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DEPARTMENT OF AEROSPACE ENGINEERING
COLLEGE OF ENGINEERING
BOSTON, MASSACHUSETTS

College of Engineering

Boston University

Boston MA. 02215

SUSSA ACTS

A Computer Program for Steady and Unsteady, Subsonic and Supersonic Aerodynamics for Aerospace Complex Transportation Systems+

by

Ka Din Tseng* and Luigi Morino**

Boston University

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* Graduate student, research assistant, student member AIAA.

** Associate professor, member AIAA.

SUSSA ACTS: A Computer Program for Steady and Unsteady, Subsonic and Supersonic Aerodynamics for Aerospace Complex Transportation Systems

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Ka Din Tseng and Luigi Morino

Boston University

Presented here is the final version of the computer program SUSSA ACTS (Steady and Unsteady, Subsonic and Supersonic Aerodynamics for Complex Transportation Systems). The paper includes the numerical formulation, the description of the program and numerical results. In particular, generalized forces for fully unsteady (complex frequency) aerodynamics for a wing-body configuration, in both subsonic and supersonic flows, are included.

The mathematical analysis, based upon an integral formulation presented in Refs. 1 and 2, includes completely arbitrary motion. The numerical implementation of Refs. 3 and 4 was limited to steady and oscillatory flows. On the other hand, in order to perform a linear-system analysis of the aircraft, it is convenient to use more general aerodynamic formulation, i.e., fully transient response for time-domain analysis, and the aerodynamic transfer function (Laplace transform of the fully unsteady operator) for frequency-domain analysis (Ref. 5). Such formulation is outlined (at least in preliminary form) in Ref. 6, where some numerical results (for pressure on thin rectangular wings) are also presented.*

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*The formulation is presented in details in Ref. 7, enclosed here.

The formulation has now been completed and implemented in the computer program SUSSA ACTS.[8] Numerical results are also available. The formulation, the program and the results are also presented in this paper. Since the present paper is an extension of Ref. 6, only the items not considered in Ref. 6 are presented here (detailed description of some of these items is given in Ref. 7, attached here). These include:

1. Evaluation of the downwash for complex configurations from prescribed three dimensional mode shapes (Ref. 6 was limited to thin wings with vertical displacements).
2. Improved evaluation of the potential from the downwash: the analysis in the supersonic regime is now as simple as its subsonic counter part (Ref. 6 had to introduce diaphragm for supersonic partially subsonic wing planform).
3. Finite-element evaluation of pressure (Ref. 6 used finite-difference and was limited to thin wings).
4. Evaluation of fully-unsteady generalized forces for arbitrary configurations (Ref. 6 was limited to lifts and moments for thin wings). To the author's knowledge this is the only computer program which can handle fully unsteady (complex-frequency) aerodynamics for complex configuration (wing-body-tail preprocessor is already available). For such configurations other programs can handle only steady state in the supersonic range, and only wing-body configurations in oscillatory motion for the subsonic range.

METHOD OF SOLUTION

The method presented here is based upon a formulation developed by Morino[1,2]. The formulation, by making use of the Green function method applied to the equation of the velocity potential, yields an integral equation relating the unknown potential on the surface of the body to its known downwash. By making use of . the finite-element method, and by the assuming that the potential is constant within each quadriare presented in Ref. 9 where it is also shown why in the formulation of Ref. 6 the use of the diaphragm was necessary in order to avoid determinants equal to zero (in the new formulation the time delay, $\theta^{\pm}$, is evaluated from the centroid of the portion of the element inside the Mach forecone, instead of the centroid of the element itself).

NUMERICAL RESULTS

Because of space limitation, only a few basic results are presented in this meeting abstract: additional results will be included in the final paper.

The results presented here are divided in two groups. In the first group the results are compared with existing ones in order to assess the accuracy of the new formulation. The second group deals with complex-frequency aerodynamics for which no other (experimental or theoretical) results exist: these are presented in order to give an idea of the capabilities of the program SUSSA ACTS.

