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ABSTRACT

An experimental investigation was conducted in the Langley 20-Inch Mach 6 Tunnel to visualize the flow field about external axial corners. The investigation was initiated to provide answers to questions about the inviscid flow pattern for continuing numerical investigations. Symmetrical and asymmetrical corner models were tested at a Reynolds number per meter of 6.07×10^7. Oil-flow and vapor-screen photographs were taken for both models at angle of attack and yaw. The paper presents the results of the investigation in the form of oil-flow photographs and the surrounding shock wave location obtained from the vapor screens.

SUMMARY

An experimental investigation was conducted in the Langley 20-Inch Mach 6 Tunnel to visualize the flow field about external axial corners. The investigation was designed to answer questions about the inviscid flow pattern about external corners for ongoing numerical investigations. Symmetrical and asymmetrical corner models were tested at angle of attack and yaw. Oil-flow and vapor-screen photographs were obtained for both models.

Examination of the photographs showed the conical nature of the inviscid flow about the corner and also the viscous aspects of the flow. For the asymmetrical model the results clearly show flow over the corner.

INTRODUCTION

Determination of the aerodynamic characteristics for a supersonic or hypersonic vehicle requires an understanding of the flow fields about its basic geometric features. External corners, such as those shown in figure 1 are found, for example, on the engine inlets of these vehicles (see ref. 1). Prediction of the flow field about the external corners is important to determine the loading on the vehicle as well as interference effects due to the corner. Therefore, an understanding of the inviscid flow pattern is necessary before the viscous effects can be examined in greater detail.

Early theoretical inviscid studies were done on external corners and related problems but were limited by their linearization of the governing equations (refs. 2 and 3). Recently several nonlinear inviscid results have been obtained for the corner flow field and are presented in references 4 and 5. However, to date there has been little or no experimental work conducted to help evaluate the numerical work.

The results presented in references 4 and 5 may not correctly represent the physical problem even though they are solutions to the equations (see ref. 6). Therefore, an experimental investigation was conducted to examine the flow field about external axial corners. The intent was to answer questions about the inviscid flow pattern and to show the viscous characteristics of the flow field. To accomplish this, oil-flow and vapor-screen studies were conducted on both symmetrical and asymmetrical corner models in the Langley 20-Inch Mach 6 Tunnel. For a description of the flow visualization techniques see reference 7. The tests included angle of attack and yaw. Reference 6 contains the results of an associated theoretical investigation of the structure of the flow field.

SYMBOLS

M_∞	Mach number
P_t	total pressure, N/m^2
T_t	total temperature, K
δ_1	face 1 wedge angle, degrees
δ_2	face 2 wedge angle, degrees
Λ_1	face 1 sweep angle, degrees
Λ_2	face 2 sweep angle, degrees
α	angle of attack, degrees
β	angle of yaw, degrees

MODEL DESCRIPTION

The results presented were obtained on the two models shown in figure 1. These configurations were selected to conform with those studied in references 5 and 6.

The symmetrical model was constructed using two 10° carbon steel wedges swept forward at 30° ($\delta_1 = \delta_2 = 10°$ and $\Lambda_1 = \Lambda_2 = 30°$). The wedges were joined as shown in figure 1a and the axial corner is defined to be the line of intersection of the two wedge surfaces. The asymmetrical corner was similarly constructed with $\delta_1 = 10°$, $\delta_2 = 5°$, $\Lambda_1 = 30°$ and $\Lambda_2 = -30°$, see figure 1b.

TEST CONDITIONS

The two models described above were tested in the Langley 20-Inch Mach 6 Tunnel under the following conditions:

$M_\infty = 6$

$Re/m = 6.07 \times 10^7$ (for oil flow and vapor screen)

$P_t = 2.76 \times 10^6$ N/m^2

$T_t = 292$ K

The following conventions were selected to describe the corner configuration tested:

(1) The wedge containing the sting mount was labeled Face 1 and the other wedge Face 2.

(2) Positive angle of attack, α, was designated nose (corner) down.

(3) Positive angle of yaw, β, was measured clockwise as seen from above in the direction of the incoming flow.

(4) All vapor screens were taken in a plane perpendicular to the free-stream flow. The plane intersected the model 7.62 cm upstream from the rear of the model measured along the axial corner.

Oil-flow and vapor-screen tests were conducted for the conditions indicated in Table 1 and Table 2. The numbers in parenthesis indicate the corresponding figure in the report which contains the photographic data. Note: For the asymmetrical model no vapor screen was taken for the α = 5° β = -5° case.

TABLE 1

SYMMETRICAL MODEL

α \ β	0	5
0	(3)	(4)
5		(5)
10		(6)

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TABLE 2

ASYMMETRICAL MODEL

α \ β	0	5	-5
0	(7)	(10)	
5	(8)	(11)	(13)
10	(9)	(12)	

RESULTS AND DISCUSSION

The results are presented by model and test condition as shown in figure 2. Photographs are included for both model faces. Shock locations obtained from the vapor-screen photographs are also presented. The locations have been corrected for line of sight and camera angle and the surrounding shock wave is displayed in the vapor-screen plane. Note: For simplicity Face 2 was aligned with the grid system, therefore, the diagram has been artificially rotated in the vapor-screen plane.

A short description of conical flow taken from reference 8 is included to assist in the discussion of the oil flow results.

> "Conical flow is an inviscid steady flow which is invariant with respect to a scale transformation. The origin of the coordinates is termed the vertex, and straight lines through the vertex are called rays. The principal property of conical flow is that the vector velocity and all thermodynamic quantities are constant along rays and thus are functions only of two independent coordinate variables

describing the rays. The coordinates are here chosen as coordinates in the surface as a unit sphere.

"It is convenient to consider the velocity vector decomposed into a radial component (normal to the unit sphere) and a cross component (tangent to the unit sphere). The projection of the velocity vector on the unit sphere gives an apparent two-dimensional cross flow in the unit sphere."

As indicated in figure 2, where appropriate, a sketch in the cross flow plane is included showing the proposed flow field near the corner, based on interpretation of the oil-flow photographs. This is the cross flow plane discussed above and is formed by projecting the flow field onto the surface of a unit sphere centered at the conical origin (the axial corner vertex) and then projecting this surface onto a plane.

Figures 3 through 6 represent the results for the symmetrical model. Similarly figures 7 through 13 were obtained for the asymmetrical model.

The following observations can be noted from the photographs. For the symmetrical model the results show the conical nature of inviscid flow about the corner, however, the viscous effects present are very weak in comparison to the asymmetrical results.

The photographs obtained with the asymmetrical model clearly show that the results obtained in references 4 and 5 do not reflect the physical problem. Their results did not allow for flow over the axial corner. Clearly evident in the photographs of Face 2 is the vortex shed due to the sharp expansion over the corner. See reference 6 for more discussion on the structure of the flow field about the corner. In some cases, the expansion also produces a separation region near the corner.

CONCLUDING REMARKS

An experimental study was conducted to investigate the flow field about external axial corners. Oil-flow and vapor-screen photographs at various test conditions show the conical nature of inviscid flow and show the viscous effects that are present. For the asymmetrical model the results clearly show flow over the corner and lend support to ongoing numerical investigations.

