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DYNAMIC PRESSURE APPROACH TO ANALYSIS OF REACTOR FUEL PLATE STABILITY

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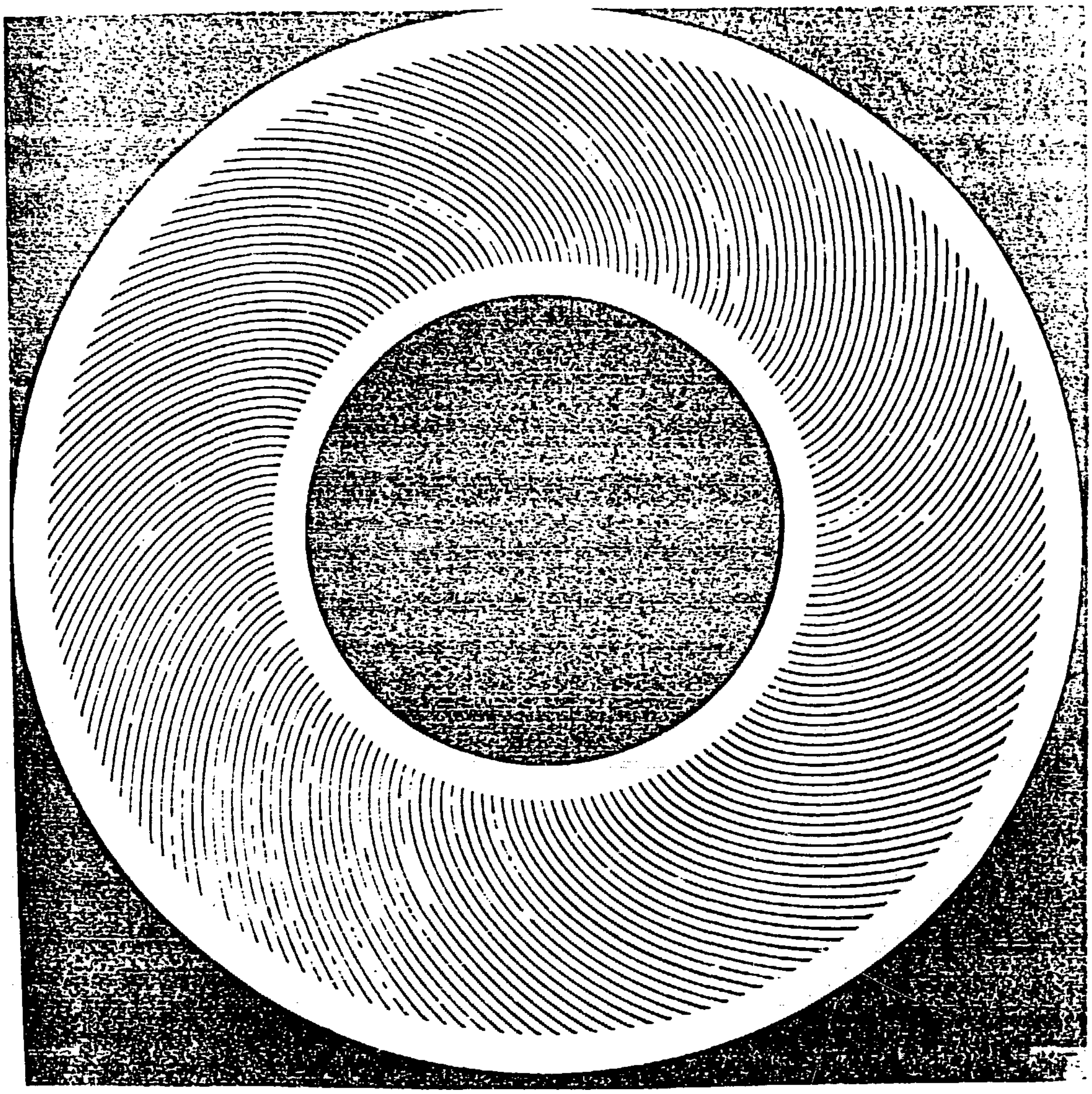
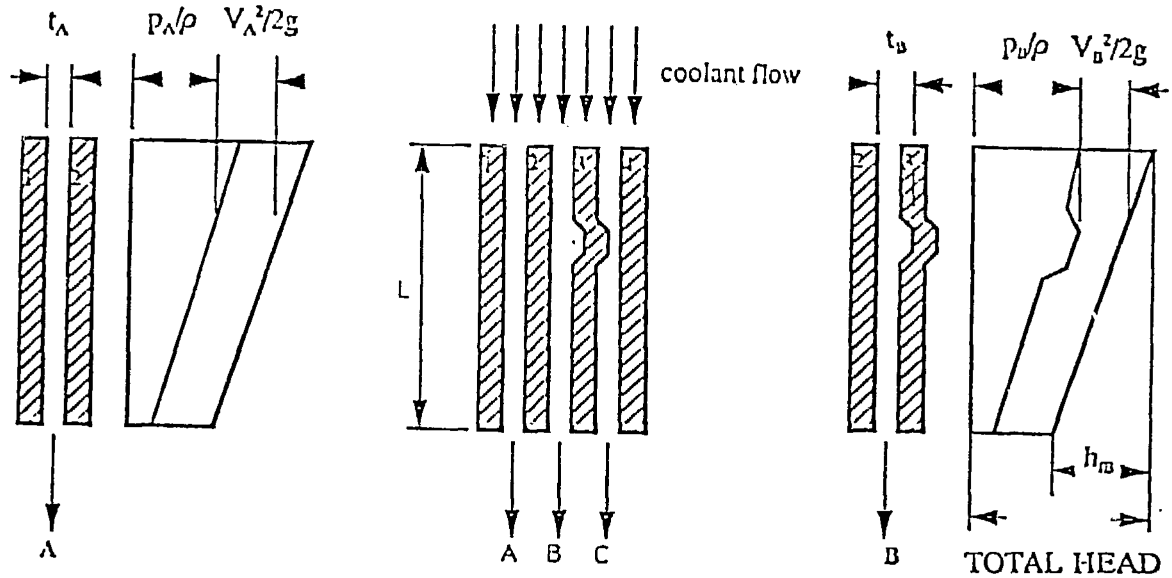
THE STRUCTURAL RESPONSE OF INVOLUTE ANS FUEL PLATES TO COOLANT FLOW MUST BE EVALUATED



