUE
      XM1N=GIVEN(2,2)-GIVEN(2,3)
      DENOM=XM1N*BCOMP(9,2)
      GIVEN(33,2)=(GIVEN(5,3)-GIVEN(5,2))/DENOM
      DS=SQRTF((GIVEN(2,2)-GIVEN(2,1))**2+(GIVEN(3,2)-GIVEN(3,1))**2)
      C2=BCOMP(2,1)**2
      C3=GR*GIVEN(33,2)
      C4(2)=(GIVEN(4,3)-GIVEN(4,1))/(GIVEN(2,3)-GIVEN(2,1))/GIVEN(4,2)
      C4(1)=(GIVEN(4,2)-GIVEN(4,3))/XM1N/GIVEN(4,2)
      C5=2.0*BCOMP(3,1)*C2
      COMP(1,1)=COSF(GIVEN(6,2)+GIVEN(7,2))
      COMP(1,2)=BCOMP(6,1)
      COMP(2,1)=COMP(1,2)/COMP(1,1)
      COMP(2,2)=1.0/COMP(2,1)
      SIGN=+1.0
      T=1.0+.5*GM/BCOMP(3,1)
      DO 23 J=1,2
      COMP(3,J)=BCOMP(2,1)*COMP(1,J)
      GIVEN(J+20,2)=COMP(2,J)/(BCOMP(4,1)*GIVEN(3,2))+SIGN*BCOMP(3,1)**2
     1 *C3/COMP(3,J)-COMP(2,J)*C4(J)/(BCOMP(2,1)*BCOMP(1,1))
      GIVEN(J+22,2)=-SIGN*BCOMP(1,1)*ACOMP(4,2)/COMP(1,J)
      JSIGN=SIGN+.5
```

```
      JJ=J+JSIGN
      GIVEN(J+24,2)=C4(JJ)*(T/C2-1.0)-SIGN*T*2.0*BCOMP(1,1)**3*C3/
     1 COMP(1,J)+T*COMP(2,J)*C4(J)/C2
      GIVEN(J+26,2)=2.0*ACOMP(4,2)/COMP(3,J)
      GIVEN(J+28,2)=GM*(-SIGN*BCOMP(1,1)*C3/COMP(1,J)+C4(JJ)/C5+
     1 COMP(2,J)*C4(J)/C5)
      GIVEN(J+30,2)=-.5*GIVEN(J+26,2)
      SIGN=-SIGN
   23 CONTINUE
      NC=NCOEFS-1
      DO 26 I=1,2
      GIVEN(I+18,2)=BMTION(I)
      IF (NC) 26,26,24
   24 K=I
      DO 25 J=1,NC
      K=K+2
      GIVEN(I+18,2)=GIVEN(I+18,2)+BMTION(K)*GIVEN(2,2)**J
   25 CONTINUE
   26 CONTINUE
      SIGN=+1.0
      DO 27 I=1,2
      JSIGN=1.5*SIGN
      J=I+JSIGN
      GIVEN(I+8,2)=COSF(GIVEN(6,2))**2* (GIVEN(I+18,2)-GIVEN(I+18,1))/
     1 (GIVEN(2,2)-GIVEN(2,1))-SIGN*COSF(GIVEN(6,2))*ACOMP(4,2)
     2 *GIVEN(J+18,2)-((GIVEN(6,2)-GIVEN(6,3))/(GIVEN(3,2)-GIVEN(3,3)))
     3 *GIVEN(I+18,2)
      SIGN=-SIGN
   27 CONTINUE
      NIT=0
      OLDMOD=0.0
C --- START ITERATION ---
   28 NIT=NIT+1
      SIGN=1.0
      IF (NIT-1) 29,29,30
   29 I=1
      HALF=1.0
      AV(1)=0.0
      AV(2)=0.0
      GO TO 31
   30 I=2
      HALF=.5
      AV(1)=AV1(1,1)
      AV(2)=AV1(1,2)
   31 DO 33 J=1,2
      JSIGN=1.5*SIGN
      JJ=J+JSIGN
      AV1(I,J)=(AV(J)+SIGN*ACOMP(4,I)*GIVEN(JJ+10,I)-GIVEN(33,I)*