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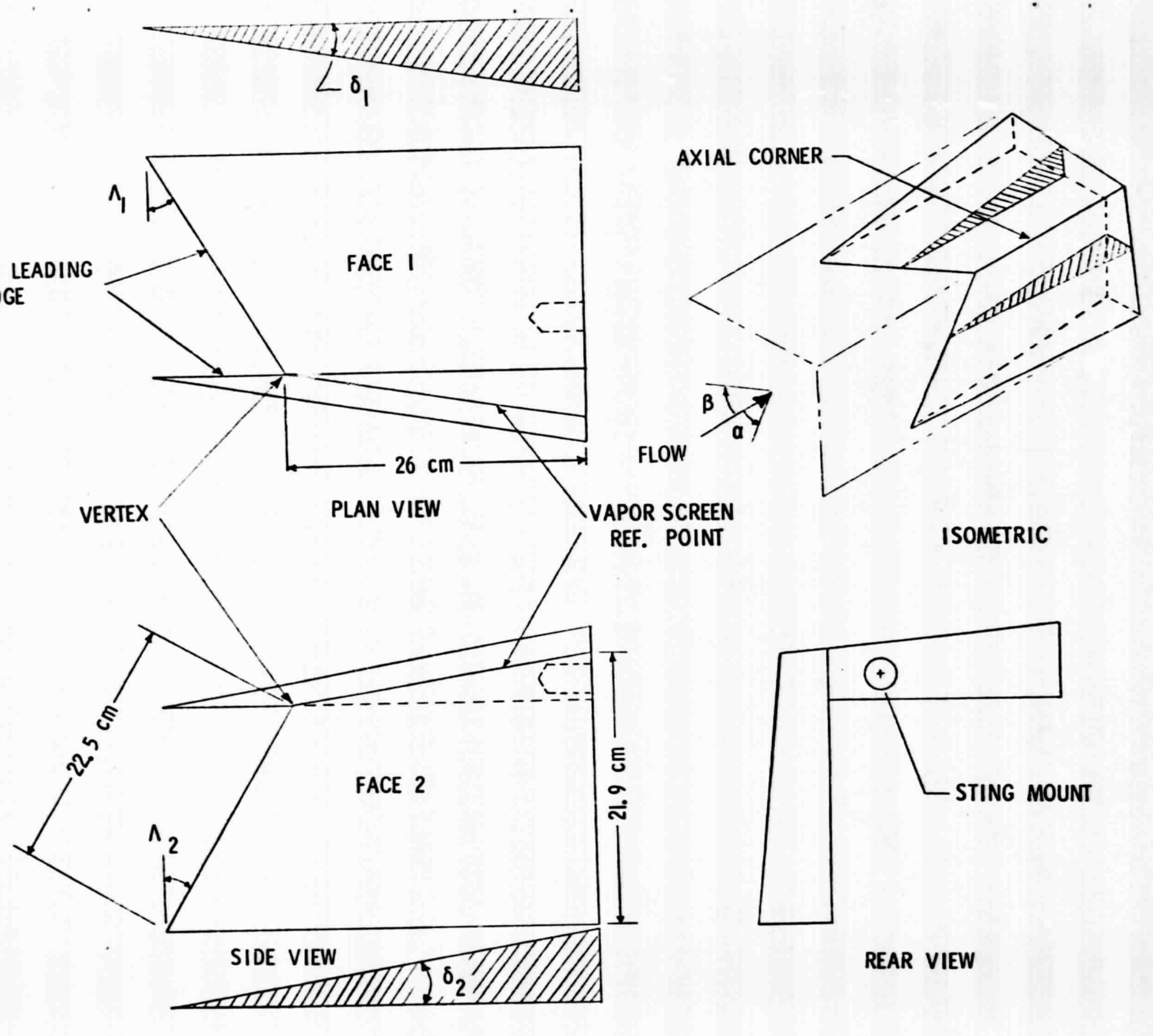

FIGURE 1a - Symmetrical External Axial Corner Model.

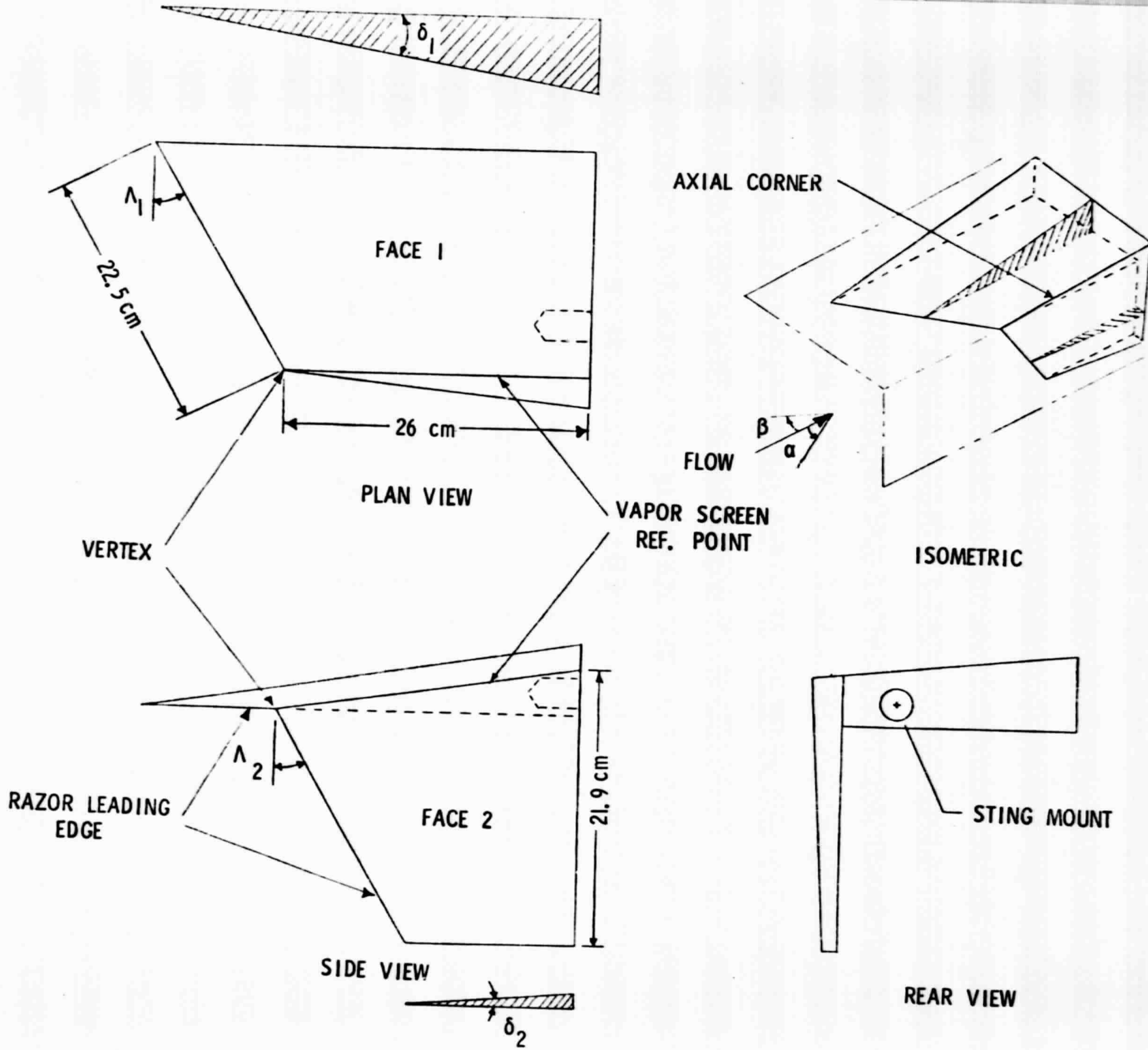

FIGURE 1b - Asymmetrical External Axial Corner Model.

