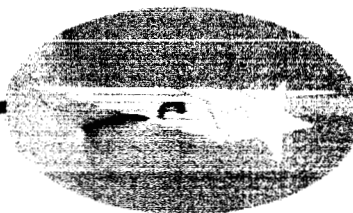


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THE AEROELASTIC CHARACTERISTICS
OF THE SATURN IB SA-201
LAUNCH VEHICLE

NASA CR 71024

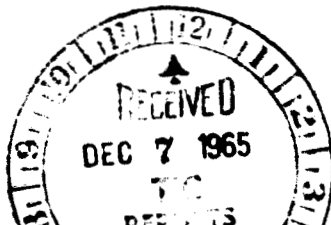
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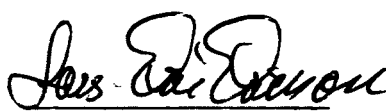
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THE AEROELASTIC
CHARACTERISTICS OF THE SATURN-IB
SA-201 LAUNCH VEHICLE

August 1965

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SUMMARY

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The flow environment surrounding the Saturn IB SA-201 vehicle is dominated by regions of separated flow in the transonic Mach number range. The highly non-linear loadings resulting from flow separation coupled with the modal deflections of a long flexible vehicle as the SA-201 have a dominant influence upon vehicle dynamics. A quasi-steady method requiring an experimental static load distribution as input has been used in analysis of the SA-201 vehicle to obtain the aerodynamic damping for the first three bending modes. The analytical results indicate that the SA-201 vehicle is aerodynamically damped over the critical Mach number range ($0.8 \leq M \leq 2.0$) and therefore is expected to be damped over the entire ascent Mach number range.

Autha

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NOTATION

C	force coefficient = $\text{Force}/\rho_{\infty}(U_{\infty}^2/2)S$
D_{REF}	reference length (6.5278 m for Saturn-IB SA-201)
M	Mach number
$\tilde{m}$	generalized mass (kg - sec ² /m)
P	pressure (kg/m ²)
q	dynamic pressure (kg/m ²)
S	reference area = $\pi D_{\text{REF}}^2/4$ (m ²)
α	angle of attack (deg or radian)
ρ	density (kg-sec ² /m ⁴)
ω	free-free bending frequency (radian/sec)
U	velocity (m/sec)
$\bar{U}$	average velocity (m/sec)
β	equivalent spike deflection angle (deg or radian)
θ	rotation angle (deg or radian)

Subscripts

m	pitching moment (kg-m)
N	normal force (kg)
s	separated flow
∞	undisturbed flow

Superscripts

i	induced, e. g. , $\Delta^i C_N$ = separation induced normal force coefficient
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Section 1
INTRODUCTION

The present study of the Saturn IB SA-201 vehicle has been conducted in support of the Saturn IB Program in providing damping characteristics for individual flight configurations as required. The results presented herein provide the damping characteristics, in percent of critical, for the Saturn IB SA-201 launch vehicle. As is characteristic of the Saturn IB series, SA-201 is a long flexible vehicle over which large regions of separated flow exist in the transonic Mach number range. The highly nonlinear aerodynamic loads resulting from flow separation are known to considerably influence the damping characteristics of such vehicles. A quasi-steady analytical method, described in Ref. 1, which includes the effects of separated flow has been applied in the present study to determine the SA-201 damping. The following section, in two parts, describes the static aerodynamic loads used in the quasi-steady analysis and contains a discussion of the damping results for the SA-201 vehicle.

Section 2

SATURN IB SA-201 ANALYSIS

2.1 STATIC AERODYNAMIC ANALYSIS

As is characteristic of the Saturn IB series vehicles, the Apollo payload is responsible for the major effects of flow separation on the SA-201 vehicle. (See Fig. 2-1.) The escape-rocket wake represents the most prominent single region of flow separation. Furthermore, due to the large modal deflections occurring at the forward portion of the vehicle, the Apollo-payload has a significant influence on the vehicle damping. Subsequently, the analytic and experimental effort was in great part directed toward obtaining an accurate description of the loading over the Apollo-payload portion of the vehicle.

The static aerodynamic load characteristics for SA-201, presented in Appendix A, correspond to the Saturn-IB characteristics presented in Ref. 2. A small difference in length of the lunar excursion module, on the order of 2.5 percent, has no measureable effect on the static load characteristics and thus the inclusion of the results of the Saturn-IB analysis is expedient. Within the Saturn-IB analysis, pressure data were correlated with segmented force data such that the magnitudes of the ill-defined negative load peaks were varied until agreement with force data was achieved for both normal force and center of pressure. Experimental data used in the analysis were obtained from Refs. 3 through 16. Excellent agreement between summed, lumped force distributions and overall force data for SA-201 is shown in Fig. 2-2.

2.2 AERODYNAMIC DAMPING ANALYSIS

The damping derivatives obtained as a result of the quasi-steady analysis may be confidently discussed by considering the geometric and elastic characteristics of the vehicle in relation to the loadings generated by the surrounding flow. The static load

distribution provides a knowledge of the location and magnitude of the important non-linear loads resulting from flow separation. This coupled with the modal characteristics of the vehicle constitute the primary factors influencing the equivalent damping distribution resulting from the quasi-steady analysis.

The SA-201 damping, as in the case of the Saturn-IB of Ref. 2, is most heavily influenced by the Apollo command module. Large loadings and large modal deflections occur for this portion of the vehicle. As seen in Fig. 2-3 the damping curves at $\alpha = 0^\circ$ for Saturn-IB and SA-201 are very similar for all three bending modes. In the first mode SA-201 exhibits slightly smaller command module deflections causing the damping to fall below that of the Saturn-IB. Second and third mode differences relate primarily to the smaller critical damping factor, $-\rho U_\infty S / 4\omega \tilde{m}$, for the SA-201 vehicle. The modal characteristics and trajectory information used in the analysis were taken from Refs. 17 and 18. The results of the SA-201 analysis are indicated in Fig. 2-4 which presents the damping in percent of critical for 0, 4 and 8 degrees angle-of-attack. In all cases SA-201 exhibits positive damping characteristics indicating that the vehicle is dynamically stable.