     1 GIVEN(J+8,I))*HALF
      GIVEN(J+10,2)=GIVEN(J+10,1)+AV1(I,J)*DS
      GIVEN(J+33,2)=(GIVEN(J+10,3)-GIVEN(J+10,2))/DENOM
      SIGN=-SIGN
   33 CONTINUE
      SIGN=+1.0
      IF (NIT-1) 34,34,35
   34 I=2
      HALF=1.0
      GO TO 36
   35 I=1
      HALF=.5
```

```
      AV(1)=AV2(2,1)
      AV(2)=AV2(2,2)
   36 DO 38 J=1,2
      JSIGN=1.5*SIGN
      JJ=J+JSIGN
      AV2(I,J)=(AV(J)+BCOMP(4,I)*(GIVEN(22,I+1)*GIVEN(J+8,I+1)-SIGN*
     1 GIVEN(24,I+1)*GIVEN(JJ+8,I+1))-BCOMP(5,I)*(GIVEN(26,I+1)*
     2 GIVEN(J+12,I+1)-SIGN*GIVEN(28,I+1)*GIVEN(JJ+12,I+1))+BCOMP(11,I)
     3 *GIVEN(J+33,I+1)+BCOMP(10,I)*GIVEN(J+14,I+1)-BCOMP(12,I)*
     4 GIVEN(J+35,I+1)-BCOMP(8,I)*(GIVEN(30,I+1)*GIVEN(J+16,I+1)-SIGN*
     5 GIVEN(32,I+1)*GIVEN(JJ+16,I+1))+SIGN*BCOMP(13,I)*
     6 GIVEN(JJ+10,I+1))*HALF
      GIVEN(J+12,2)=GIVEN(J+12,3)+1.0/(.5*(BCOMP(5,1)+BCOMP(5,2)))*
     1 (GIVEN(9,3)-GIVEN(9,2)+AV2(I,J)*XM1N)
      SIGN=-SIGN
   38 CONTINUE
      IF (NIT-1) 39,39,40
   39 I=1
      HALF=1.0
      AVA(1)=0.0
      AVA(2)=0.0
      GO TO 41
   40 I=2
      HALF=.5
      AV(1)=AV3(1,1)
      AV(2)=AV3(1,2)
      AVA(1)=AV4(1,1)
      AVA(2)=AV4(1,2)
   41 SIGN=+1.0
      DO 43 J=1,2
      JSIGN=1.5*SIGN
      JJ=J+JSIGN
      AV3(I,J)=(AV(J)-GIVEN(J+12,I)/GIVEN(3,I)-ACOMP(3,I)*GIVEN(J+14,I)
     1 +SIGN*ACOMP(4,I)*GIVEN(JJ+14,I)+ACOMP(6,I)*GIVEN(J+16,I)-
     2 ACOMP(5,I)*GIVEN(J+10,I))*HALF
      AV4(I,J)=(AVA(J)+SIGN*ACOMP(7,I)*GIVEN(JJ+12,I)+ACOMP(8,I)*
     1 GIVEN(JJ+10,I))*HALF
      GIVEN(J+14,2)=GIVEN(J+14,1)+AV3(I,J)*DS
      GIVEN(J+16,2)=GIVEN(J+16,1)+AV4(I,J)*DS
      GIVEN(J+35,2)=(GIVEN(J+16,3)-GIVEN(J+16,2))/DENOM
      SIGN=-SIGN
   43 CONTINUE
      FMOD=SQRTF(GIVEN(13,2)**2+GIVEN(14,2)**2)
      IF (ABSF(FMOD-OLDMOD)-1.0E-7) 46,46,44
   44 IF (NIT-99) 45,45,48
   45 OLDMOD=FMOD
      GO TO 28
C --- CONVERGED ---
   46 DO 47 I=9,37
      POINT3(I)=GIVEN(I,2)
   47 CONTINUE
      RETURN
C --- ERROR EXIT ---
   48 WRITE OUTPUT TAPE NTAPE, 100, OLDMOD,FMOD,GIVEN(13,2),GIVEN(14,2)
      CALL EXIT