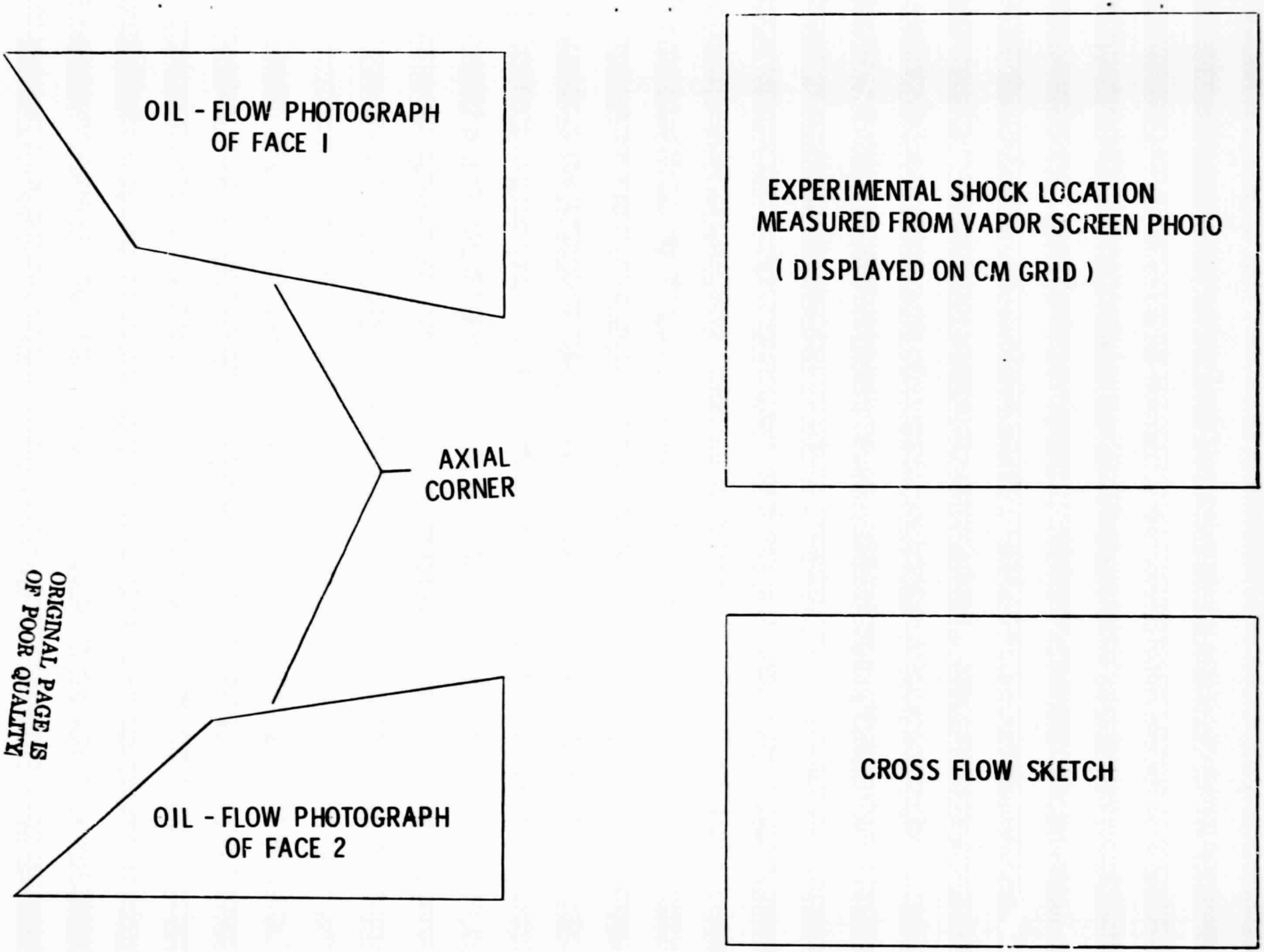

FIGURE 2 - Display Format Used For Experimental Results.

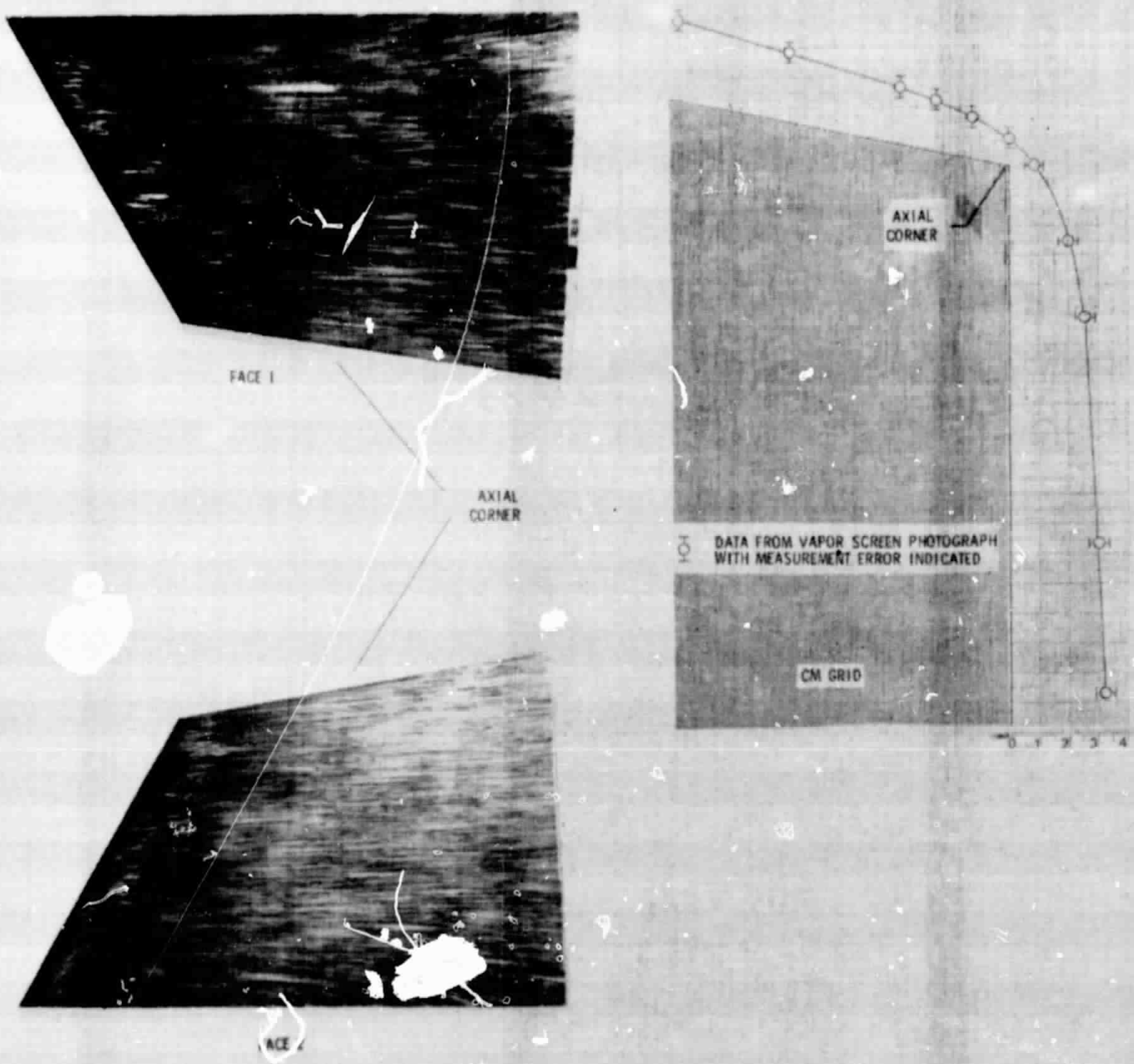

FIGURE 3 - Symmetrical Model $\alpha = 0$, $\beta = 0$.