Tipical results of the first group are presented in Fig. 1: lift and moment for a rectangular wing oscillating in pitch with reduced frequency k=1, as functions of the Mach number. The analysis of convergence for the supersonic range is presented in Fig. 2 and indicates that the small difference with existing results might be due to convergence. A more thorough convergence analysis is now under way. It should be emphasized again that the results of Morino and Chen are obtained using a diaphragm, while the present results are obtained without diaphragm.

In the second group of results, a wing - body configuration oscillating in pitch with complex frequency $s = .2 + i1$ is considered. The wing is rectangular with chord $c = 1$, span $s = 6$, thickness $h = .09$. The body is composed of three parts. The central portion is cylindrical with radius $r_c = .5$ and length $l_c = 1$. The forward portion has $r_f = 1/2 -1/8(x - x_{LE})^2$ and length $l_f = 2$. The aftward portion simulates the body wake and is cylindrical with length $l_A = 9$ and radius $r_A = .5$. The configuration is symmetric. Therefore the results are antisymmetric.

The pressure distribution is presented in Fig. 3 and 4 for $M = .24$ and 1.42 respectively. The lift (per unit dynamic pressure is $L = 1.39 + i1.51$, for $M = .24$, $L = 1.85 + i1.78$ for $M = .5$, $L = 2.77 + i2.39$ for $M = .75$ and $L = 1.35 + i0.36$ for $M = 1.42$.

CONCLUSIONS

The formulation, the computer program SUSSA ACTS and numerical results have been presented. The program is the only existing program for steady, oscillatory and fully unsteady, subsonic and supersonic aerodynamics around completely arbitrary aircraft configurations. Other existing programs for complex configurations can handle only wing-body configurations in oscillatory subsonic flow, and arbitrary configurations in steady subsonic and supersonic flows.

Improvements with respect to the formulation of Ref. 6 include (see Introduction) the arbitrary-configuration complex frequency evaluation of the downwash, of the pressure coefficient and the generalized forces, as well as a new technique which allows for the same treatment for both subsonic and supersonic range (no diaphragm required).

The results are in good agreement with existing ones. Also, the results for complex-frequency subsonic and supersonic generalized forces for wing-body configuration are the first ones ever obtained.