THE CLASSICAL MILLER MODEL IS USED TO PREDICT FUEL PLATE STABILITY IN REACTORS



- LOCALIZED DEFLECTION PERTURBATION, t_B
- ASSUME EQUAL FLOW
- LOCAL PRESSURE IN CHANNEL B INCREASES, VELOCITY DECREASES, AS t_B INCREASES

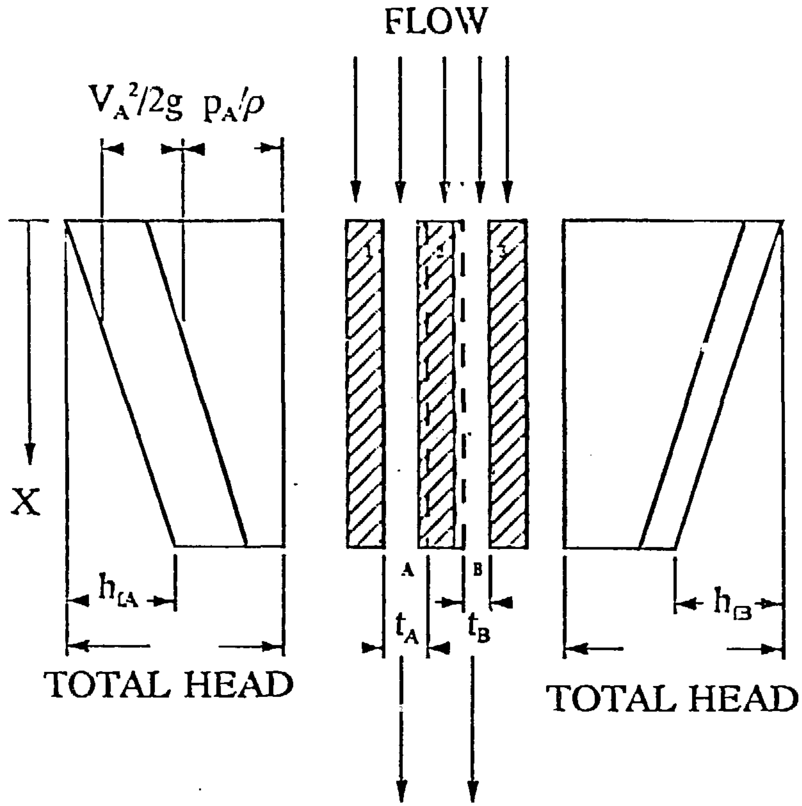
EXPERIMENTAL DATA FROM FLAT PLATES DO NOT VERIFY THE MILLER MODEL

- SUDDEN COLLAPSE NOT OBSERVED
- SLOW STABLE OSCILLATIONS OBSERVED BELOW MILLER VELOCITY
- FLUTTER OBSERVED ABOVE TWICE MILLER VELOCITY
- MAXIMUM DEFLECTIONS WERE AT THE ENTRANCE AND INCREASED WITH FLOW VELOCITY

ALTERNATIVE APPROACH HAS BEEN DEVELOPED THROUGH A DYNAMIC PRESSURE MODEL

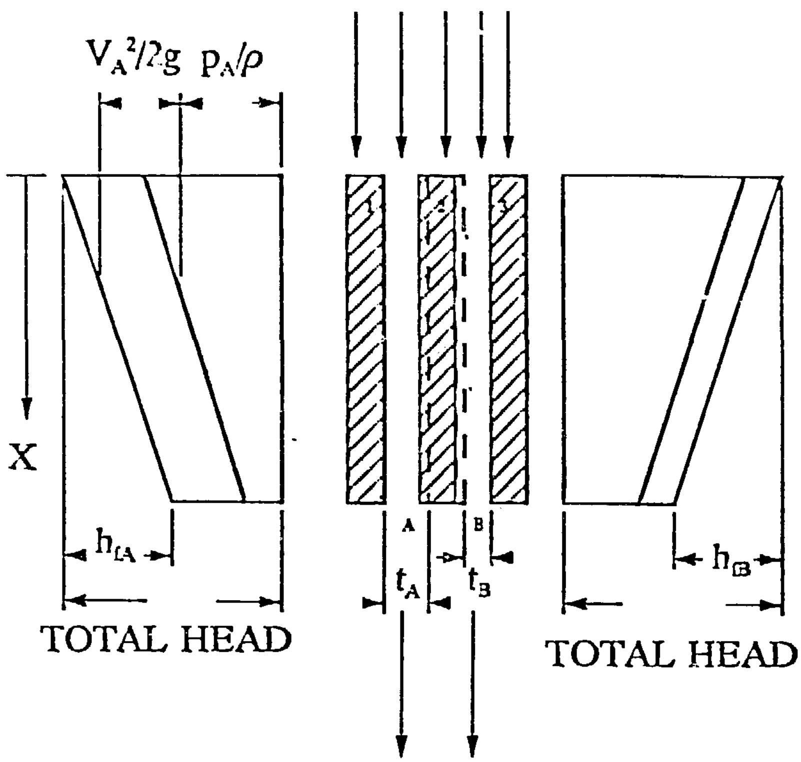
- DYNAMIC (STAGNATION) PRESSURE RESULTS FROM A FLOW RESTRICTION
- MODEL ASSUMES EQUAL HEAD LOSS IN CHANNELS
- FLOW RATE IS LESS IN NARROWED CHANNEL
- FLOW VELOCITY IS REDUCED IN NARROWED CHANNEL

CONSIDER THE HEAD VARIATION IN PARALLEL CHANNELS OF DIFFERENT DIMENSIONS



- TERMS:
  - VELOCITY HEAD - $V^2/2g$
  - PRESSURE HEAD - P/ρ
  - FLOW RATE - Q
  - CHANNEL LENGTH - L
  - FRICTIONAL LOSSES - $h_f=(fLV^2)/(t2g)$

THE FLOW RATE IN CHANNEL A IS GREATER THAN THE FLOW RATE IN CHANNEL B



NOTE:

$$h_{fA} = h_{fB}$$

OR

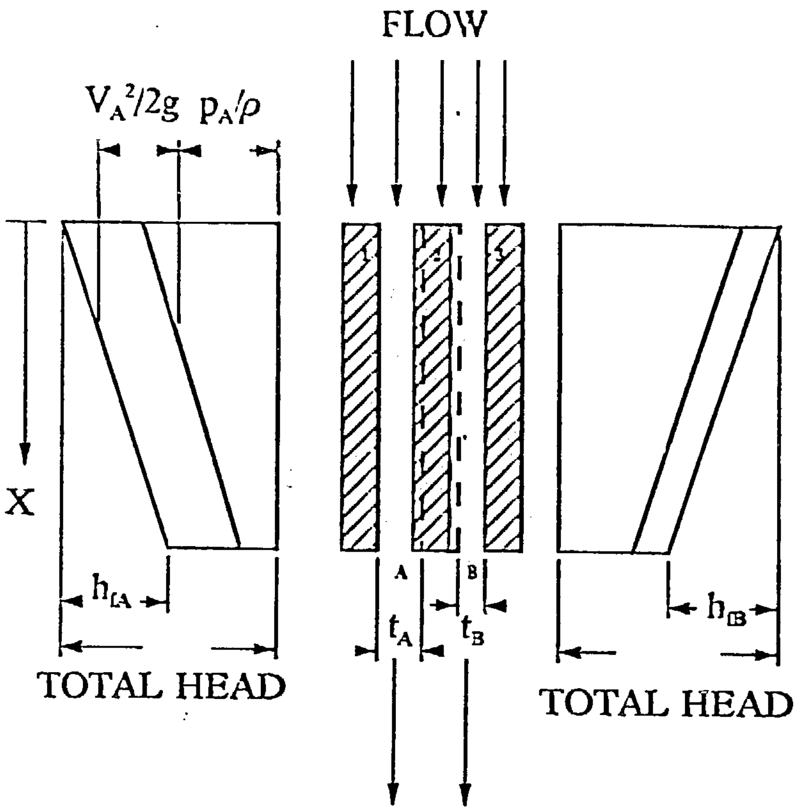
$$(f_A L_A V_A^2)/(t_A 2g) = (f_B L_B V_B^2)/(t_B 2g)$$