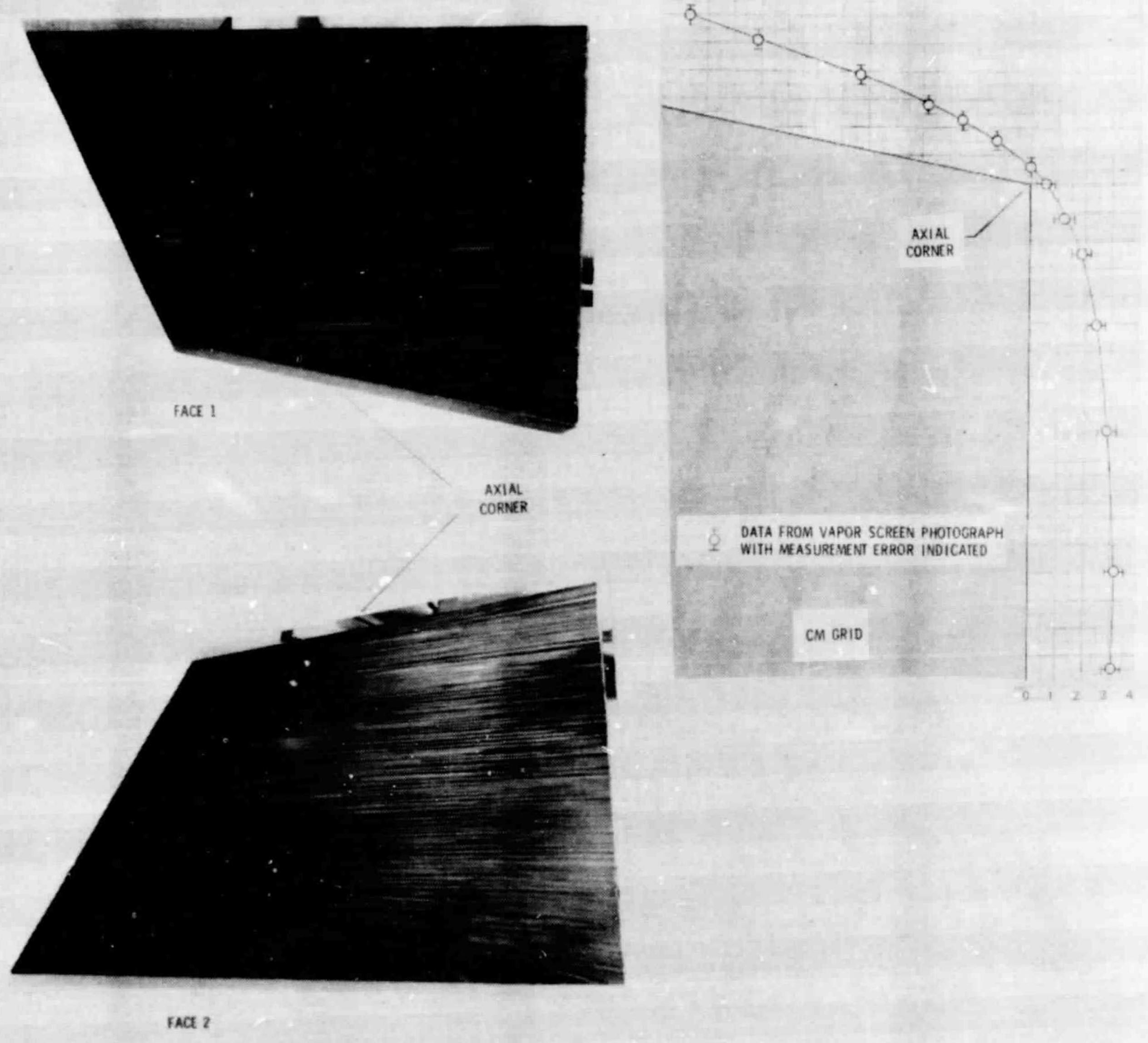

FIGURE 4.- Symmetrical Model α = 0, β = 5.