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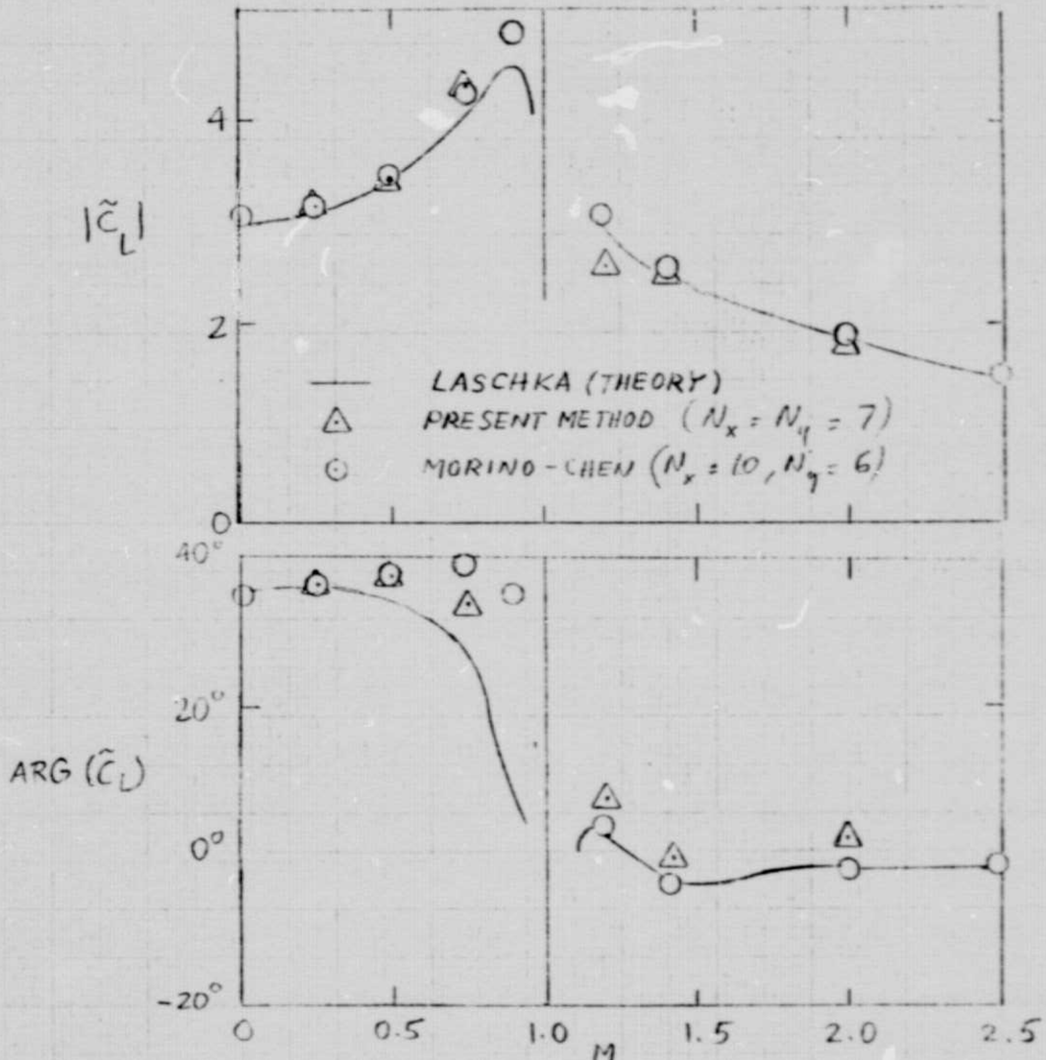

Fig. 1a. Lift coef., $\tilde{C}_L$ versus M for rectangular wing oscillating in pitch with $AR = 2$, $\tau = 0.001$, $k = 1.0$ results compared with Refs. 6 and 7