OR IN TERMS OF FLOW RATE, Q

$$(Q_A/Q_B) = (f_B/f_A)^{1/2} (t_A/t_B)^{3/2}$$

THUS $Q_A > Q_B$

IN THIS MODEL THE FLOW VELOCITY IN THE SMALL CHANNEL IS SMALLER THAN THE FLOW IN THE LARGE CHANNEL



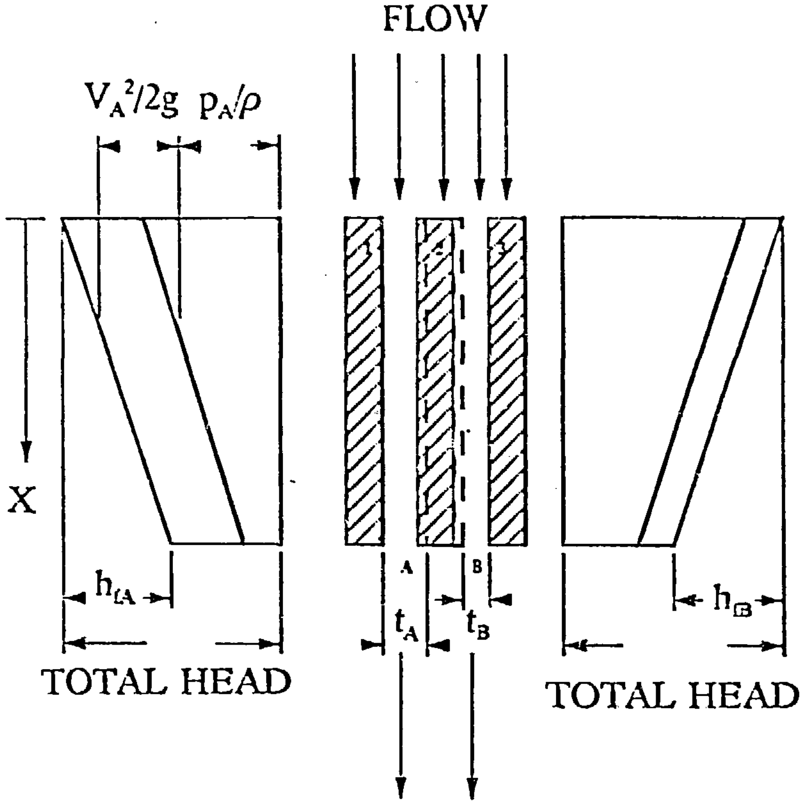
IF $$h_{fA} = h_{fB}$$