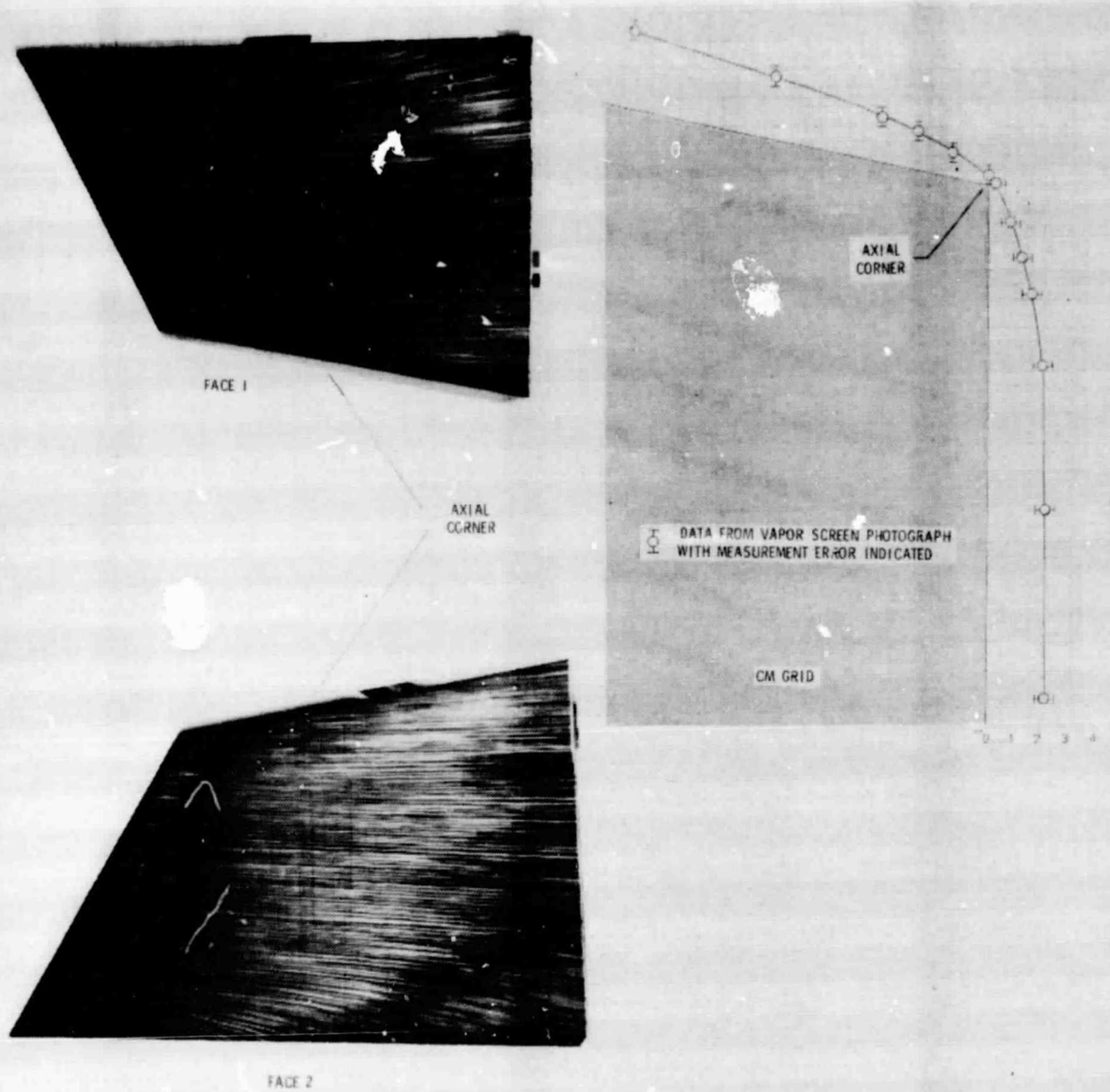

FIGURE 5 - Symmetrical Model $\alpha = 5$, $\beta = 5$

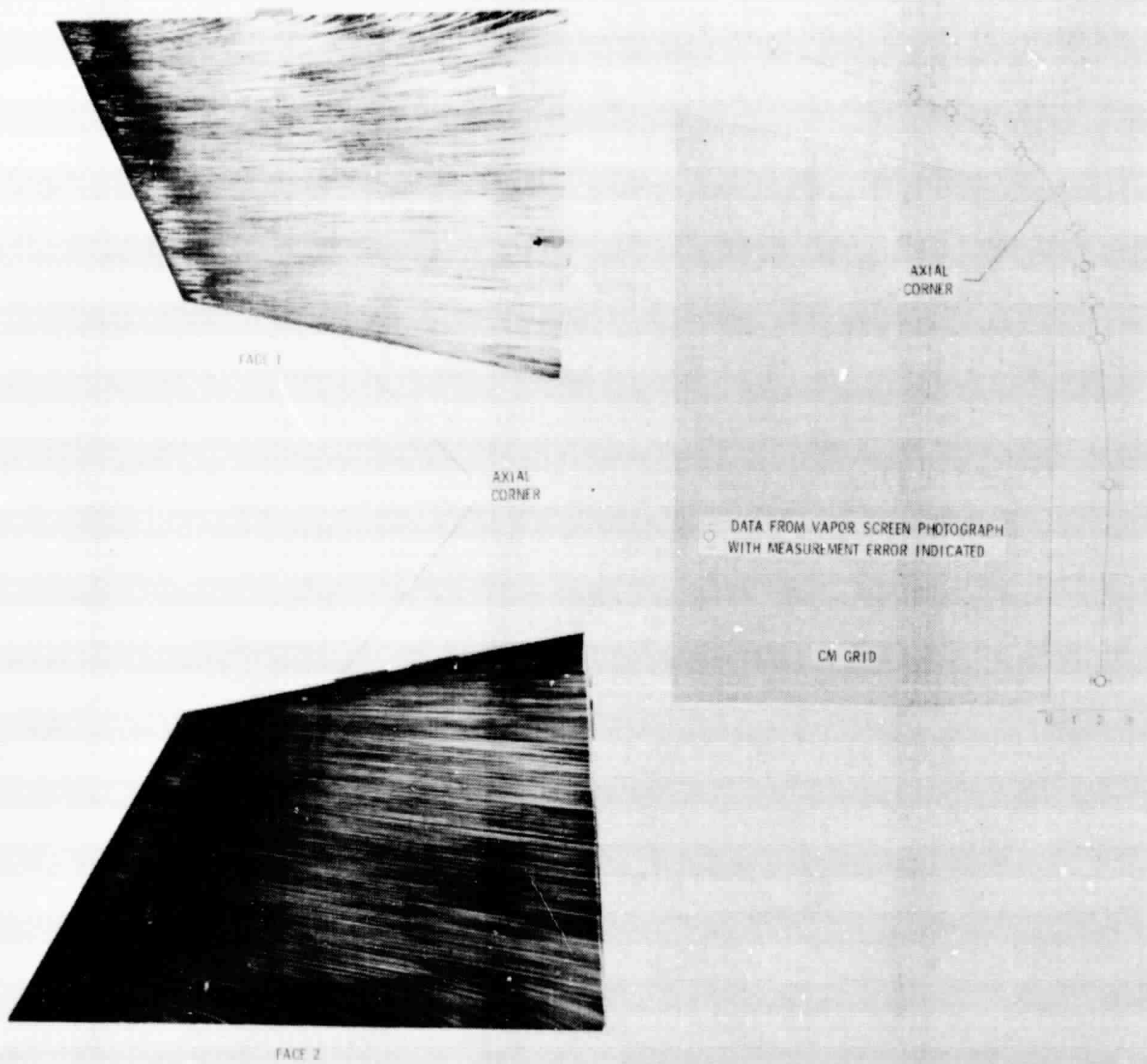

FIGURE 6 - Symmetrical Model α = 10, β = 5.

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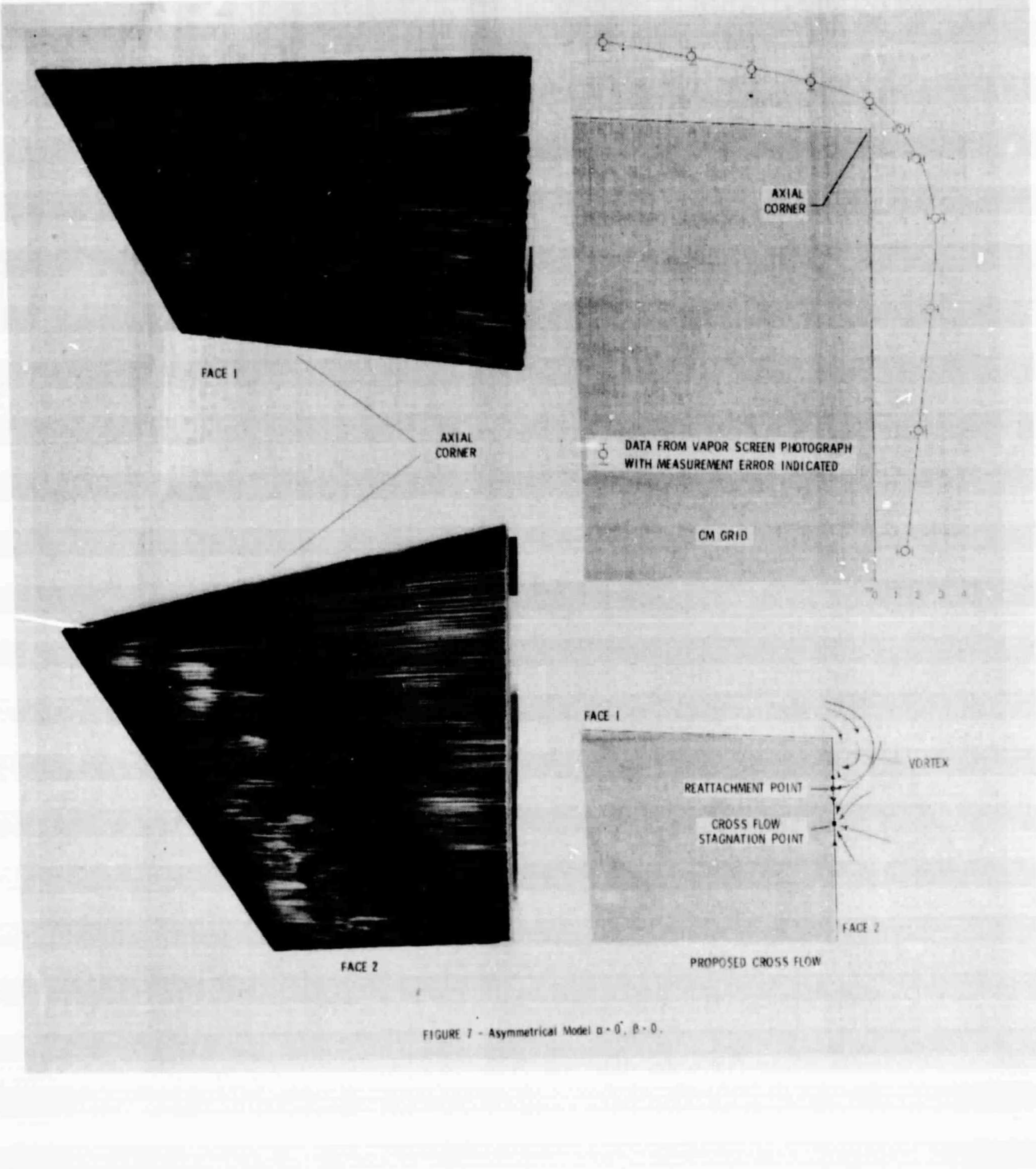

FIGURE 7 - Asymmetrical Model α - 0°, β - 0.