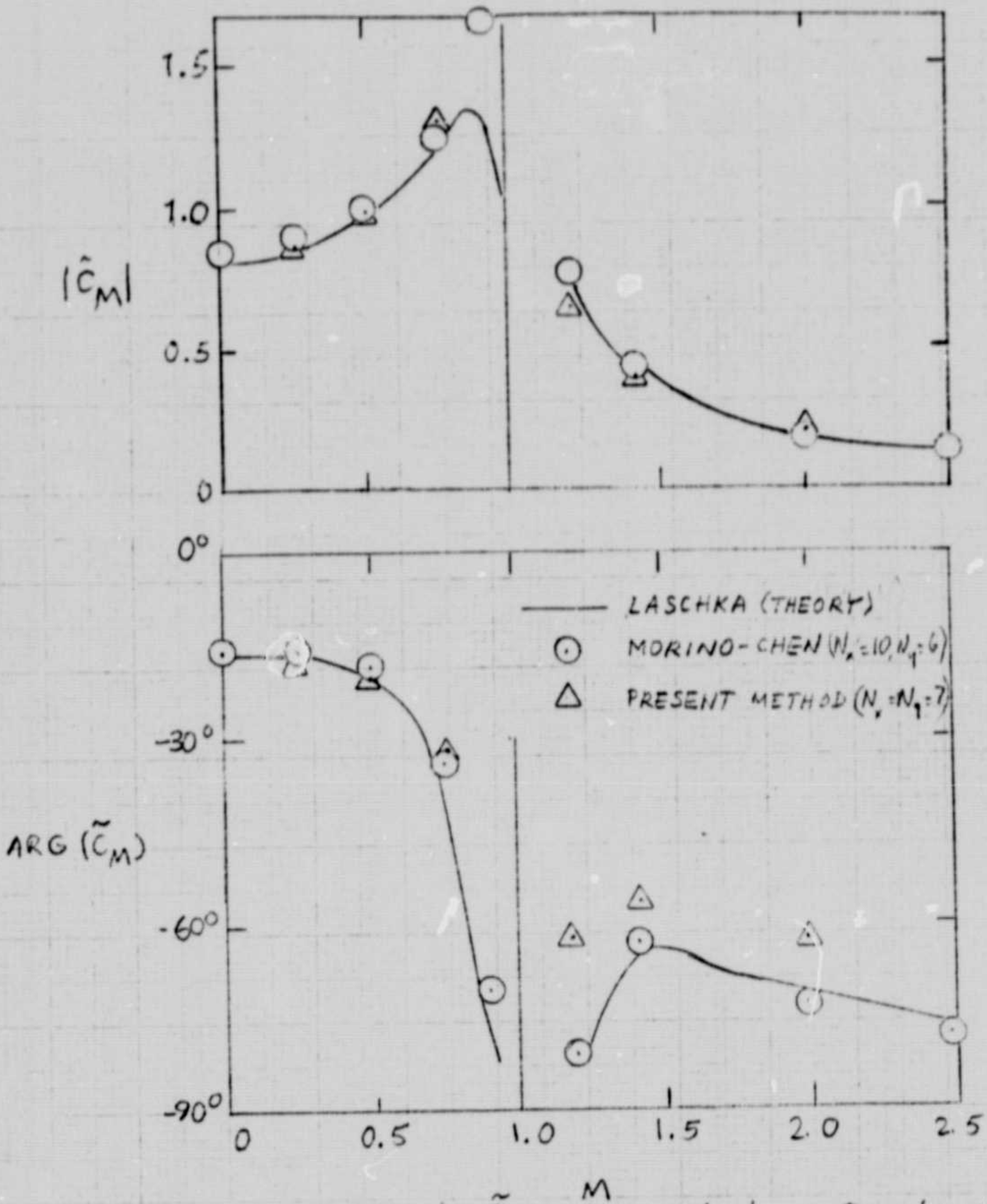

Fig. 16. Moment coef., $\tilde{C}_M$, versus M, for rectangular wing oscillating in pitch, with $AR = 2$, $\tau = 0.001$, $k = 1.0$ results compared with Refs 6 and 7