IS EXPRESSED IN TERMS OF VELOCITY

$$V_A/V_B = (t_A/t_B)^{1/2} (f_B/f_A)^{1/2}$$

THUS $$V_A > V_B$$

THE LIMITING VALUE OF THE PRESSURE DIFFERENTIAL IS THE DYNAMIC PRESSURE



NOTE THE TOTAL HEAD AT LOCATION X

$$h_{fA}|_x + p_A/\rho|_x + V_A^2/2g|_x = h_{fB}|_x + p_B/\rho|_x + V_B^2/2g|x$$

OR

$$(p_B - p_A)/\rho = (V_A^2 - V_B^2)/2g$$

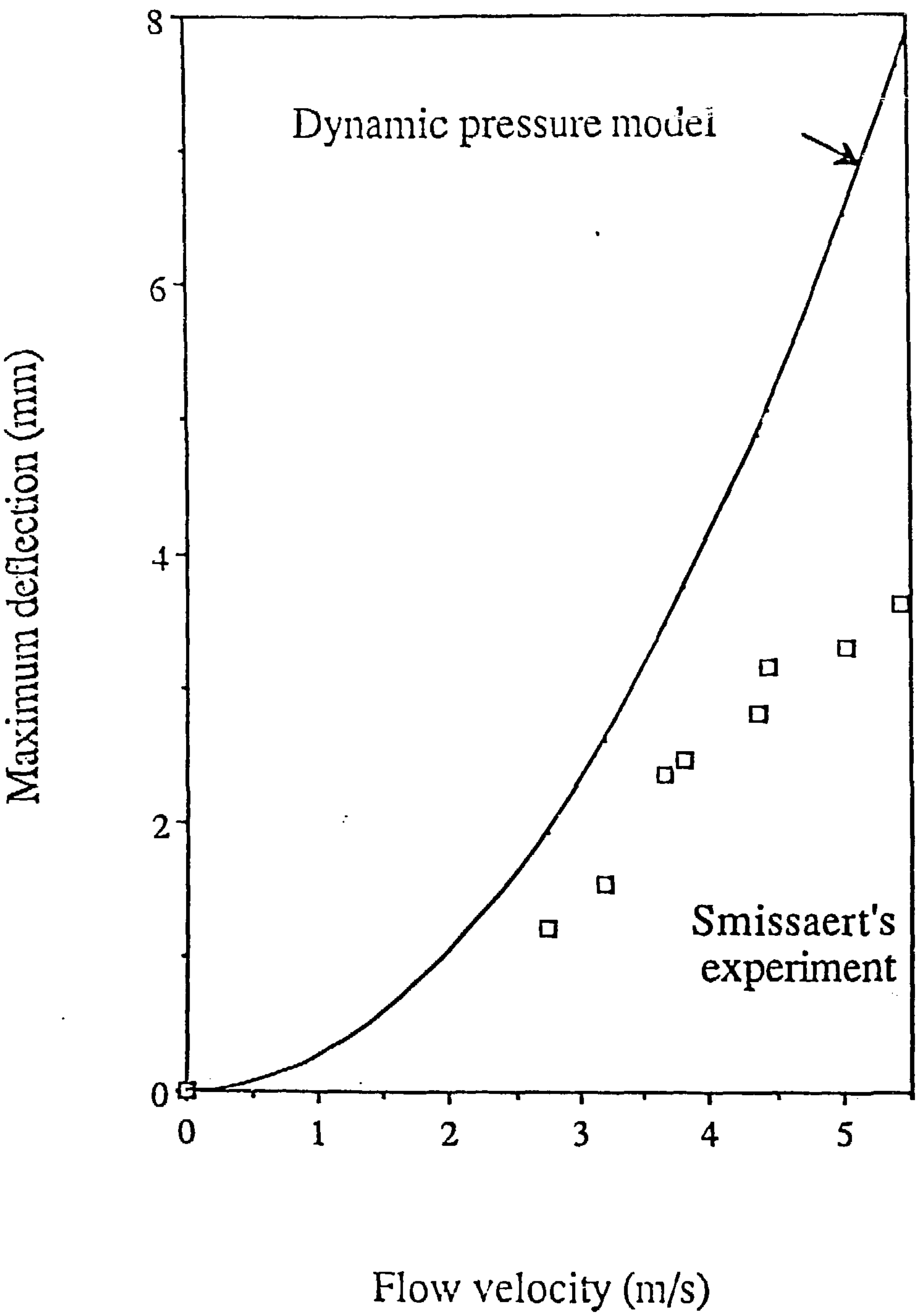
IF $V_B = 0$,

$$p_B - p_a = \rho V_A^2/2g$$

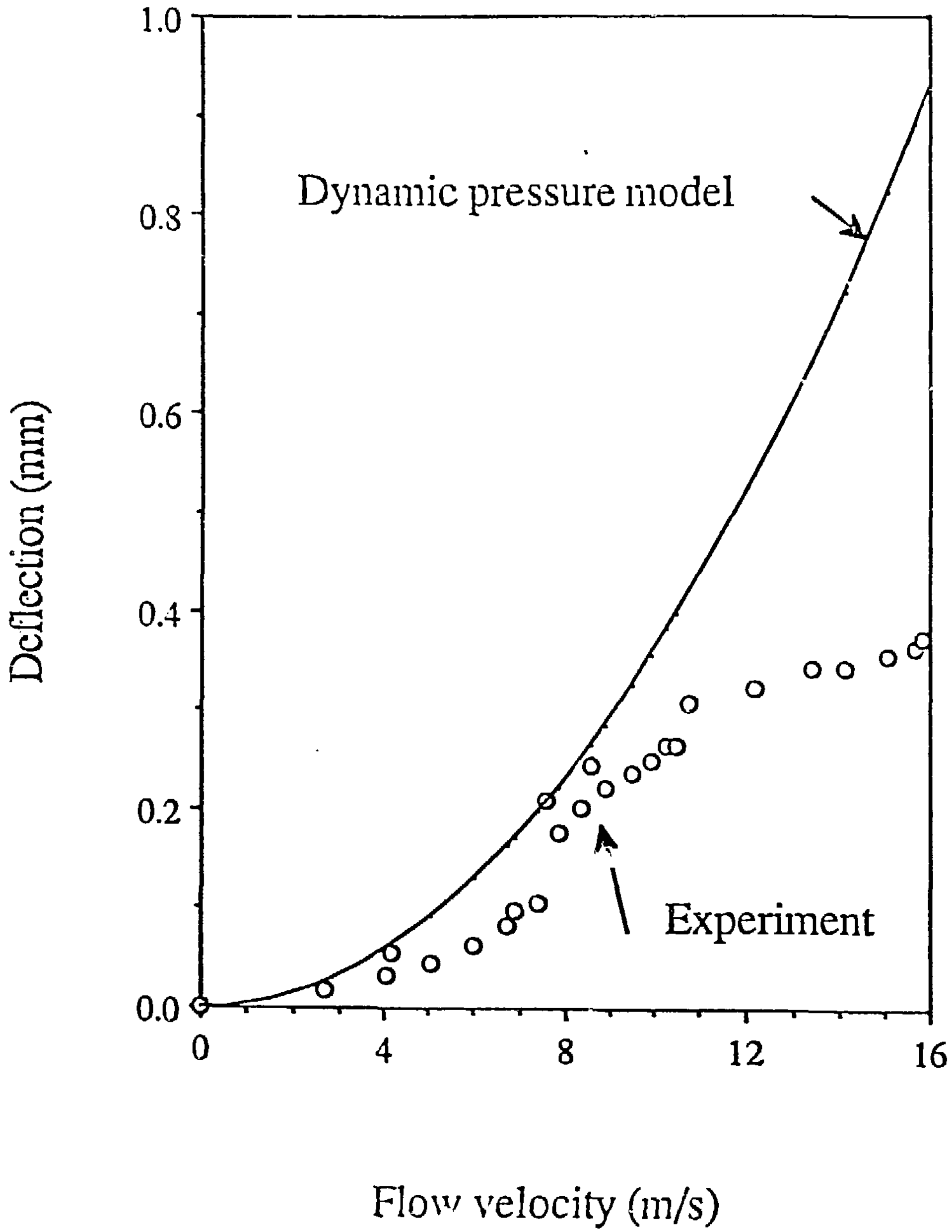
PLATE DEFLECTIONS AND STRESSES DUE TO THE DYNAMIC PRESSURE CAN BE EVALUATED USING BEAM/PLATE/SHELL THEORY