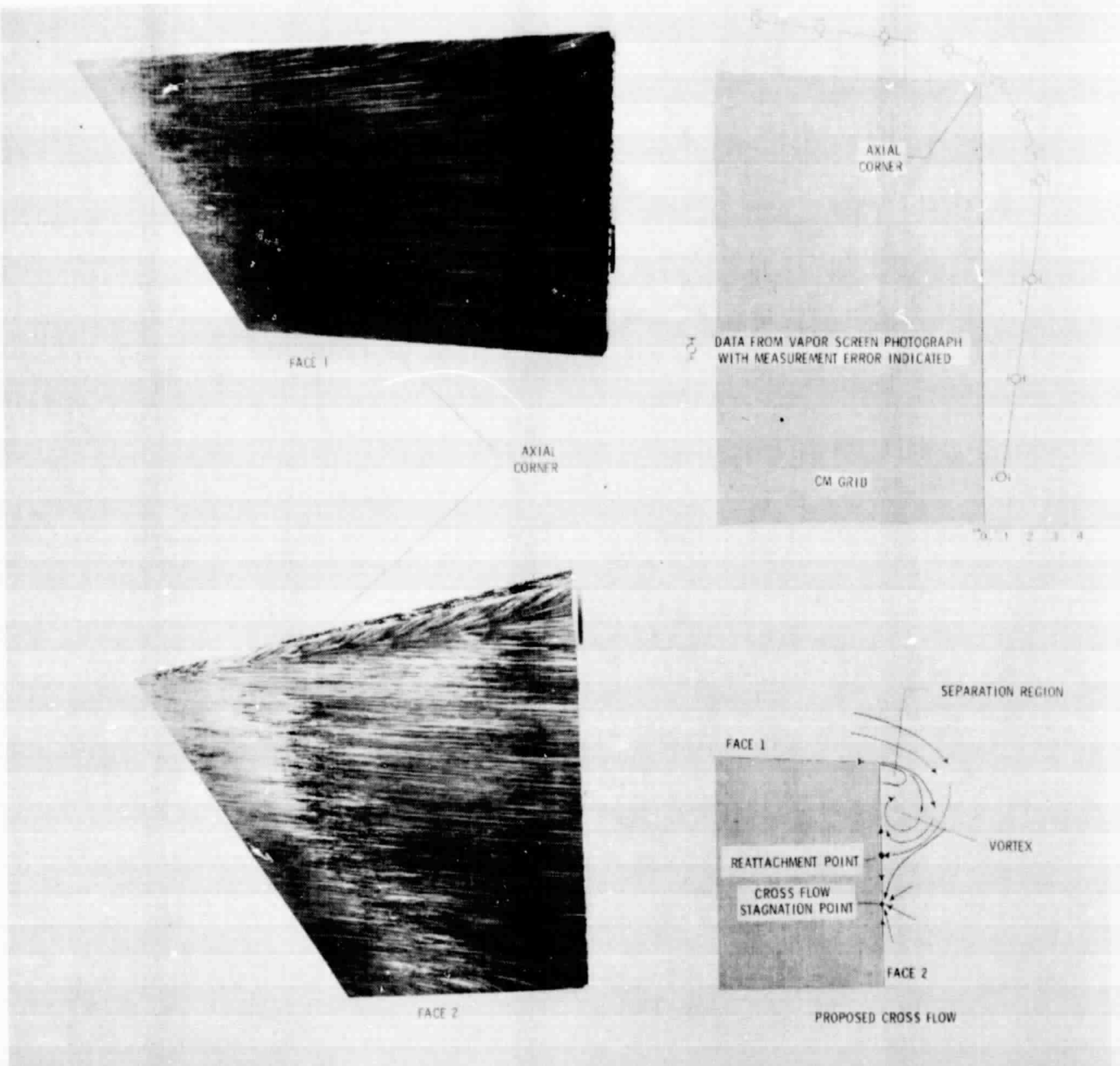

FIGURE 8 - Asymmetrical Model $\alpha = 5$, $\beta = 0$.

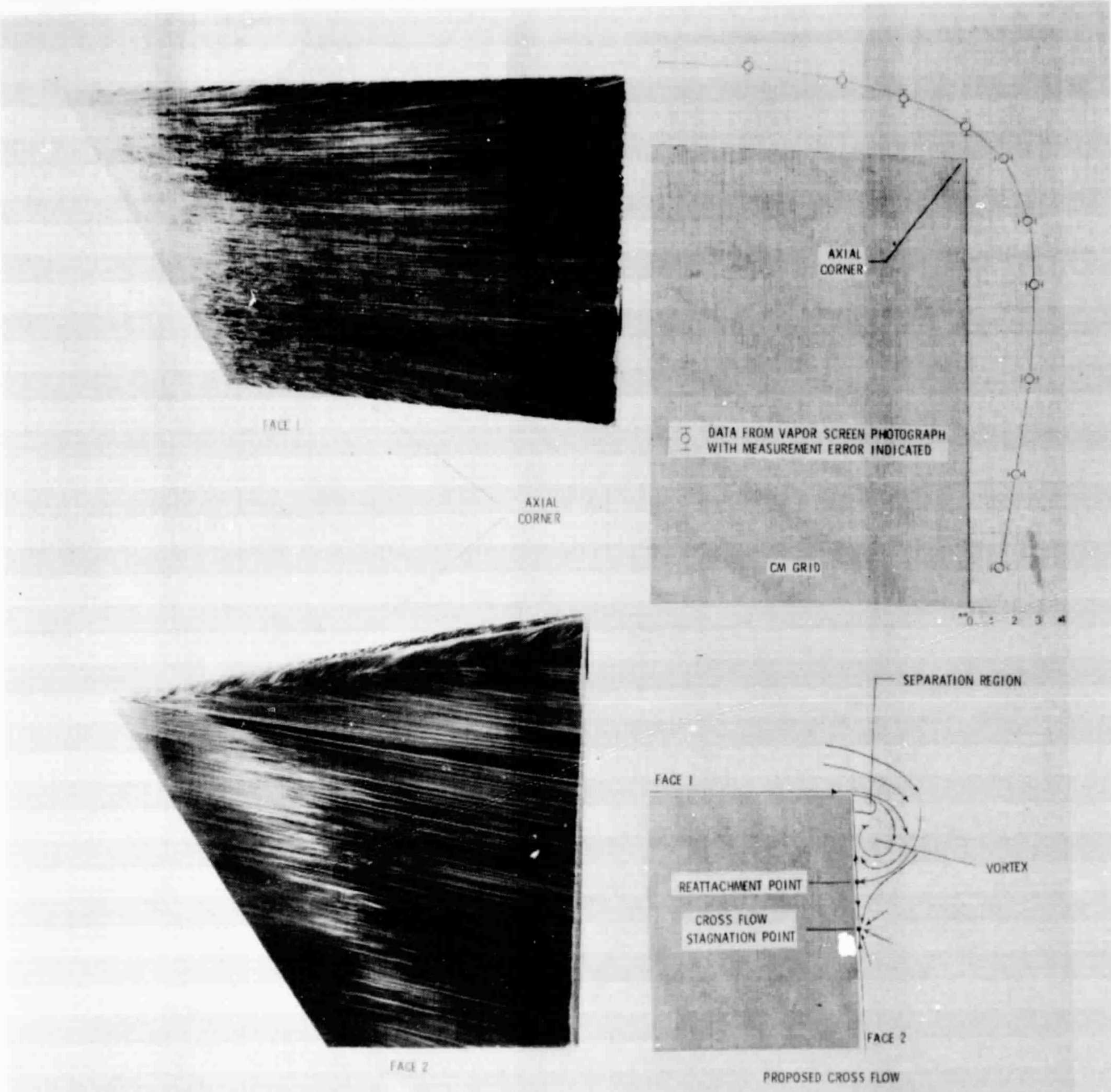

FIGURE 9 - Asymmetrical Model α = 10, β = 0.