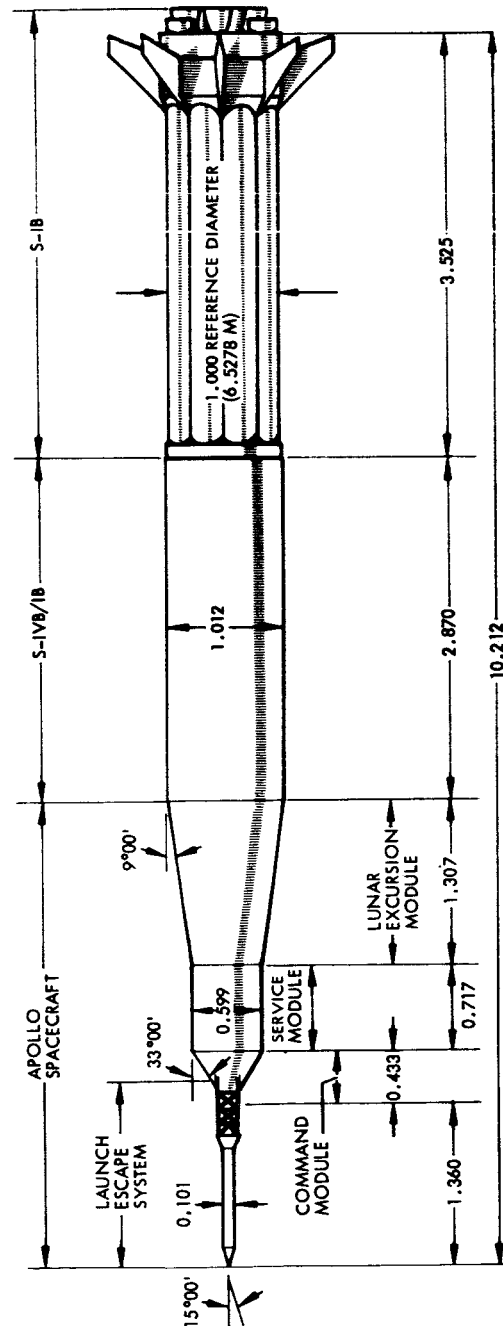


Fig. 2-1 SA-201 Configuration

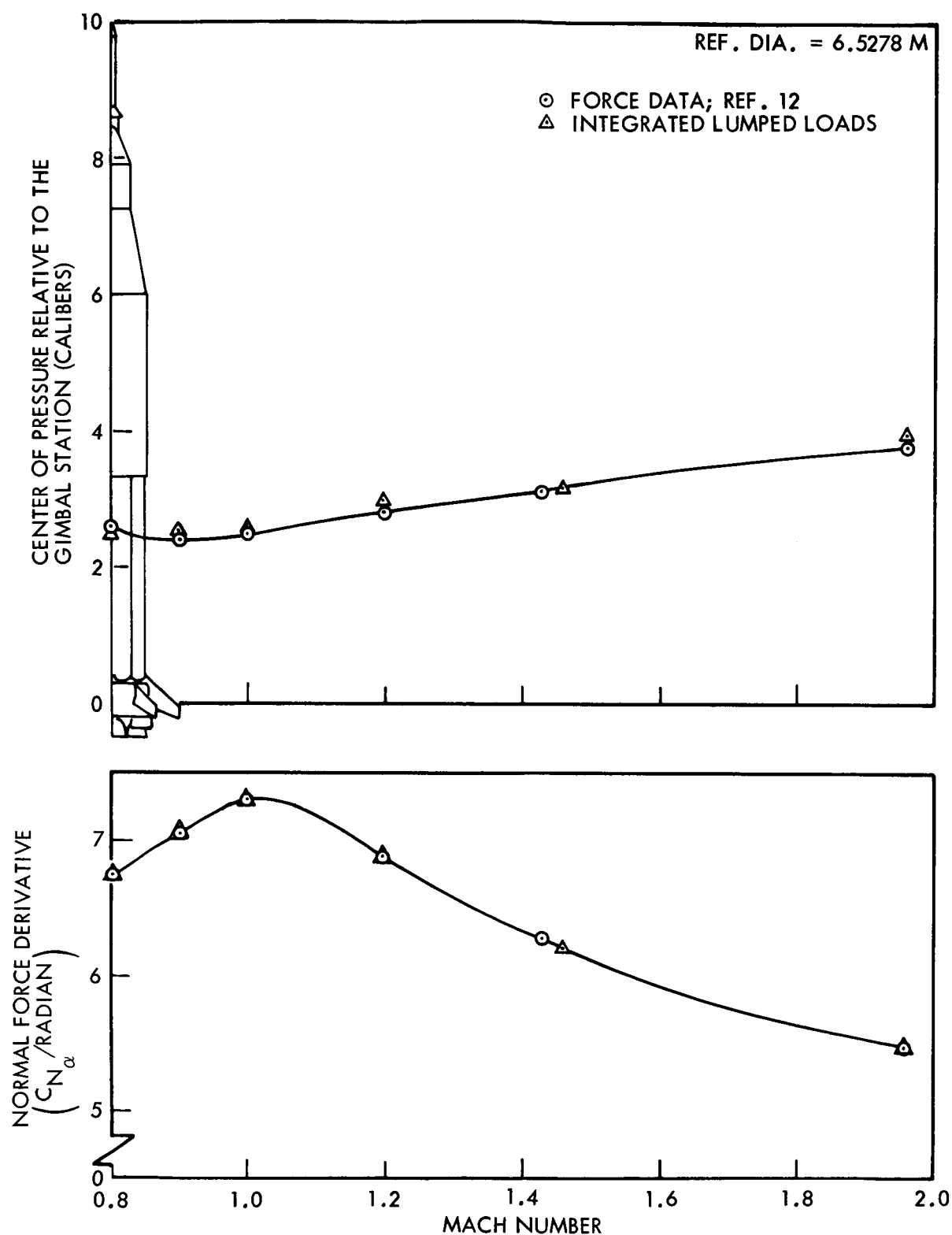


Fig. 2-2 Comparison of SA-201 Integrated Lumped Loads with Force Data Results at $\alpha = 0$

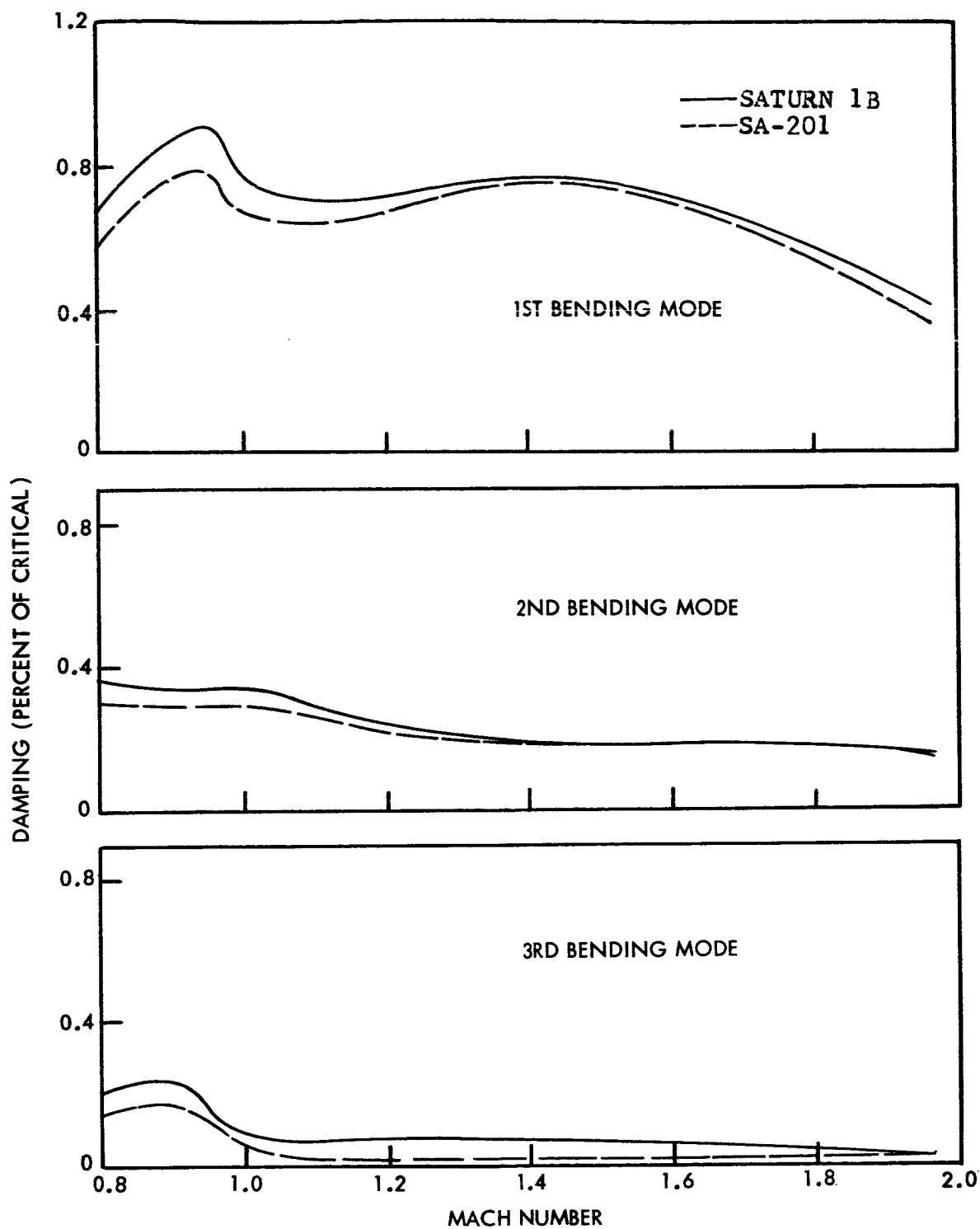


Fig. 2-3 Comparison of Saturn 1B and SA-201 Damping Characteristics at $\alpha = 0$