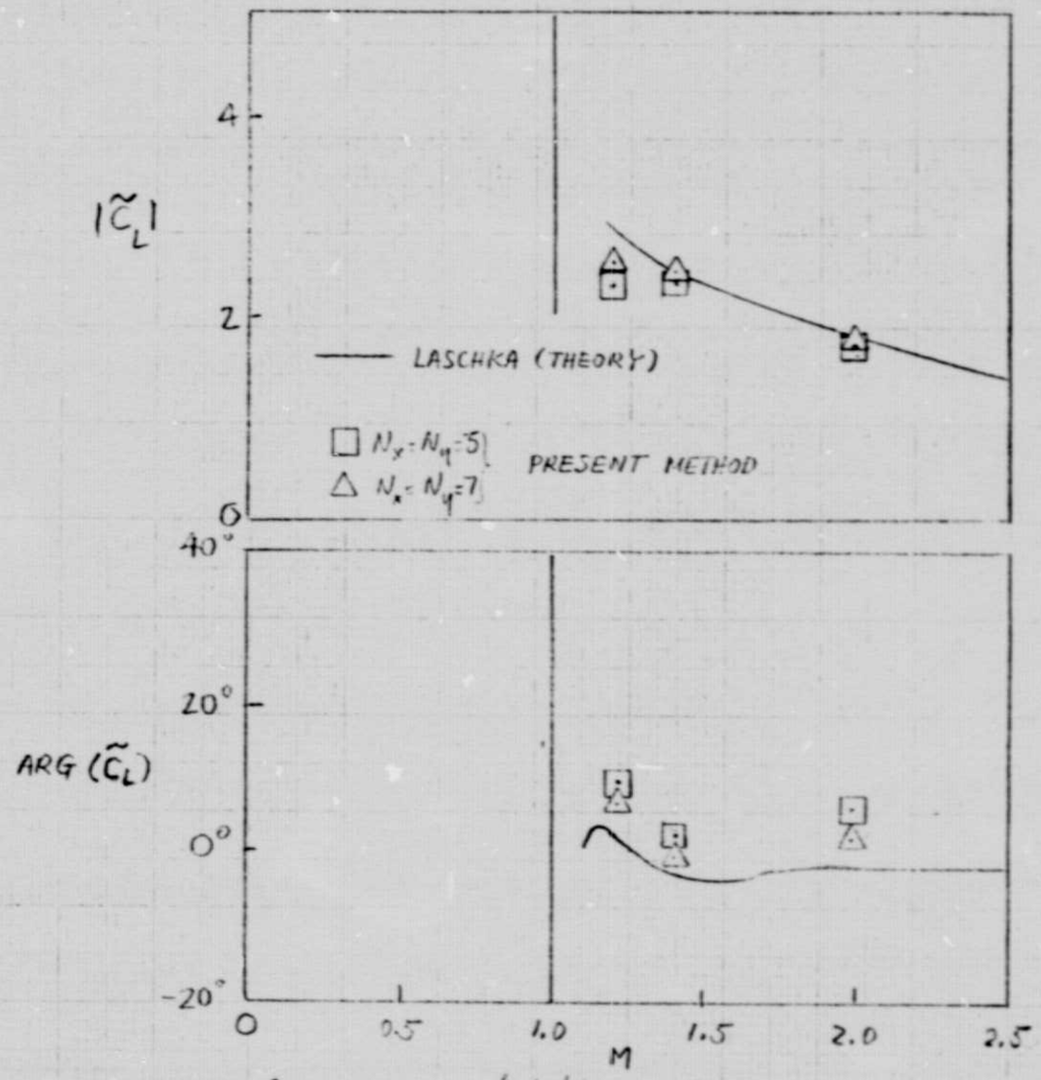

Fig. 2a. Convergence analysis for Fig. 1a

lateral element, the integral equation is approximated by a linear system of N equations relating N (unknown) values of the potential to N (known) values of downwash at the centroids of N elements.

For the sake of generality and flexibility, in particular, for structural analysis, the downwash is expressed in terms of the generalized coordinates and generalized velocities (see section 3-3 of Ref. 7).

From the potentials at centroids of elements, by an averaging scheme (by which the potential at a corner is approximated by the average value of potentials at the centroids of the elements in its immediate surroundings, see section 3-4 of Ref. 7) the potentials at the nodal points are obtained and consequentially the potential at any point on the surface can be expressed by a finite-element interpolating formulation with bi-linear global shape functions. Finally, the pressure coefficients and generalized forces can be evaluated by eqs. 3-51 and 3-54 of Ref. 7.

COMMENTS ON SUPERSONIC FORMULATION

In Refs. 4 and 6, the equations for the upper and lower surfaces were solved independently for supersonic leading edge wings while diaphragms were used for wings with partially or totally subsonic leading edge. In the final version of SUSSA ACTS, supersonic unsteady flow is treated exactly as in the subsonic case, that is, both surfaces are considered simultaneously and diaphragms can be removed without any loss of accuracy or efficiency. This is a considerable improvement. For, the use of the program is now very simple in the subsonic regime as well as in the supersonic range. The details of the new formulation