  100 FORMAT (47H- ITERATIONS IN COMPUTING BODY POINT EXCEED 100 /
     1 37H0 MODULUS OF M * PREVIOUS ITERATION =E14.8/16H0 MODULUS OF M *
     2 20X,1H=E14.8/9H0 M * R =E14.8,6X,7HM * I =E14.8)
      END
```

```
      SUBROUTINE OUSHOK(POINT1,POINT2,POINT3,R,GR,GRAT,GM,OMA,GP,FSHOK)
C---FOR UNSTEADY FLOW---
C---COMPUTES SHOCK POINT M,N GIVEN POINT M,N-1 AND POINT M-1,N-1---
C--- AND GIVEN STEADY STATE VALUES FOR ALL THESE POINTS
      DIMENSION GIVEN(37,3),FSHOK(28),PAP(2),RAR(2),DML(2),BCOMP(2,2),
     1 ACOMP(8,2),RP(2),THECON(2),AV(2),AV1(2)
      DIMENSION POINT1(1),POINT2(1),POINT3(1)
      COMMON NTAPE
C---STORE POINTS IN GIVEN---
      DO 2 I=1,37
      GIVEN(I,1)=POINT2(I)
      GIVEN(I,3)=POINT1(I)
  2   CONTINUE
      DO 3 I=1,8
  3   GIVEN(I,2)=POINT3(I)
      EF=GIVEN(8,2)-FSHOK(6)
      C1=COSF(GIVEN(8,2))
      S1=SINF(EF)
      S2=S1*S1
      S3=SINF(GIVEN(8,2))
      C2=COSF(EF)
      C3=C2/S1
      TT=GIVEN(6,2)-FSHOK(6)
      S4=SINF(TT)
      C4=COSF(TT)
      EA=GIVEN(8,2)-GIVEN(6,2)
      C5=COSF(EA)
      S5=SINF(EA)
      C6=C1*C1*FSHOK(4)
      CS1=S3*C1
      DX1=GIVEN(2,2)-GIVEN(2,3)
      DX2=GIVEN(2,3)-GIVEN(2,1)
      DX3=GIVEN(2,2)-GIVEN(2,1)
      DR=GIVEN(3,2)-GIVEN(3,3)
      DM=(GIVEN(4,2)-GIVEN(4,3))/DR
      DT=(GIVEN(6,2)-GIVEN(6,3))/DR
      DSR=(GIVEN(5,2)-GIVEN(5,3))/DR
      DML(1)=(GIVEN(4,2)-GIVEN(4,3))/(DX1*GIVEN(4,2))
      DML(2)=(GIVEN(4,3)-GIVEN(4,1))/(DX2*GIVEN(4,2))
      DENOM=DX1*SINF(GIVEN(7,3))/COSF(GIVEN(6,3)+GIVEN(7,3))
      DSN=(GIVEN(5,2)-GIVEN(5,3))/DENOM
      GIVEN(33,2)=DSN
      E1=SINF(GIVEN(7,2))
      E4=COSF(GIVEN(7,2))
      E3=E1*DSN*GR
      E2=E1*E1
      E5=E1/(E4*GIVEN(3,2))
      E6=E1*E4
      T=1.+.5*GM/E2
      E7=E4*E4
      E8=T/E7
      E9=E1*OMA/GIVEN(4,2)
      E10=2.*T*E2*E3
      E11=E8-1.
      E12=OMA/(E4*GIVEN(4,2))
      E13=E3*E1*E2/E4
      E14=2.*E2*E7
      SIGN=1.
      DO 7 J=1,2
      BCOMP(1,J)=COSF(GIVEN(6,2)-SIGN*GIVEN(7,2))
```

```
      BCOMP(2,J)=COSF(GIVEN(6,2)+SIGN*GIVEN(7,2))
      BCOMP(3,J)=BCOMP(1,J)/BCOMP(2,J)
    7 SIGN=-SIGN
      SIGN=1.