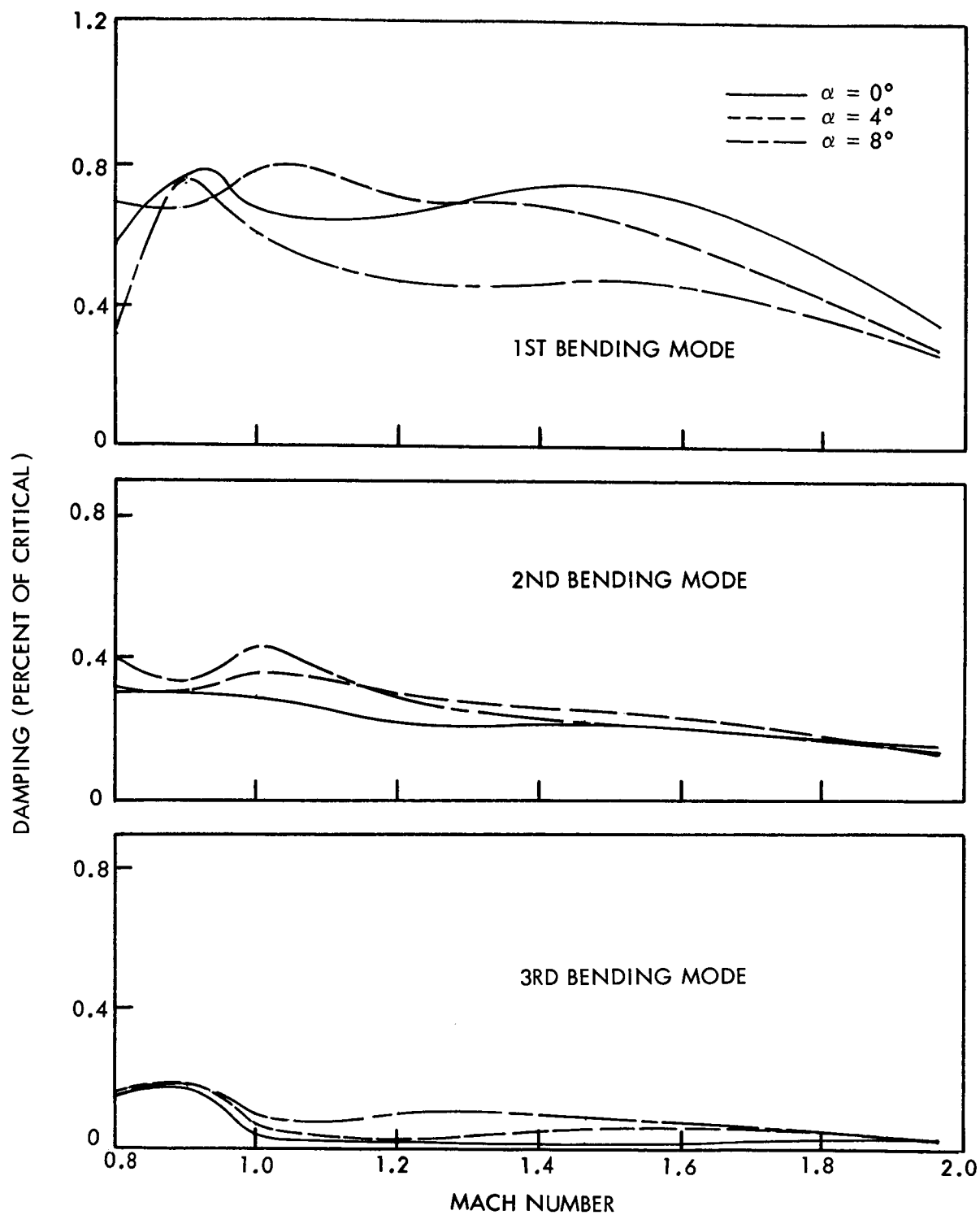


Fig. 2-4 SA-201 Aerodynamic Damping

Section 3
CONCLUSIONS

The Saturn-IB SA-201 vehicle has been studied using a quasi-steady analysis to determine the damping characteristics. The results indicate that SA-201 is aerodynamically damped over the critical Mach number range ($.8 \leq M \leq 2.0$) for the first three bending modes. It may be concluded that the vehicle will be damped throughout atmospheric ascent.

Section 4

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Appendix A
DOCUMENTATION OF SA-201 LUMPED LOADS

The $\alpha = 0^\circ$, lumped load representation used in computing the SA-201 damping is documented in this Appendix. Figure A-1 relates the lumped loads to the general SA-201 force distribution. Both local and induced lumped loads are plotted in Figs. A-1 through A-4, and their centers of pressure appear in Fig. A-5. Figure A-6 presents the local and induced axial force moments on the command module and interstage flares, and Fig. A-7 shows the velocity ratios for each of the separated regions.