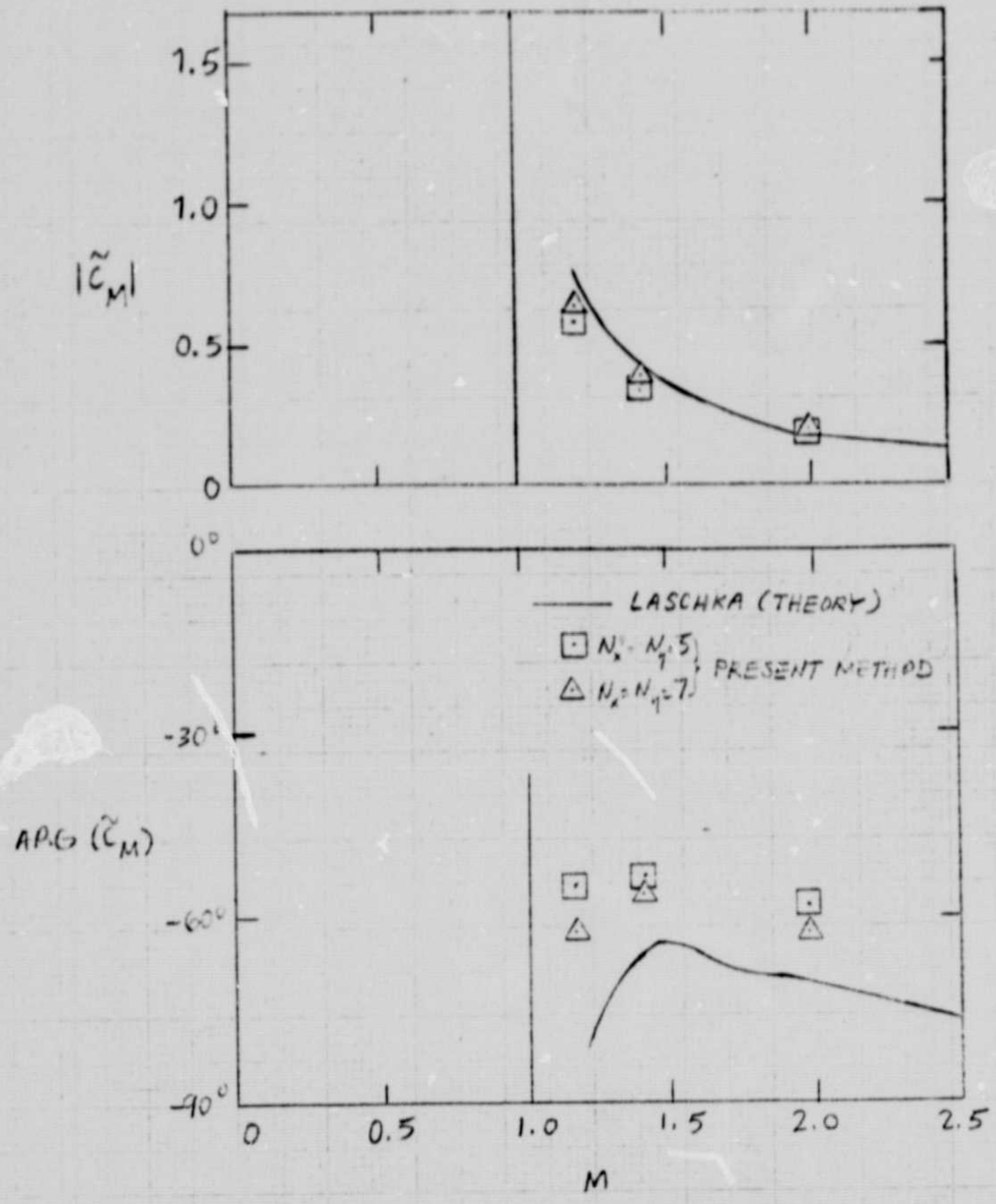

Fig 2b. Convergence analysis for Fig. 1b.