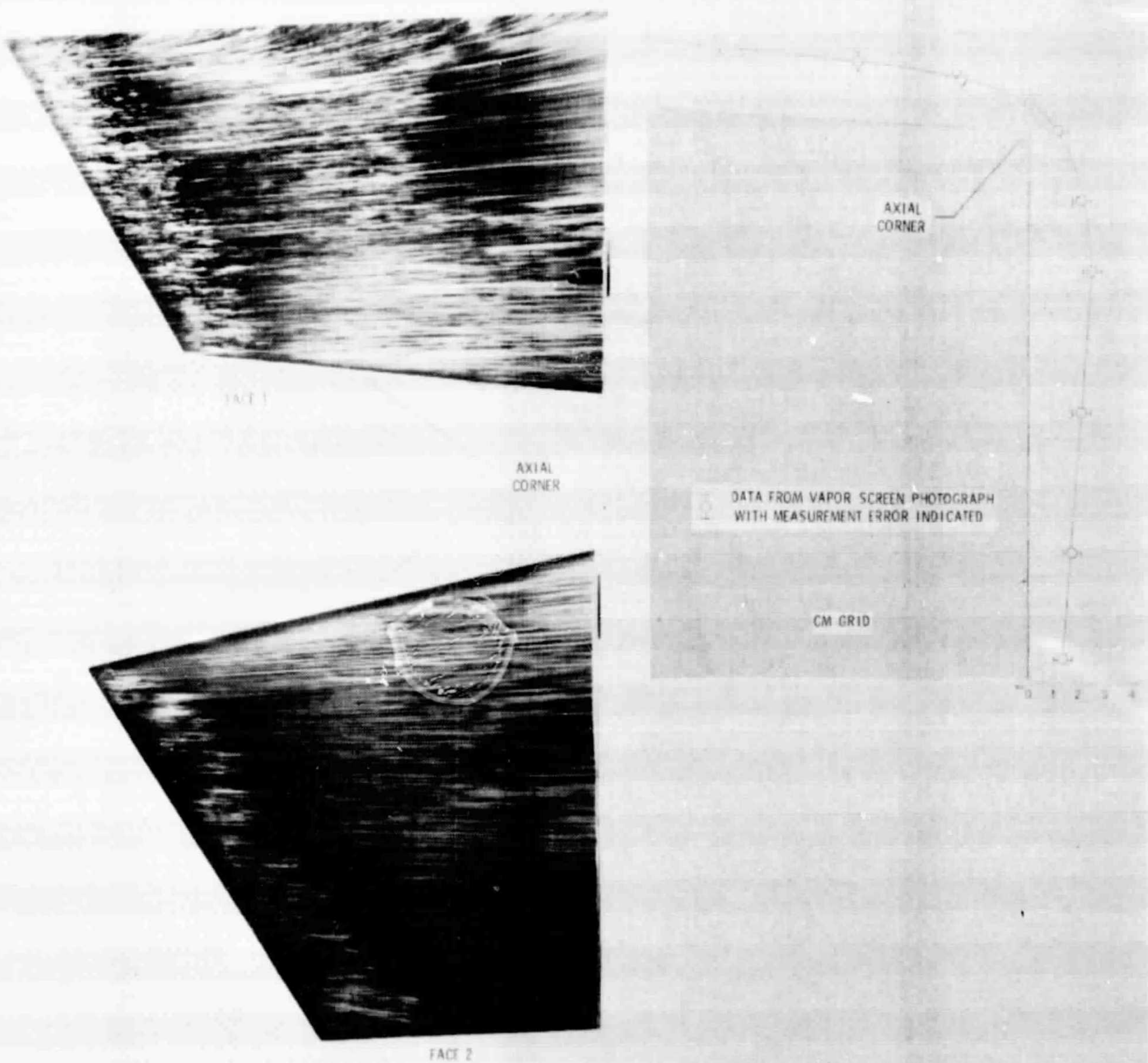

FIGURE 10 - Asymmetrical Model α = 0, β = 5.

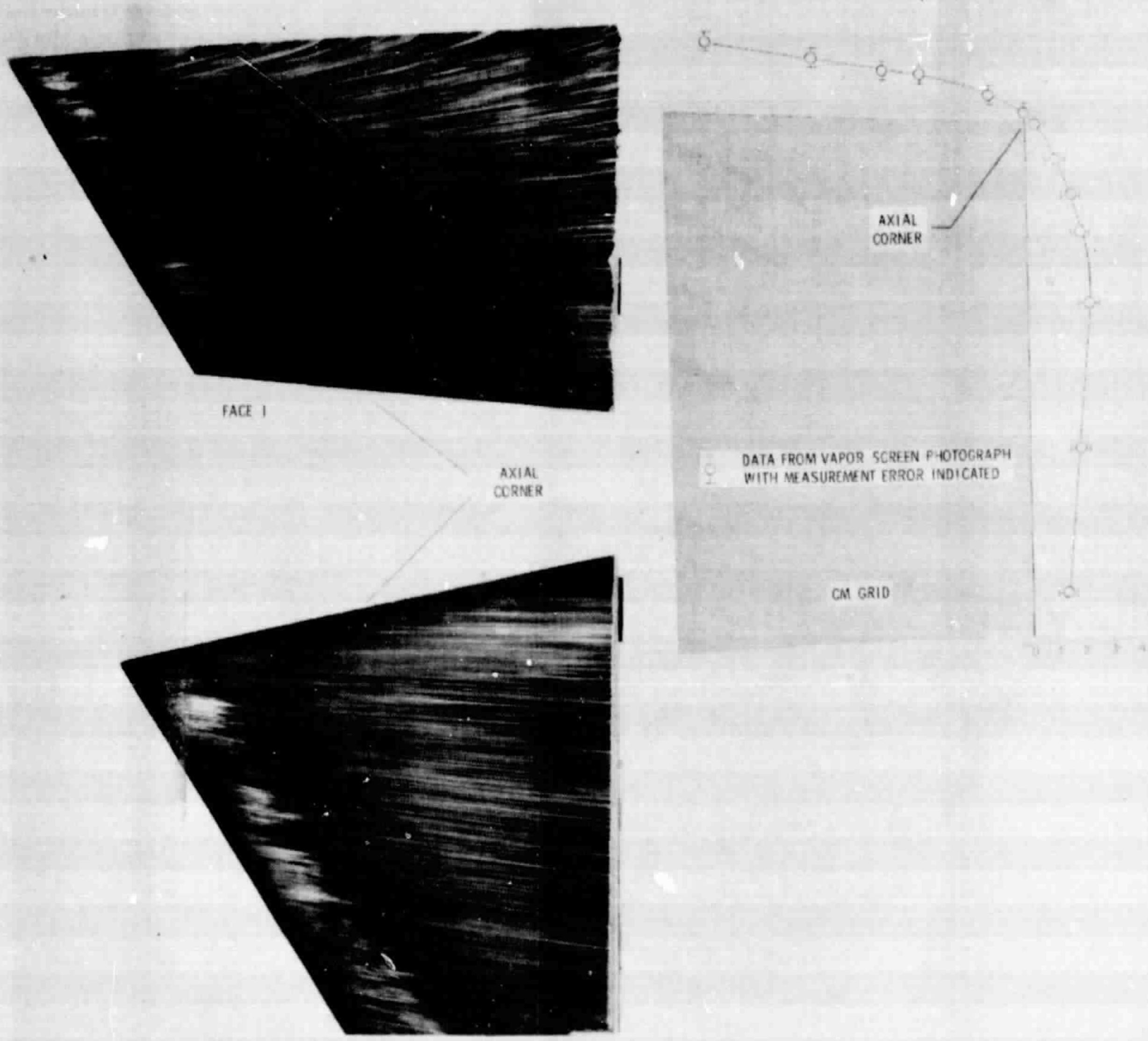

FIGURE 11 - Asymmetrical Model α = 5, β = 5.