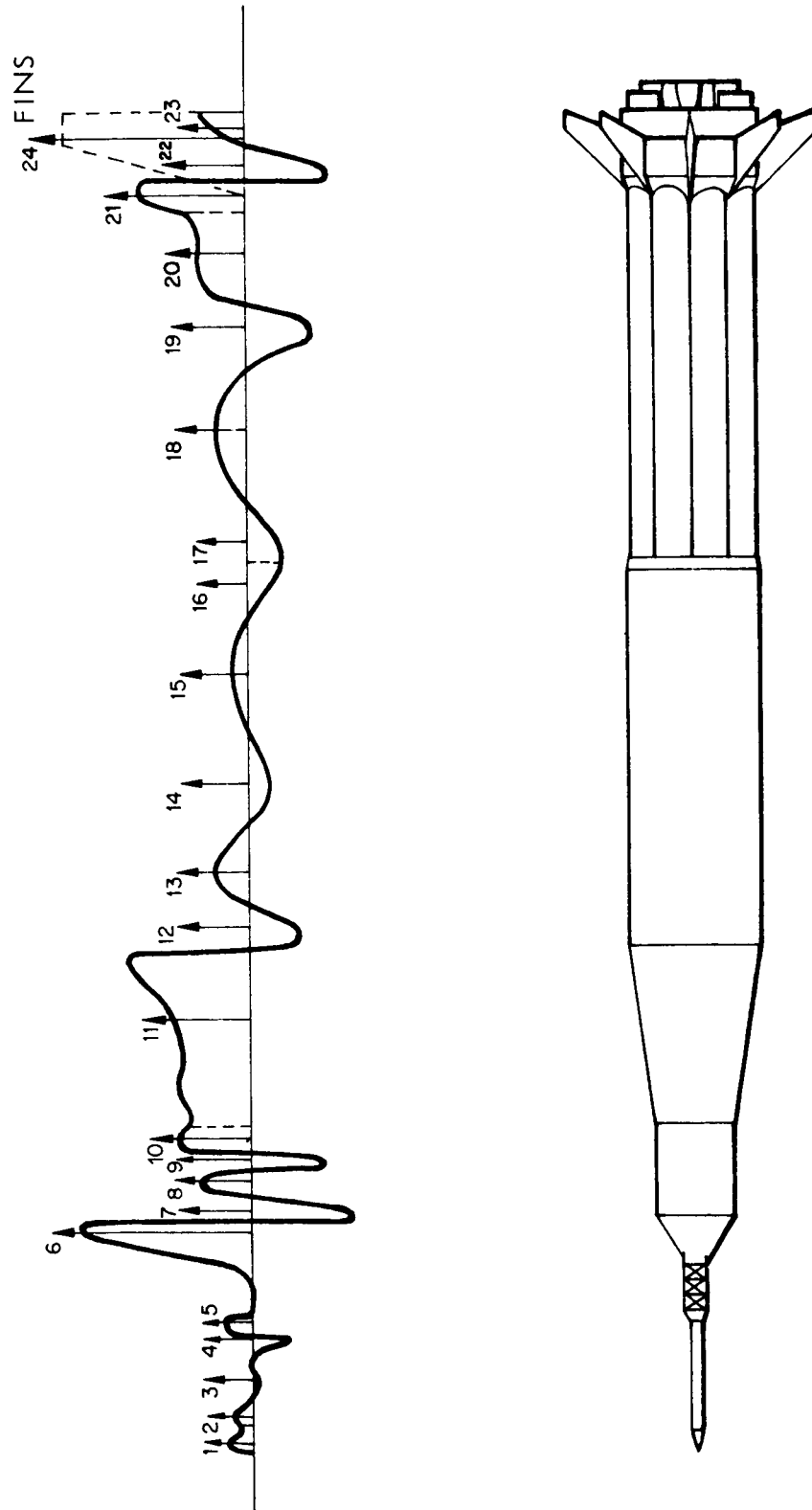


Fig. A-1 SA-201 Definition of Lumped Normal Force Vectors

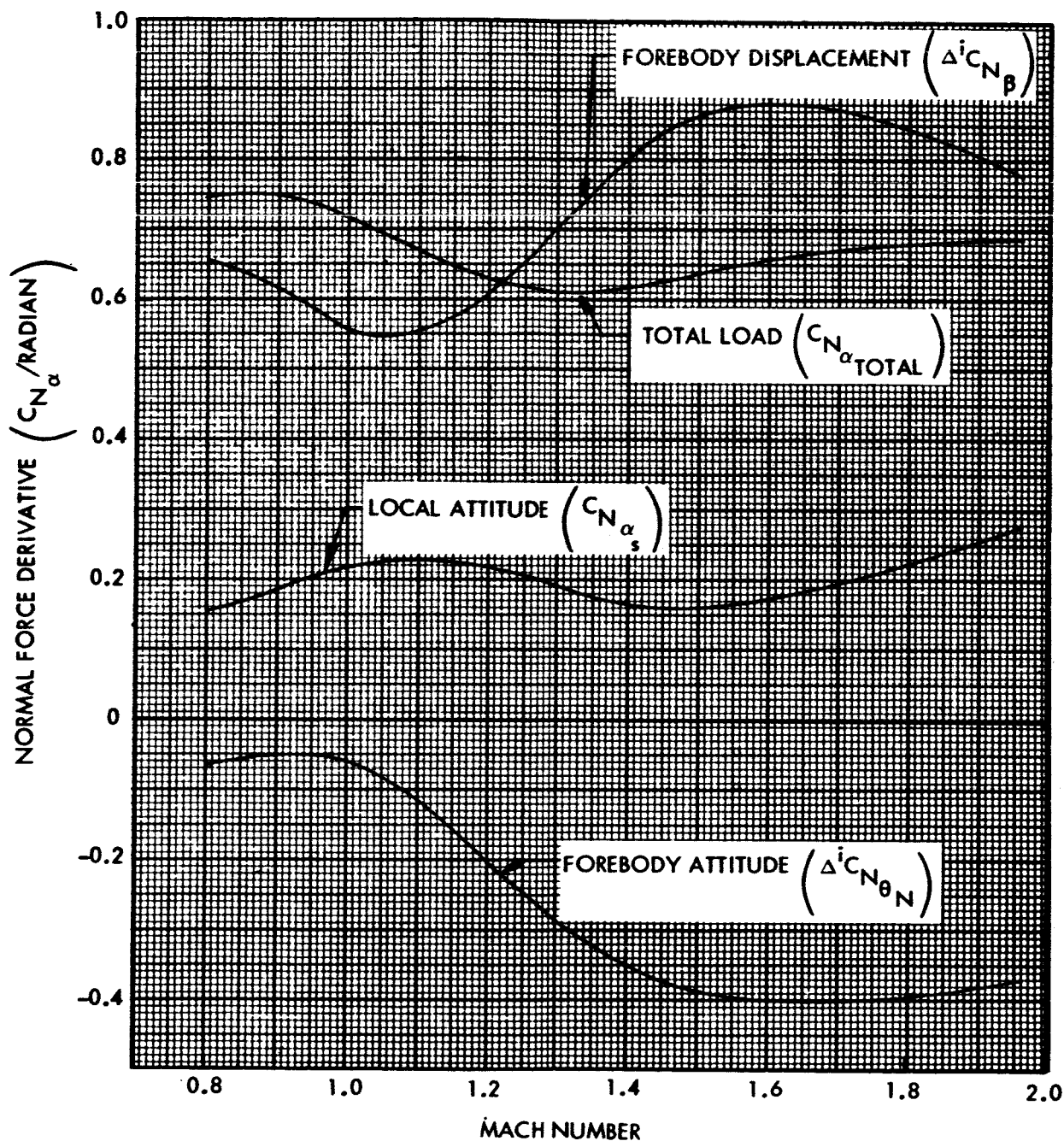


Fig. A-2 SA-201 Local and Forebody-Dependent Command Module Loads at $\alpha = 0$