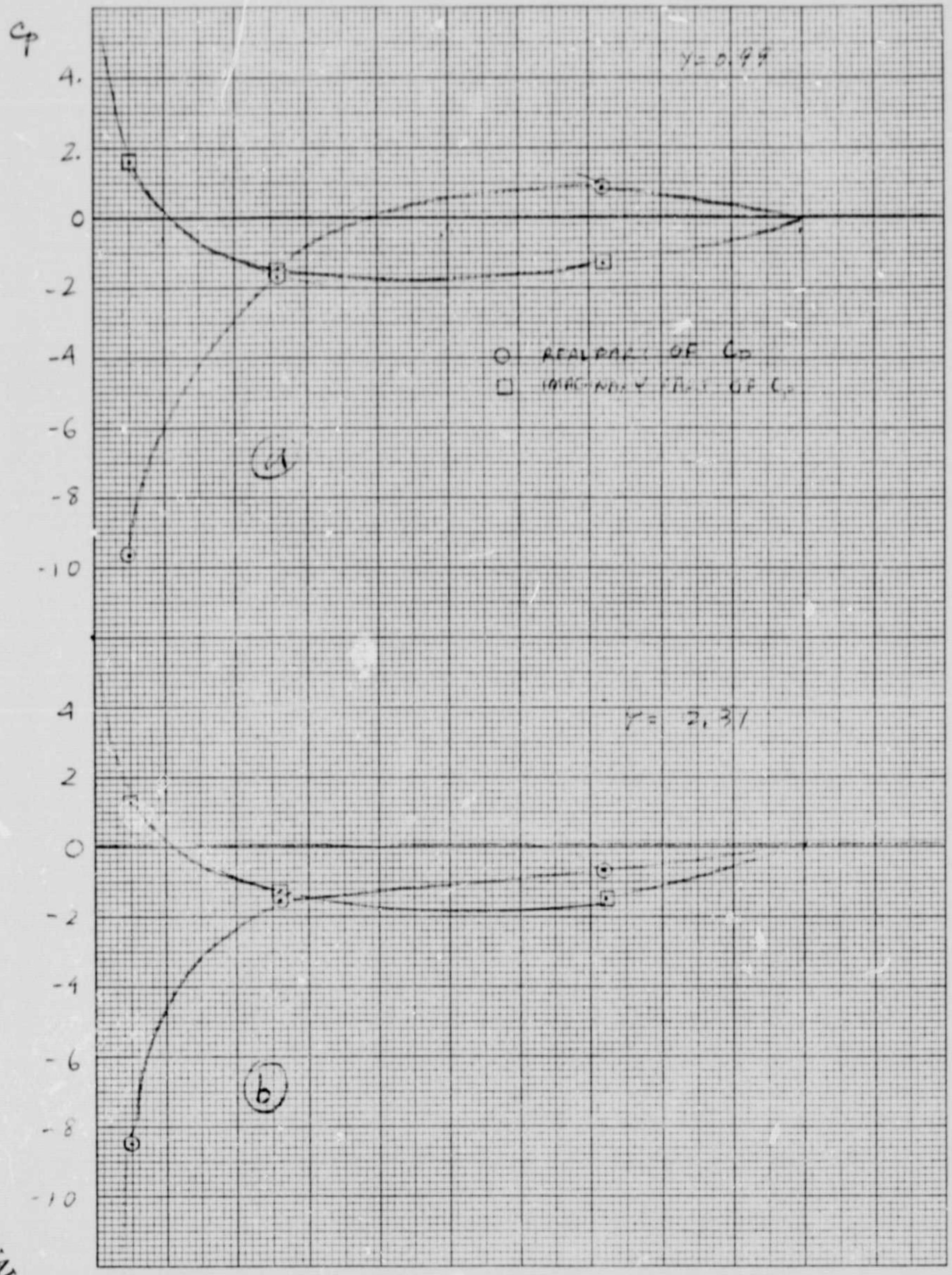

Fig. 3a and 3b. Pressure coefficient c_p on wing (at y = .99 and y = 2.31) as function of x for wing body configuration oscillating in pitch (M = .24)