C---NOW COMPUTE A,B,P
      DO 8 J=1,2
      JSIGN=1.5*SIGN
      K=J+JSIGN
      GIVEN(J+20,2)=BCOMP(3,J)*(E5-DML(K)/E6)+SIGN*E13/BCOMP(2,J)
      GIVEN(J+22,2)=-SIGN*E9/BCOMP(2,J)
      GIVEN(J+24,2)=E11*DML(J)-SIGN*E10/BCOMP(2,J)+E8*DML(K)*BCOMP(3,J)
      GIVEN(J+30,2)=-E12/BCOMP(2,J)
      GIVEN(J+28,2)=GM*((DML(J)+DML(K)*BCOMP(3,J))/E14-SIGN*E3/BCOMP(2
     1,J))
      GIVEN(J+26,2)=-2.*GIVEN(J+30,2)
    8 SIGN=-SIGN
      AM1FS=S2*FSHOK(22)
      A1=(2.+2./AM1FS)/GP
      C=C6*(A1*S4-4.*S1*C5/GP)/DX3
      D=-A1*OMA*C1*S5
      GCON=C*GIVEN(19,1)+S5*(FSHOK(25)/S1-A1*(C2*FSHOK(23)-S1*FSHOK(13)
     1))-FSHOK(23)*S4-FSHOK(13)*C4
      HCON=S5*(FSHOK(26)/S1-A1*(FSHOK(24)*C2-FSHOK(14)*S1))-C4*FSHOK(14
     1)-S4*FSHOK(24)+C*GIVEN(20,1)
      C=C-DM
      CSDS=C*C+D*D
      PAPCON=2.*FSHOK(3)*S2/(FSHOK(3)*S2-GRAT)
      RARCON=2.*FSHOK(2)/(1.-FSHOK(1)*C2*C2)
      DO 10 J=1,2
   10 THECON(J)=-FSHOK(J+12)*S4+C4*FSHOK(J+22)+A1*C5*(FSHOK(J+12)*S1
     1-C2*FSHOK(J+22))-FSHOK(J+24)*C5/S1
      DO 13 J=1,2
      K=J+1
      CC=COSF(GIVEN(7,K))
      SS=SINF(GIVEN(7,K))
      ACOMP(1,J)=CC/SS
      ACOMP(2,J)=ACOMP(1,J)/GIVEN(4,K)
      ACOMP(3,J)=CC*SS*GR
      ACOMP(4,J)=SS/COSF(GIVEN(7,K)+GIVEN(6,K))
      ACOMP(5,J)=1./(GIVEN(4,K)*GIVEN(3,K))
      ACOMP(6,J)=.5+SS*SS/GM
      ACOMP(7,J)=ACOMP(1,J)*ACOMP(4,J)
      ACOMP(8,J)=OMA*GR/GIVEN(4,K)
      GIVEN(J+8,2)=0.
   13 CONTINUE
      A2=(GIVEN(4,2)*SINF(GIVEN(6,2))-FSHOK(27))/GIVEN(3,2)
      A4=GRAT*GIVEN(4,2)
      A5=1.-A4*GIVEN(4,2)
      A6=A5/FSHOK(2)
      AVCOT=2./(ACOMP(2,1)+ACOMP(2,2))
C---START ITERATION---
      OLDMOD=0.
      NIT=0
   28 NIT=NIT+1
C---FIRST DEFINE M2*---
      IF (NIT-2) 30,31,32
   30 I=2
      HALF=1.
      AV(1)=0.
      AV(2)=0.
```

```
      GO TO 32
 31   I=1
      HALF=.5
      AV(1)=AV1(1)
      AV(2)=AV1(2)
 32   SIGN=1.
      DO 35 J=1,2
      JSIGN=1.5*SIGN
      K=J+JSIGN
      AV1(J)=HALF*(AV(J)+ACOMP(1,I)*(GIVEN(21,I+1)*GIVEN(J+8,I+1)-SIGN
     1*GIVEN(23,I+1)*GIVEN(K+8,I+1))+ACOMP(2,I)*(GIVEN(25,I+1)*GIVEN(J+1
     2 2,I+1)-SIGN*GIVEN(27,I+1)*GIVEN(K+12,I+1))+ACOMP(4,I)*(ACOMP(3,I)
     3*GIVEN(J+33,I+1)-ACOMP(5,I)*GIVEN(J+14,I+1)-SIGN*ACOMP(8,I)*
     4GIVEN(K+10,I+1))+ACOMP(6,I)*(ACOMP(1,I)*(GIVEN(29,I+1)*GIVEN(J+16,
     5 I+1)-SIGN*GIVEN(31,I+1)*GIVEN(K+16,I+1))-ACOMP(7,I)*GIVEN(J+35,
     6 I+1)))
      GIVEN(J+12,2)=GIVEN(J+12,3)+AVCOT*(GIVEN(J+8,2)-GIVEN(J+8,3)
     1-DX1*AV1(J))
 35   SIGN=-SIGN
C---DEFINE R2 AND ITS DERIVATIVES---
      G=GCON+GIVEN(13,2)
      H=HCON+GIVEN(14,2)
      GIVEN(19,2)=(C*G+D*H)/CSDS
      GIVEN(20,2)=(C*H-D*G)/CSDS
      SIGN=1.