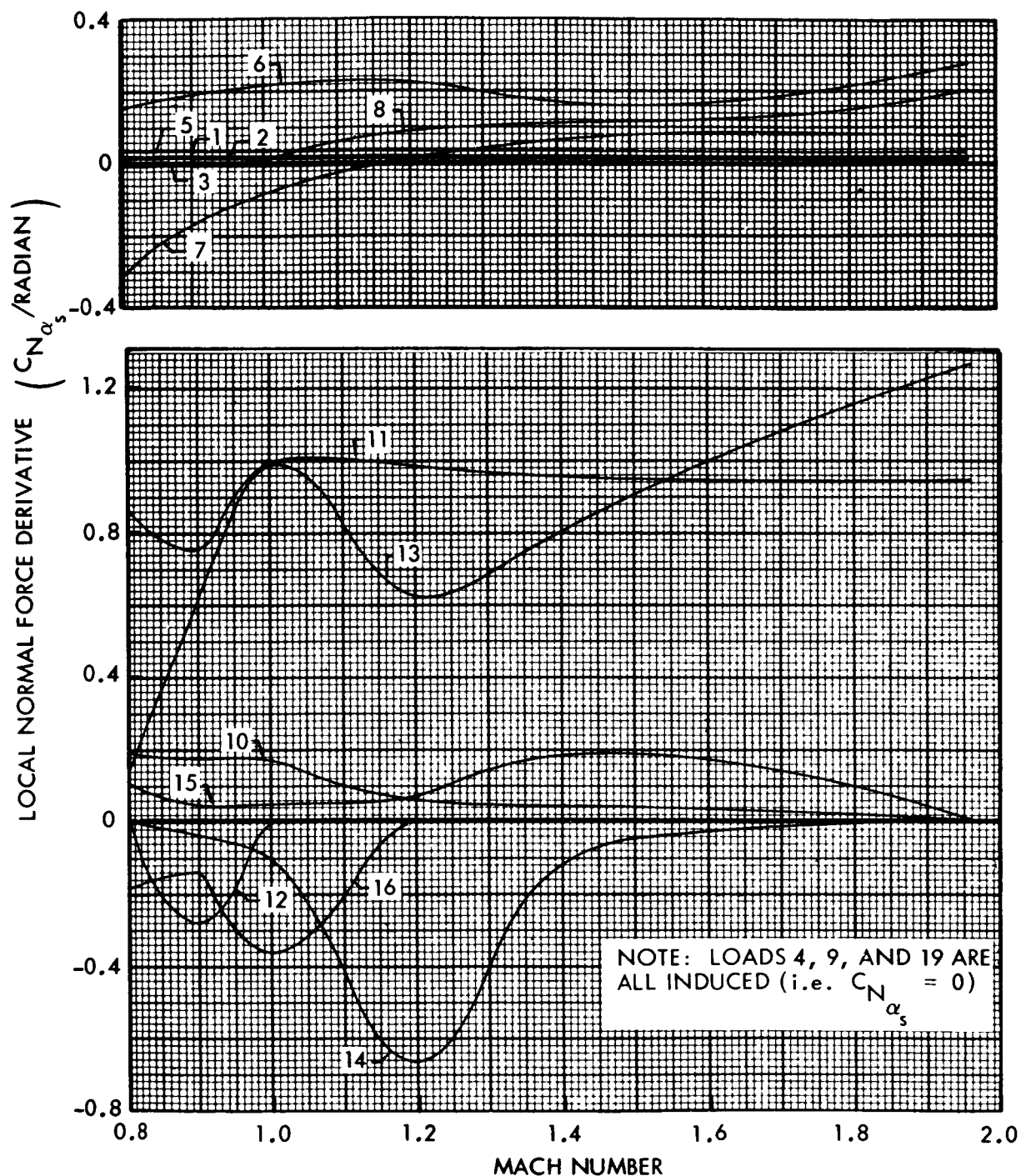


Fig. A-3 SA-201 Local Normal Force Derivatives at $\alpha = 0$

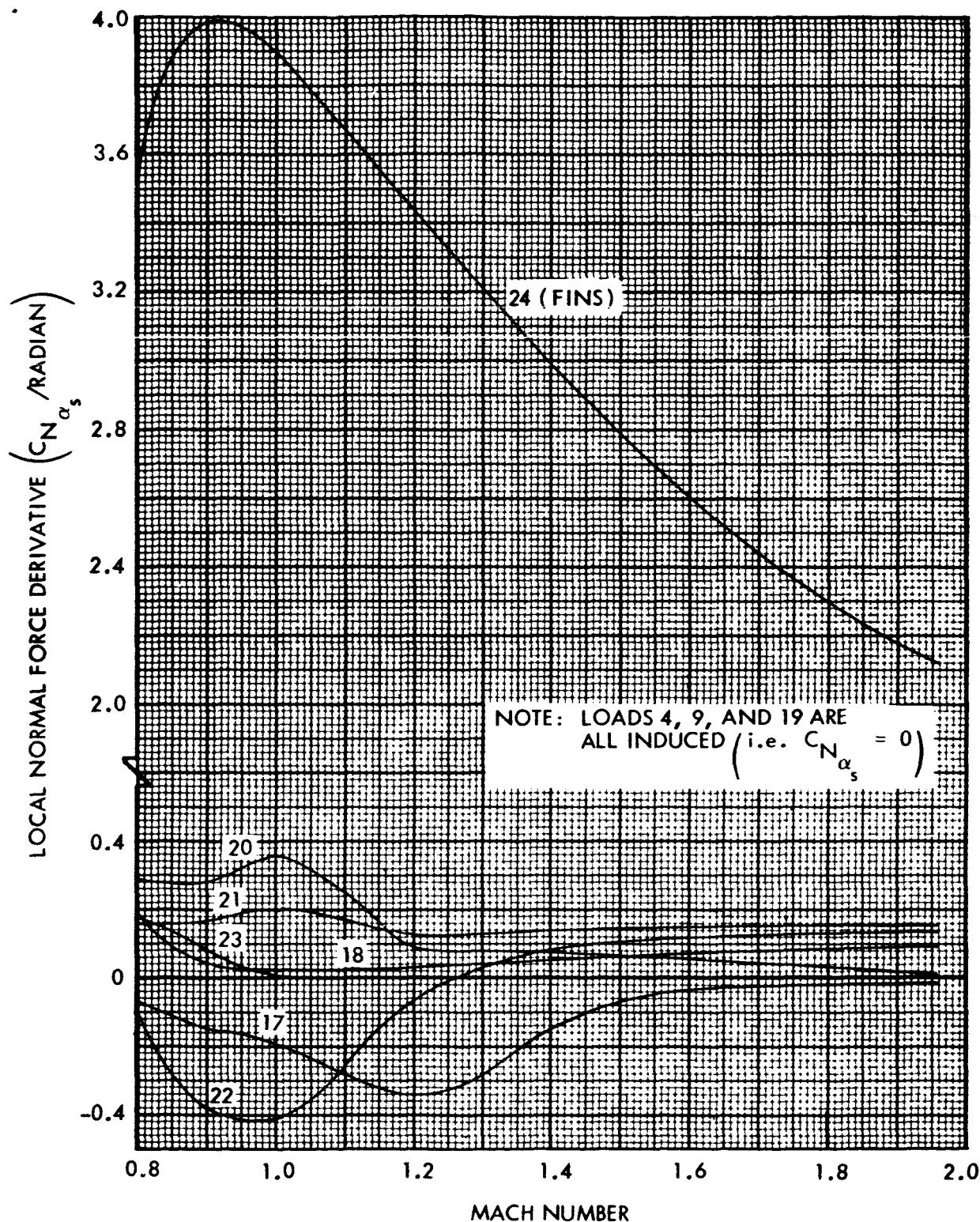


Fig. A-3 SA-201 Local Normal Force Derivatives at $\alpha = 0$ (cont.)