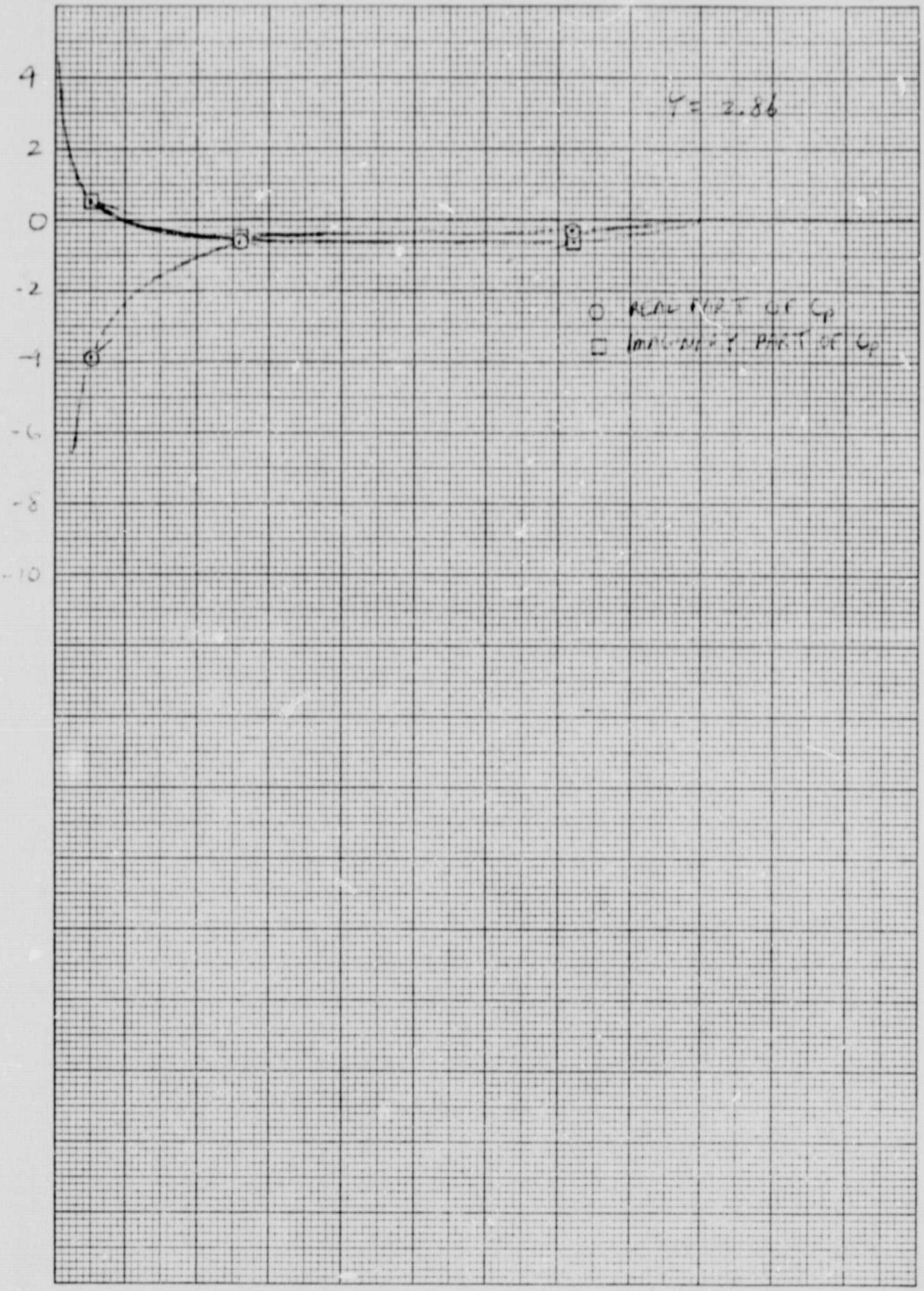

Fig. 3c Cont'd (y = 2.86)