      DO 36 J=1,2
      RP(J)=(GIVEN(J+18,2)-GIVEN(J+18,1))/DX3
      GIVEN(J+14,2)=FSHOK(J+14)+A2*GIVEN(J+18,2)
 36   CONTINUE
      DO 37 J=1,2
      JSIGN=1.5*SIGN
      K=J+JSIGN
      RAR(J)=-RARCON*(FSHOK(J+18)-C3*FSHOK(J+8)+FSHOK(J+6)-RP(J)
     1*(FSHOK(28)/S1-CS1)+GIVEN(K+18,2)*SIGN*C1*OMA/(S1*FSHOK(4)))
      PAP(J)=PAPCON*(FSHOK(J+18)-FSHOK(J+6)-FSHOK(J+8)*C3
     1+(C6*C3*RP(J)-SIGN*OMA*C1*GIVEN(K+18,2)/S1)/FSHOK(4))
      GIVEN(J+16,2)=A5*(PAP(J)-RAR(J))+A6*(FSHOK(J+16)-2.*FSHOK(1)
     1*FSHOK(J+18))+2.*GRAT*GIVEN(4,2)*(GIVEN(J+12,2)-DM*GIVEN(J+18,2))
      GIVEN(J+35,2)=(GIVEN(J+16,2)-GIVEN(J+16,3))/DENOM
      GIVEN(J+10,2)=FSHOK(J+10)-GIVEN(J+18,2)*DSR+(R*PAP(J)-RAR(J)/GR)
     1 /GM
      GIVEN(J+33,2)=(GIVEN(J+10,2)-GIVEN(J+10,3))/DENOM
      GIVEN(J+8,2)=(THECON(J)+RP(J)*C6*(A1*C4-4.*S1*S5/GP)-GIVEN(J+18
     1,2)*GIVEN(4,2)*DT-A1*GIVEN(K+18,2)*OMA*C1*C5*SIGN)/GIVEN(4,2)
 37   SIGN=-SIGN
      FMOD=SQRTF(GIVEN(13,2)**2+GIVEN(14,2)**2)
      IF (ABSF(FMOD-OLDMOD)-1.E-7) 61,61,63
C---HAVE CONVERGED---
 61   DO 62 J=9,37
      POINT3(J)=GIVEN(J,2)
 62   CONTINUE
      RETURN
 63   IF (NIT-99) 64,64,66
 64   OLDMOD=FMOD
      GO TO 28
C---ERROR - NO CONVERGENCE---
 66   WRITE OUTPUT TAPE NTAPE,67,OLDMOD,FMOD,GIVEN(13,2),GIVEN(14,2)
 67   FORMAT(54H- ITERATIONS IN COMPUTING OUTER SHOCK POINT EXCEED 100
     1/37H0 MODULUS OF M * PREVIOUS ITERATION = E14.8/16H0 MODULUS OF M
     2* 20X,1H=E14.8/9H0 M * R = E14.8,6X,7HM * I = E14.8)
```

```
      SUBROUTINE STAR(POINT,GR,GM,OMA,DML)
C---THIS SUBROUTINE COMPUTES THE COEFFICIENTS A1,A2,B3,B4,P3,P4---
C---FOR A GIVEN POINT---
      DIMENSION POINT(1),BCOMP(3,2),DML(2)
      SIGN=1.