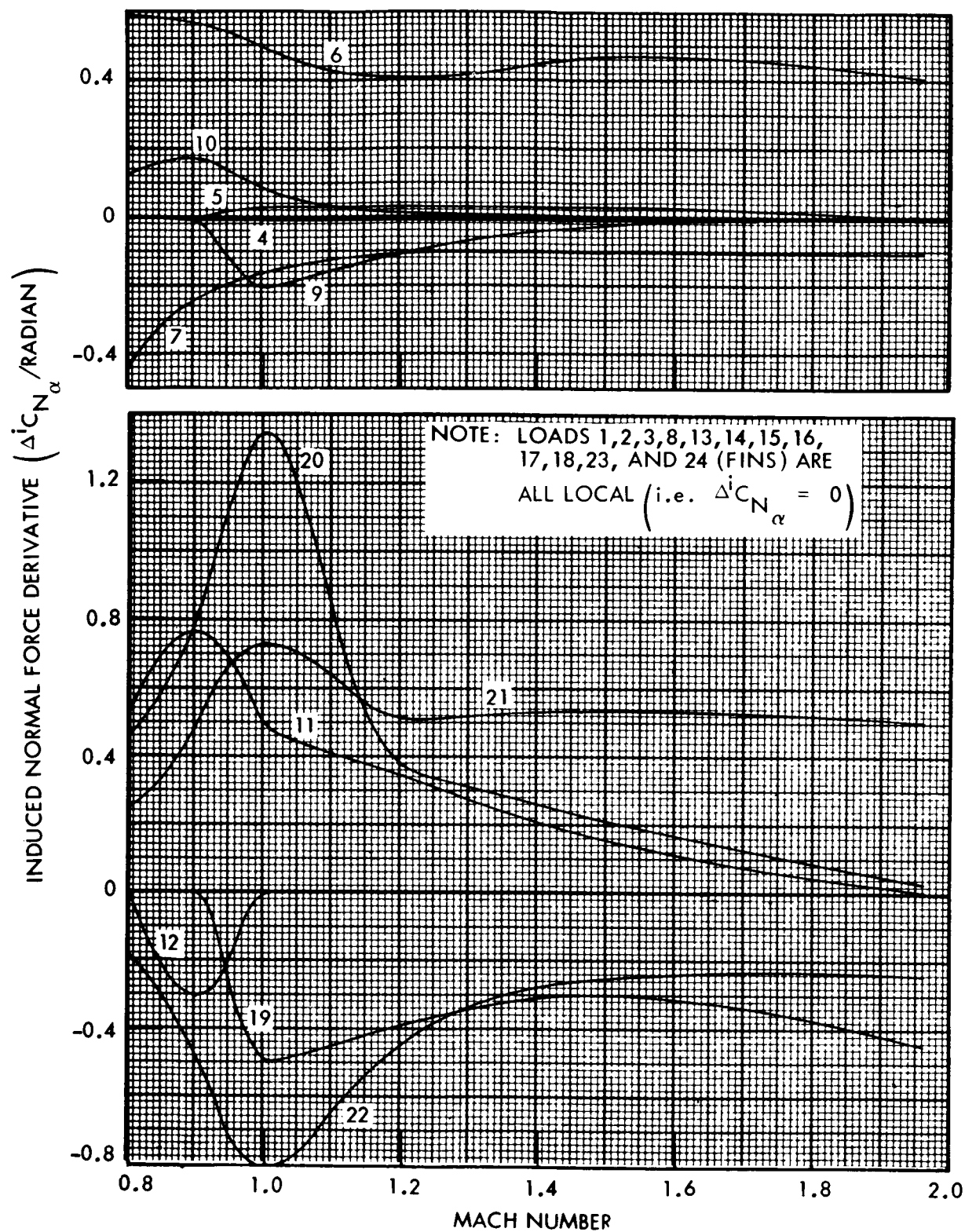
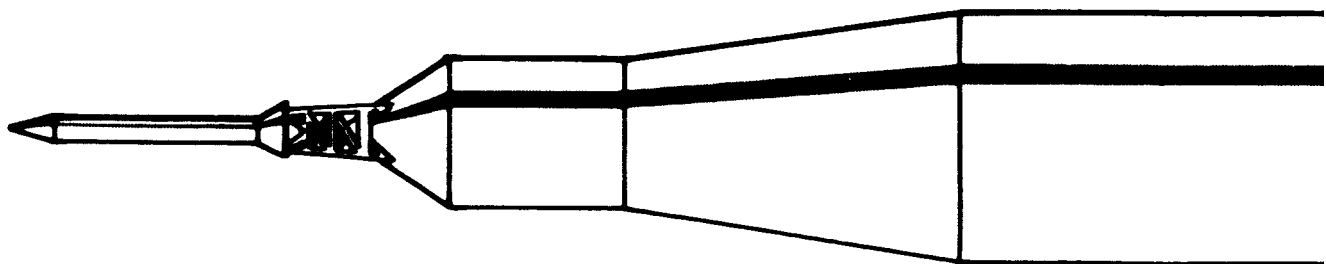
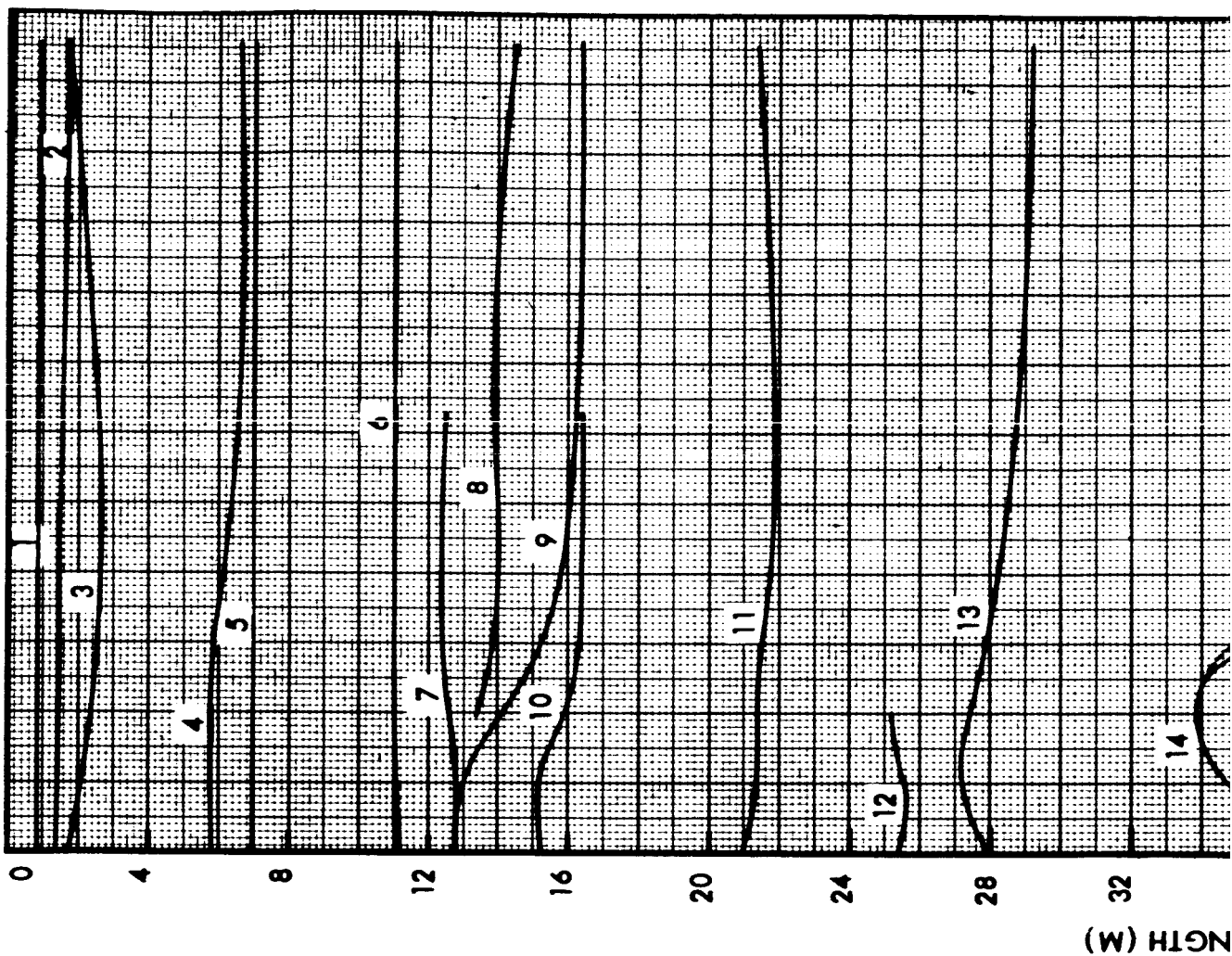