- FLAT PLATE CALCULATIONS DONE TO COMPARE WITH SMISSAERT'S EXPERIMENTS
- INVOLUTE PLATE CALCULATIONS DONE TO COMPARE WITH SINGLE EPOXY PLATE EXPERIMENTS

DYNAMIC PRESSURE MODEL BOUNDS SMISSAERT'S FLAT PLAT TEST DATA



DYNAMIC PRESSURE MODEL ALSO BOUNDS EPOXY INVOLUTE PLATE TEST DATA



AN ALTERNATIVE ANALYTICAL METHOD FOR PREDICTING HYDRAULIC STABILITY OF CLOSELY SPACED REACTOR FUEL PLATES HAS BEEN DEVELOPED

- ASSUMES THAT PLATE IS LOADED BY A PRESSURE EQUAL TO THE DYNAMIC PRESSURE
- CALCULATED DEFLECTIONS BOUND EXPERIMENTAL RESULTS
- STRESSES CAN BE CALCULATED
- METHOD IS WELL SUITED FOR USE IN DESIGN
- DYNAMIC PRESSURE METHOD IS ONE OF THE METHODS BEING USED FOR DESIGN OF ANS FUEL ELEMENTS

DYNAMIC PRESSURE APPROACH TO ANALYSIS OF REACTOR FUEL PLATE STABILITY*

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The Advanced Neutron Source (ANS) and several existing reactors including the High-Flux Isotope Reactor (HFIR) and the Materials Test Reactor (MTR) use closely spaced arrays of fueled-plates which are cooled by water flowing through the channels between the plates. The usual procedure is to hold the plates in place by welding the side edges into slots of support boundaries. In tests at Oak Ridge and in early ETR tests,[1-3] failures have occurred when adjacent plates touched. The flow velocity necessary to cause adjacent plates to touch is termed the critical velocity. A considerable amount of research has been expended in an effort to understand and quantify this phenomenon.[1-10]

One of the earliest models used to predict this critical velocity was proposed by Miller.[4] This model assumes constant mass flow through each channel. Some of the concepts of this model are illustrated in Fig. 1. Assume as noted in the first pictorial Fig. 1(a) , that one plate, say plate 3, deflects locally due to some flow perturbation. With a constant mass flow assumption the static pressure in channel B increases and the velocity decreases as the channel dimension t_B increases, Fig. 1(c). In an opposite response, as the dimension t_c of channel C gets smaller a decrease in pressure and an increase in velocity occurs for constant mass flow, Fig. 1(d). In a progressive manner the higher pressure in channel B causes more deflection which in turn increases the pressure, and thus collapse is predicted. Of course, the whole process is resisted by the elasticity of the plate, but at some point collapse occurs. This model indicates a sudden collapse and further that the event will occur away from the entrance and/or exit.

Experiments on flat plates by Groninger and Kane[5] and Smissaert[6] showed that the critical velocity was approximately twice that predicted by Miller's model. In most cases maximum deflection of the plates occurred at the entrance to the flow channel and increased as the flow velocity increased. It was noted during the experiments that slow stable oscillations or "breathing" of the plates occurred until the critical velocity was realized; but, above the critical velocity rapid unstable oscillations (flutter) of the plates occurred. An experiment was conducted at ORNL with a single epoxy involute plate and two flow channels, all of equal thickness. Similar results to the flat plate experiments were found. No instabilities were evident and maximum deflection was not restricted to locations away from the entrance/exit regions. The maximum velocity of the test facility was about twenty percent above the critical velocity predicted by the Miller model.