      DO 7 J=1,2
      BCOMP(1,J)=COSF(POINT(6)-SIGN*POINT(7))
      BCOMP(2,J)=COSF(POINT(6)+SIGN*POINT(7))
      BCOMP(3,J)=BCOMP(1,J)/BCOMP(2,J)
    7 SIGN=-SIGN
      E1=SINF(POINT(7))
      E2=E1**2
      E3=E1*POINT(33)*GR
      E4=COSF(POINT(7))
      E5=E1/(E4*POINT(3))
      E6=E1*E4
      T=1.+.5*GM/E2
      E8=T/(E4*E4)
      E9=E1*OMA/POINT(4)
      E10=2.*T*E2*E3
      E11=E8-1.
      E12=OMA/(E4*POINT(4))
      E13=E3*E1*E2/E4
      E14=2.*E2*E4*E4
      SIGN=1.
      DO 8 J=1,2
      JSIGN=1.5*SIGN
      K=J+JSIGN
      POINT(J+20)=BCOMP(3,J)*(E5-DML(K)/E6)+SIGN*E13/BCOMP(2,J)
      POINT(J+22)=-SIGN*E9/BCOMP(2,J)
      POINT(J+24)=E11*DML(J)-SIGN*E10/BCOMP(2,J)+E8*DML(K)*BCOMP(3,J)
      POINT(J+30)=-E12/BCOMP(2,J)
      POINT(J+28)=GM*((DML(J)+DML(K)*BCOMP(3,J))/E14-SIGN*E3/BCOMP(2,J)
     1)
      POINT(J+26)=-2.*POINT(J+30)
    8 SIGN=-SIGN
      RETURN
      END
```

```
      SUBROUTINE PRESSD (GM,GP,GAMA,R,EMI,TEMP)
C --- CALCULATES AND PRINTS PRESSURE RATIO AND DENSITY RATIO ---
C --- FOR BODY POINT ---
      COMMON NTAPE
      DIMENSION TEMP(1),PRESSR(2),DENSR(2)
      G=(1.0+.5*GM*EMI)*(1.0-GM*TEMP(4)**2/GP)
      E=EXPF(-TEMP(5)/R)
      P1=G**(GAMA/GM)*E
      RHO1=G**(1.0/GM)*E
      VH=1.0/(.5+SINF(TEMP(7))**2/GM)
      HR=(TEMP(17)-VH*TEMP(13)/TEMP(4))/(1.0-.5*VH)
      HI=(TEMP(18)-VH*TEMP(14)/TEMP(4))/(1.0-.5*VH)
      PRESSR(1)=P1*(HR*GAMA/GM-TEMP(11)/R)
      PRESSR(2)=P1*(HI*GAMA/GM-TEMP(12)/R)
      DENSR(1)=RHO1*(HR/GM-TEMP(11)/R)
      DENSR(2)=RHO1*(HI/GM-TEMP(12)/R)
      WRITE OUTPUT TAPE NTAPE, 900, PRESSR(1),PRESSR(2),DENSR(1),
     1 DENSR(2)
      RETURN
 900  FORMAT (36X,16HPRESSURE RATIO =E14.7,E16.7/36X,16HDENSITY  RATIO =
     1 E14.7,E16.7//)
      END
```

```
      SUBROUTINE PRINT (N,M,ANS)
      DIMENSION ANS(1)
      COMMON NTAPE
      ID=ANS(1)+.5
      IF (ID-6) 10,11,11
10    WRITE OUTPUT TAPE NTAPE, 900, N,M,ID,ANS(2),ANS(9),ANS(10),
     1 ANS(13),ANS(14)
      GO TO 12
11    WRITE OUTPUT TAPE NTAPE, 901, ID,ANS(2),ANS(9),ANS(10),ANS(13),
     1 ANS(14)
12    WRITE OUTPUT TAPE NTAPE, 902, ANS(3),ANS(11),ANS(12),ANS(15),
     1 ANS(16)
      GO TO (13,14,14,15,13,13,14),ID
13    WRITE OUTPUT TAPE NTAPE, 903, ANS(17),ANS(18)
       RETURN
14    WRITE OUTPUT TAPE NTAPE, 904, ANS(19),ANS(20),ANS(17),ANS(18)
       RETURN
15    WRITE OUTPUT TAPE NTAPE, 905, ANS(8),ANS(19),ANS(20),ANS(17),
     1 ANS(18)
       RETURN
900   FORMAT (1HO,I3,I6,I5,7X,3HX =E13.7,6X,8HTHETA 2=E14.7,E16.7,6X,
     1 7HM * 2 =E14.7,E16.7)
901   FORMAT (1HO,9X,I5,7X,3HX =E13.7,6X,8HTHETA 2=E14.7,E16.7,6X,
     1 7HM * 2 =E14.7,E16.7)
902   FORMAT (22X,3HR =E13.7,6X,8HS 2    =E14.7,E16.7,6X,7HM * W2=