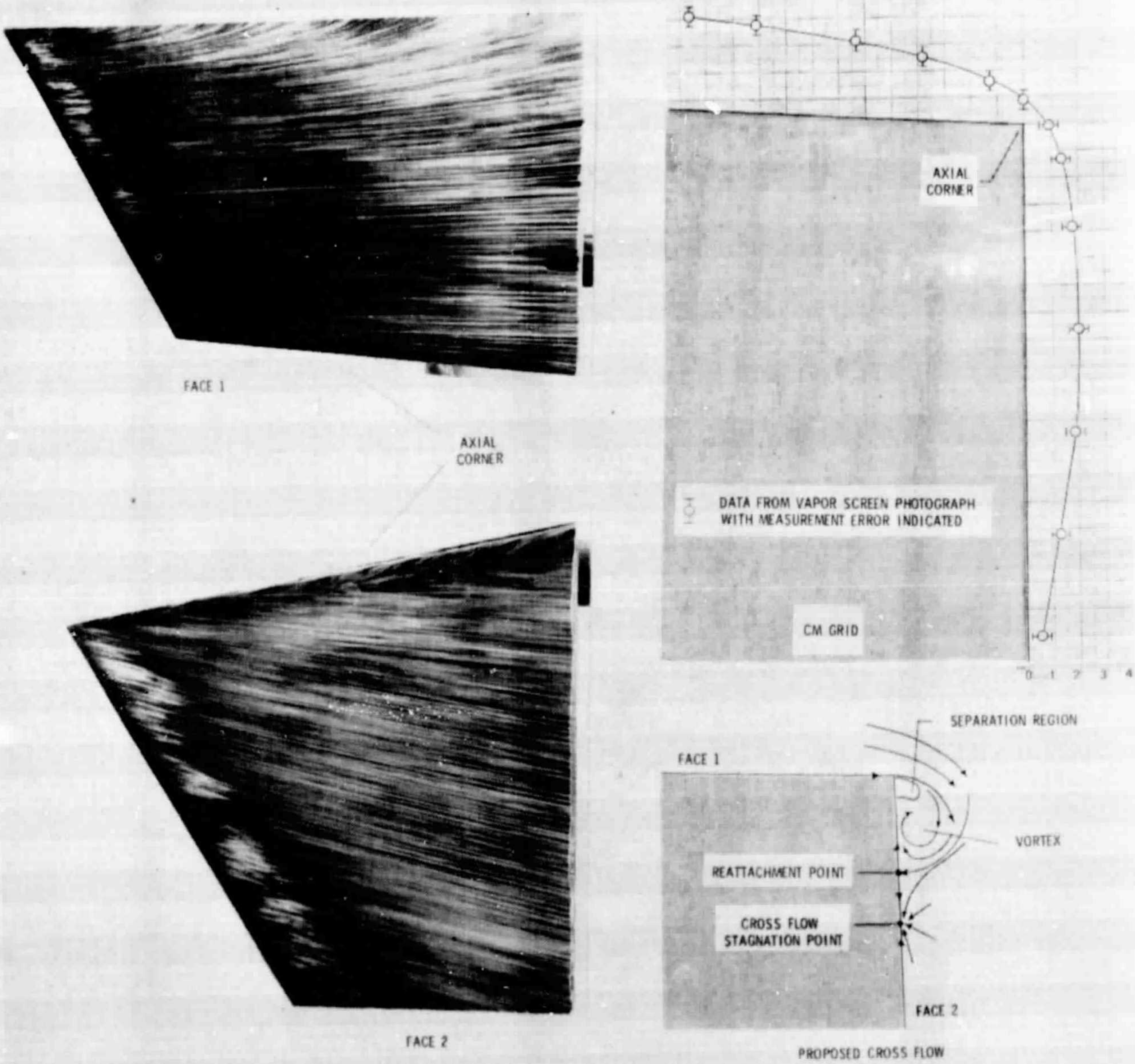

FIGURE 12 - Asymmetrical Model $\alpha = 10$, $\beta = 5$.

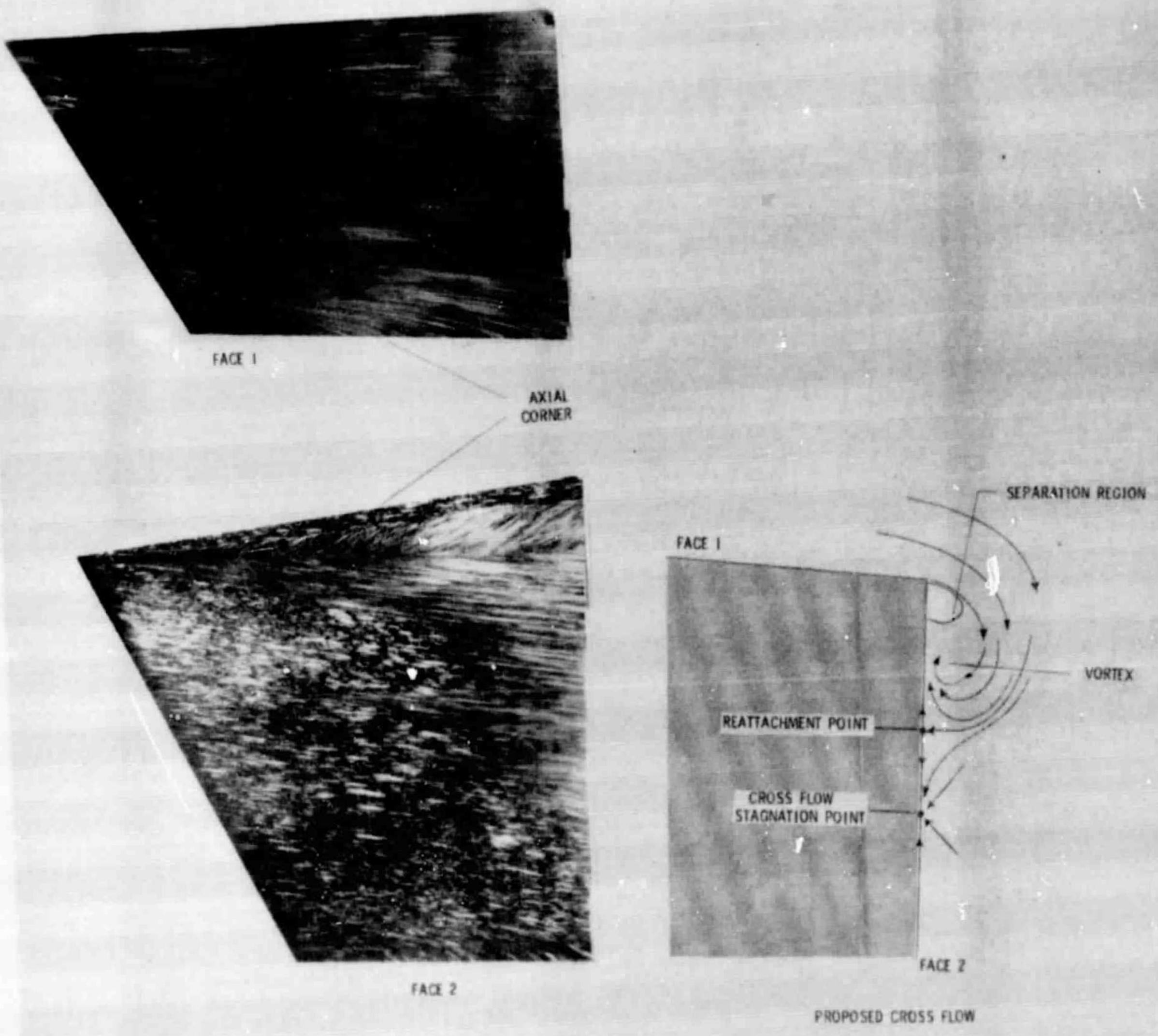

FIGURE 13 - Asymmetrical Model α = 5, β = -5.

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16. Abstract

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