Fig. A-4 SA-201 Induced Normal Force Derivatives at $\alpha = 0$



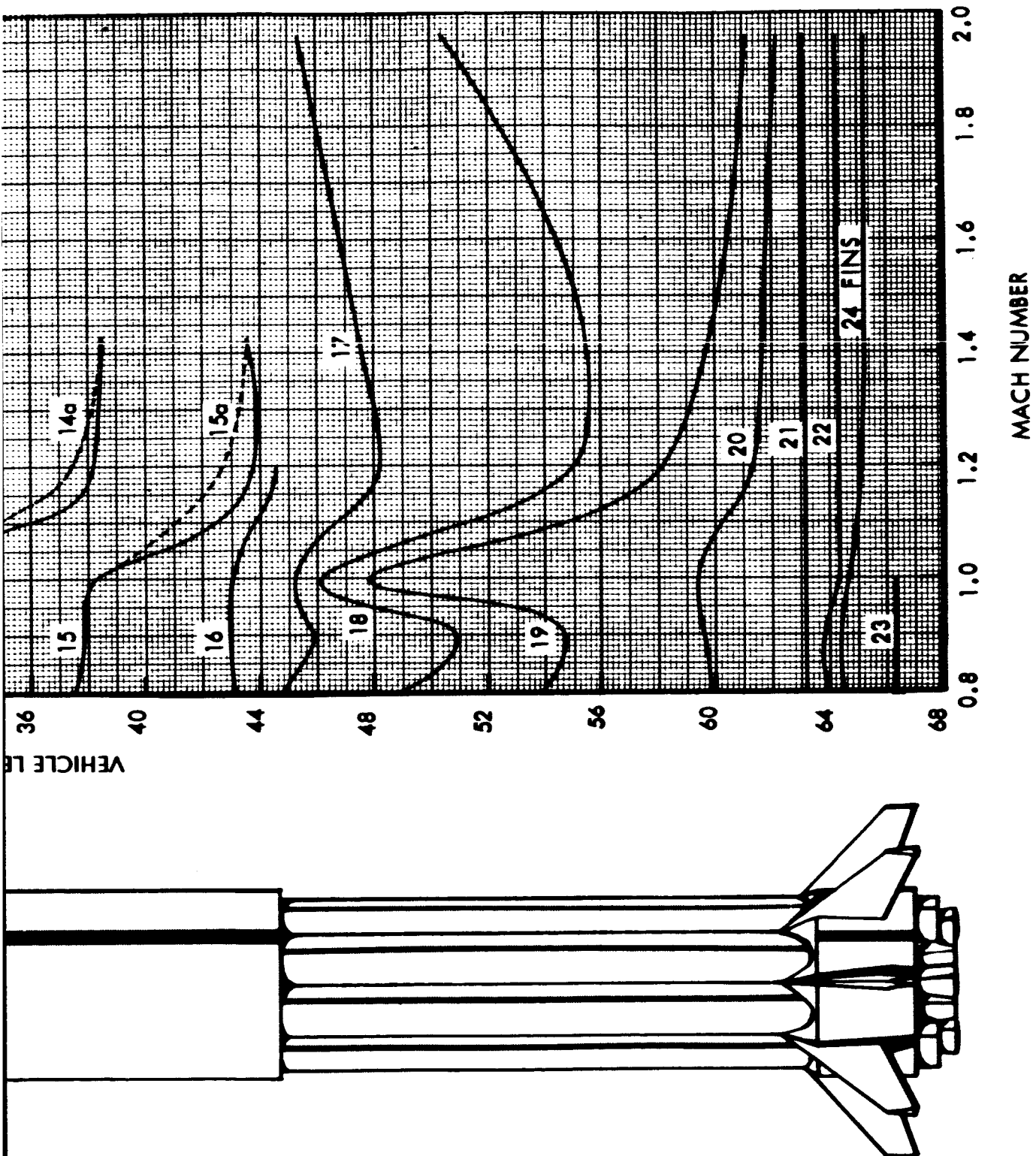


Fig. A-5 SA-201 Lumped Load Centers of Pressure at $\alpha = 0$

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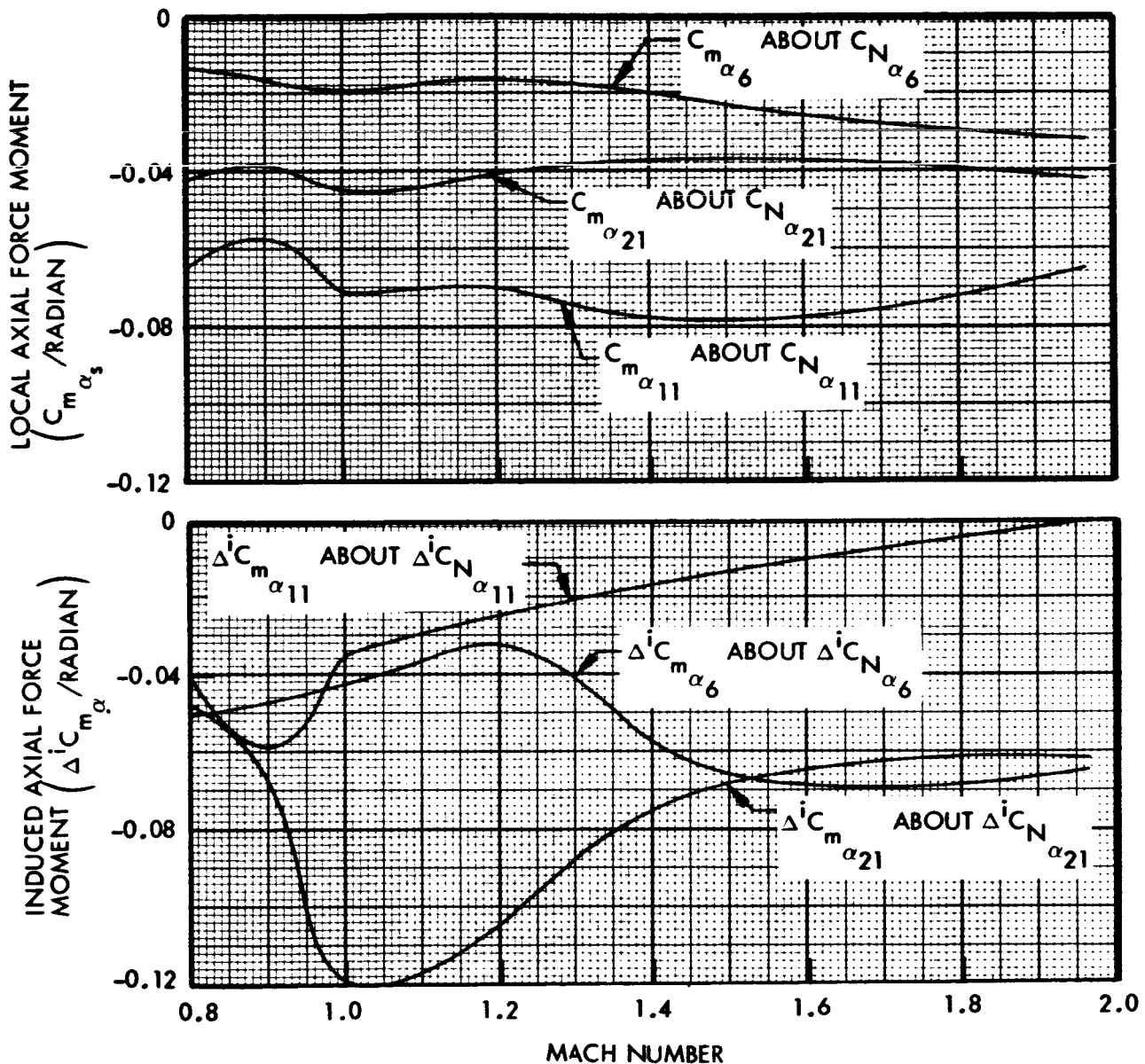


Fig. A-6 SA-201 Local and Induced Command Module and Flare Axial Force Moment Derivatives at $\alpha = 0$