     1 E14.7,E16.7)
903   FORMAT (88X,7HH2/H1 =E14.7,E16.7)
904   FORMAT (44X,8HR 2 B  =E14.7,E16.7,6X,7HH2/H1 =E14.7,E16.7)
905   FORMAT (19X,6HEPSLN=E13.7,6X,8HR 2    =E14.7,E16.7,6X,7HH2/H1 =
     1 E14.7,E16.7)
      END
```

BSHAPE (1,NSEG)= ID# (0≡last point, 1≡straight line, 2≡parabola, 3≡ogive)

BSHAPE (2,NSEG)= x

BSHAPE (3,NSEG)= r

BSHAPE (4,NSEG)= θ

BSHAPE (5,NSEG)= $\Delta\theta$

Card No. 5 BMTIΦN(I), I = 1,NC

2E14.8

where BMTIΦN= one dimensional array containing coefficients of polynomial equation describing body motion; stored as a_{0R}, a_{0I}, a_{1R}, a_{1I}, etc.

Card No. 6 ((START(I,N),I=1,11),N=1,NSTPTS)

4E13.8/4E13.8/3E13.8

where STARPT= Two dimensional array containing the unsteady quantities given for the starting points along the first left running characteristic line i.e. θ_{2R}, θ_{2I}, S_{2R}, S_{2I}, M^*_{2R}, M^*_{2I}, M^*_{W2R}, M^*_{W2I}, $\left(\frac{h_2^\circ}{h_1^\circ}\right)_R$, $\left(\frac{h_2^\circ}{h_1^\circ}\right)_I$, X

Card No. 7 FSHΦK(I) I=4,5,6,9, through 18

5E14.8

where FSHΦK= I=4–6, M^*_{1f}, S_{1f}, θ_{1f},

I=9–18, θ_{2fR}, θ_{2fI}, S_{2fR}, S_{2fI}, M^*_{2fR}, M^*_{2fI}, M^*_{W2fR}, M^*_{W2fI}, $(h_2^\circ/h_1^\circ)_R$, $(h_2^\circ/h_1^\circ)_I$

Card No. 8 NCΦNT only if NΦP1 $\neq$ 0

I4

where NCΦNT= Row number at which continuation run will start

V. DESCRIPTIONS OF INPUTS

The inputs are read in on punched cards. Eight types of cards are used for this program. The description of each is listed below.

Card No. 1	NSEGS	NSTPTS	NCϕEFS	NϕP1
	I4	I4	I4	I4

where

- NSEGS= Total number of segments in the body
- NSTPTS= Number of starting points given along the first left running characteristics
- NCϕEFS= Number of coefficients in the polynomial equation describing body motion
- NϕP1= 0, if this is not a continuation run; 1, if this is a continuation run.

Card No. 2	GAMA	R	EMI	THETAC	ϕMA
	5E14.8				

where

- GAMA = γ (ratio of specific heats)
- R= Gas constant
- EMI= M_∞^2, free stream mach number squared
- THETAC= θ_c, semi-cone angle
- ϕMA= ω/a^*, circular frequency divided by the modified sound velocity

Card No. 3	R2SR	R2SI
	2E14.8	

where

- R2SR, R2SI= The real and imaginary parts of r_2 at the starting point on the shock.

Card No. 4 (BSHAPE(I,NSEG), I=1,5), NSEG=1, NSEGS+1

F 2.0 4E13.7

where

- BSHAPE= Two dimensional array containing body shape information for each segment

REFERENCES

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3. Hsu, P. T., Solution of the Supersonic Flow Field Around an Oscillating Circular Cone, MIT Fluid Dynamics Research Laboratory Report No. 64-5, December 1964, NASA Contract No. NAS8-873.