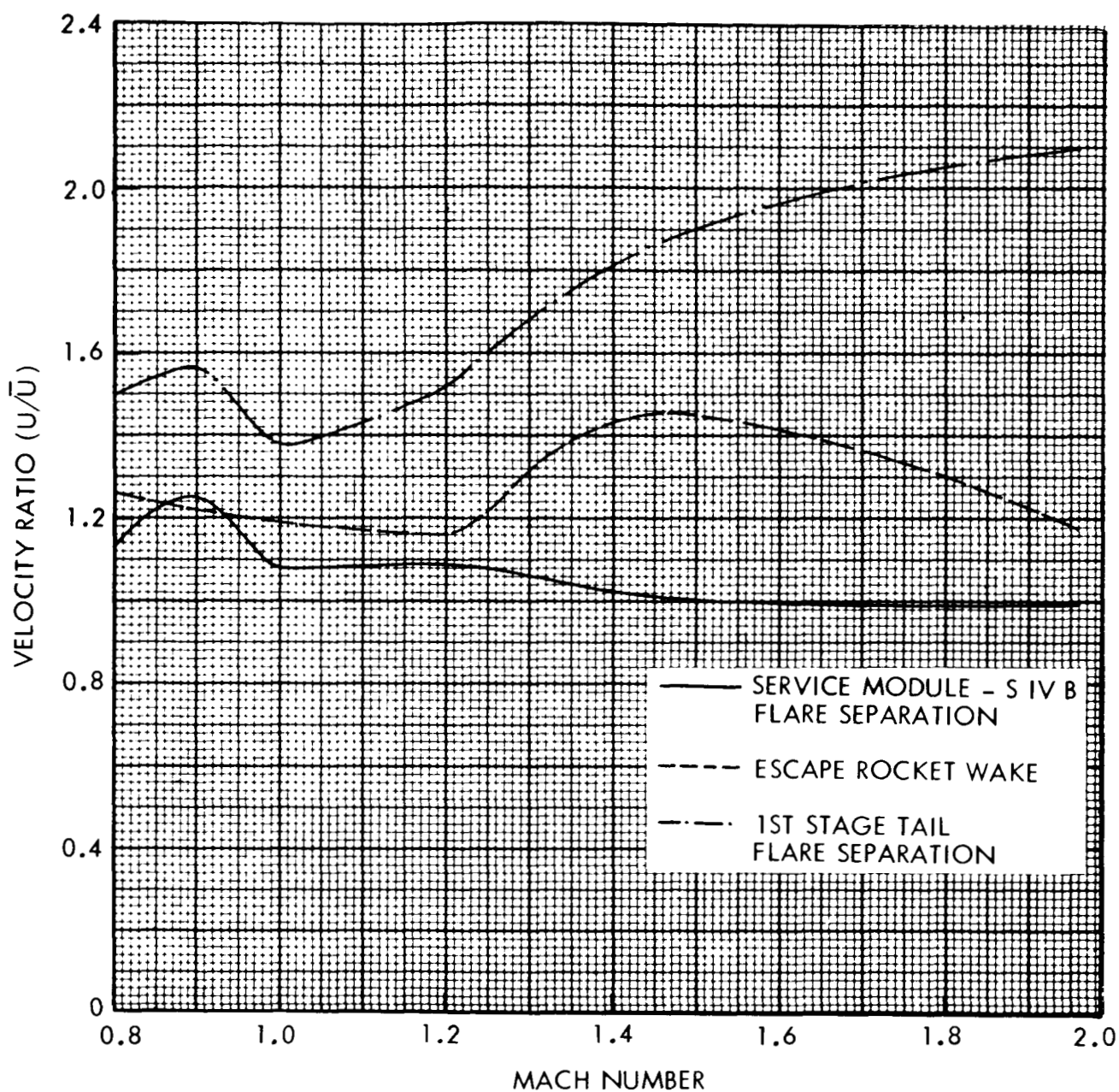


Fig. A-7 SA-201 Separated-Flow Velocity Ratios at $\alpha = 0$

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THE AEROELASTIC
CHARACTERISTICS OF THE SATURN-1B
SA-202 LAUNCH VEHICLE

(Addendum to LMSC Report M-37-65-2)

5-19-66

ADDENDUM

Analysis of the Saturn IB SA-202 Launch Vehicle

The results of the SA-202 damping analysis are presented herein as an addendum to LMSC report M-37-65-2. Since there have been no changes in the configuration or the structural characteristics of the Saturn IB vehicle between the flight vehicles SA-201 and SA-202, both the aerodynamic characteristics, presented in Appendix A, and the structural characteristics documented in Ref. 17 and 18 for SA-201 vehicle apply as well to the SA-202 vehicle. The launch trajectory data, secured from Ref. 19, has been used in the calculation of the damping characteristics presented (in percent of critical) in Fig. 1 of this addendum. It is observed from the quasi-steady method that perturbations in launch trajectory will affect only the relative magnitude of the damping and will not change the sign. This is confirmed by the results in Fig. 1-ADD which predict positive damping for the SA-202 which is characteristically similar to the SA-201. It is concluded that the SA-202 vehicle will be dynamically stable throughout atmospheric ascent.

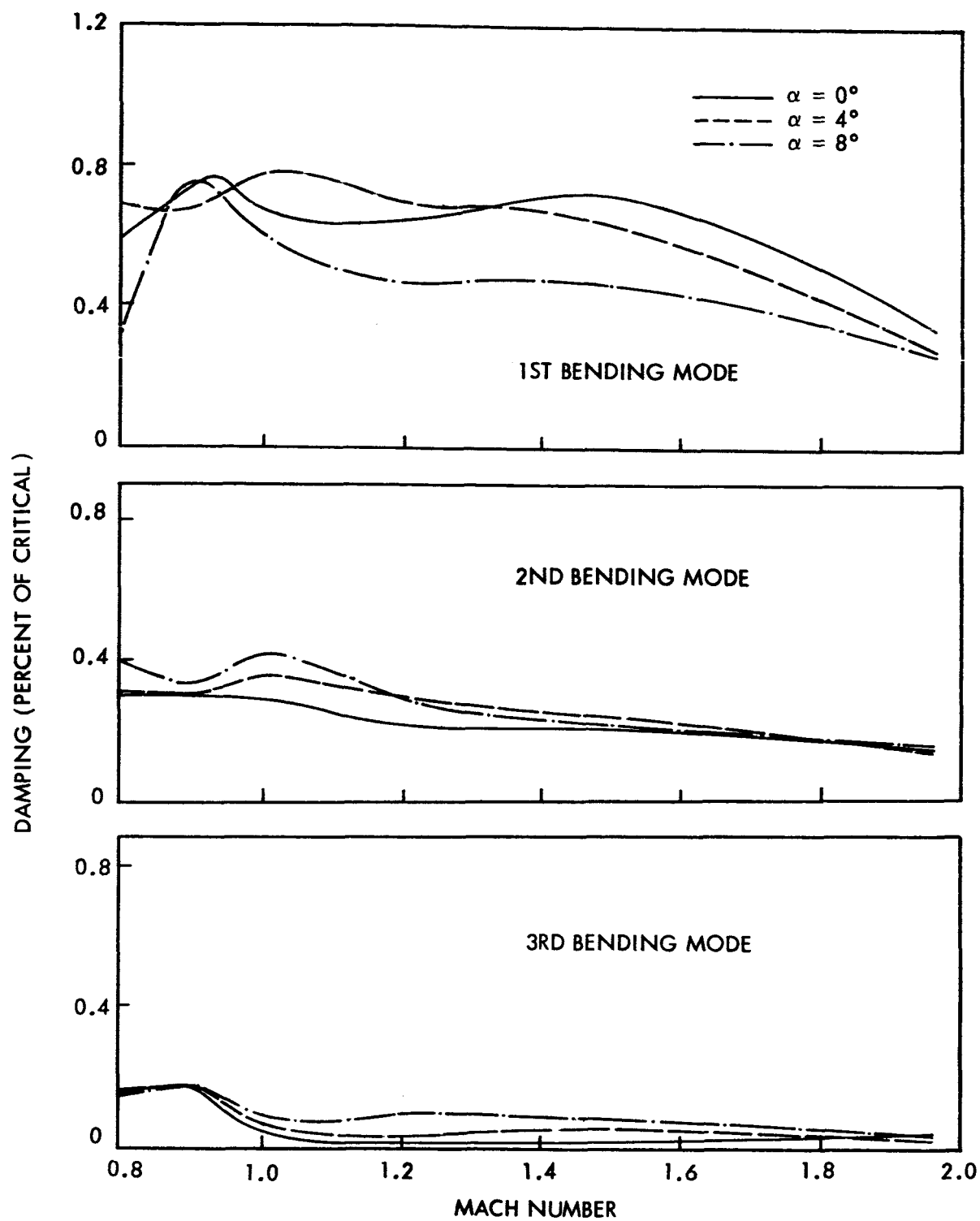


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