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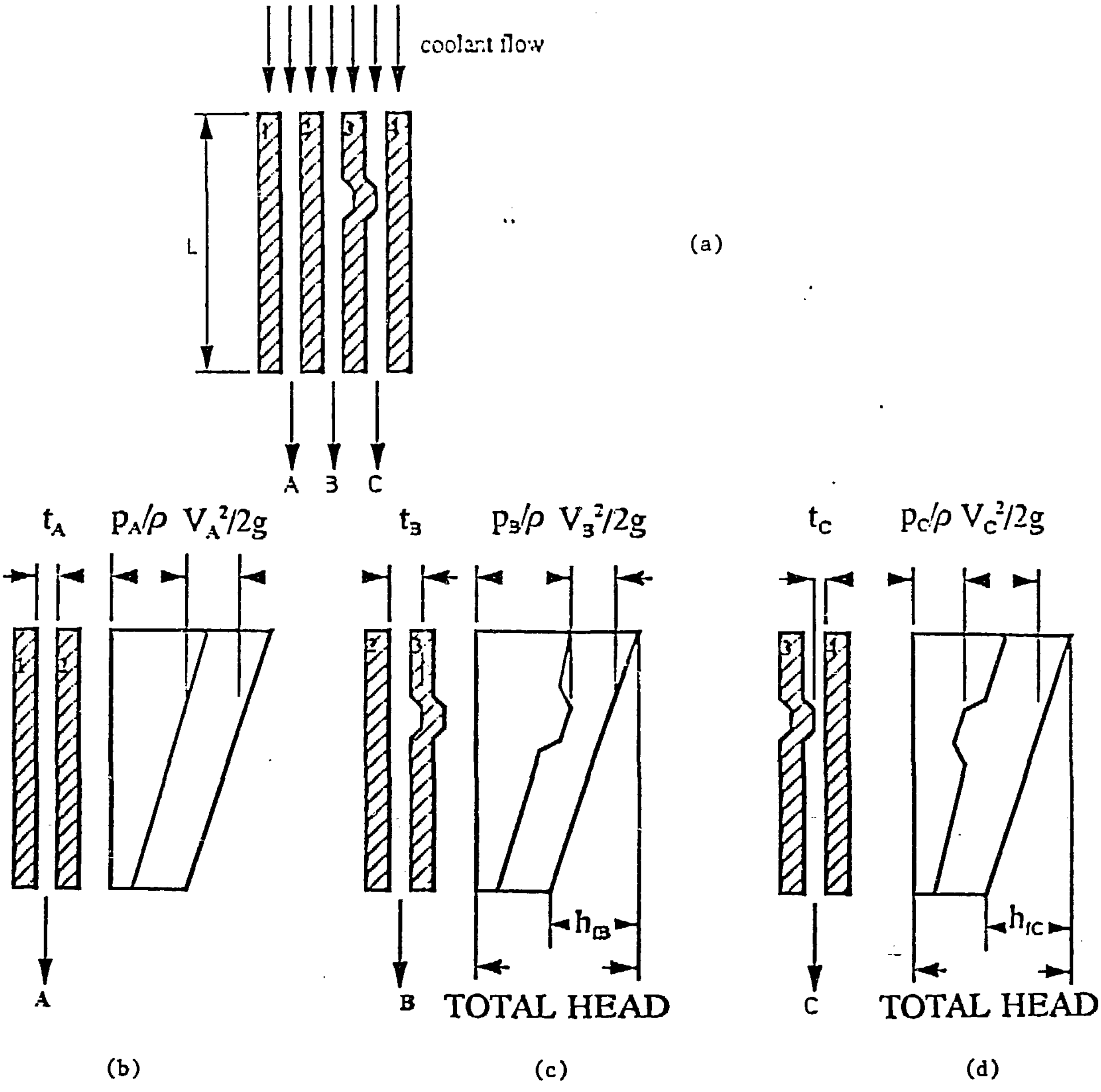

Fig. 1. Flow Through Parallel Plates With Head in Each Channel

The model proposed in this paper to describe the plate response uses the dynamic (stagnation) pressure as the loading mechanism. The technique is simple, and versatile. This model does not assume constant mass flow. The rationale for the model assumes parallel flow as illustrated in Fig. 2. Assume that channel B dimension t_B, is smaller than channel dimension t_A. This could occur due to dimensional tolerance or to some flow disturbance. For parallel plates the head lost in each channel is equal, thus

$$h_{fA} = h_{fB} \tag{1}$$

The lost head is usually expressed as

$$h_f = (fLV^2)/(t2g) \tag{2}$$

where

f	=	the friction factor
L	=	flow path length
V	=	flow velocity
g	=	gravitational constant
t	=	principal flow dimension (in a pipe this would be the diameter or some times related to the hydraulic radius)

If eq. (2) is expressed in terms of the flow rate, Q, such that

$$V = Q/ts$$

where t and s are the channel cross-sectional dimensions and substituted into eq. (1) the result gives

$$Q_A/Q_B = (f_B/f_A)^{1/2}(t_A/t_B)^{3/2} \tag{3}$$

For purposes of discussing eq. (3) the ratio (f_B/f_A) is taken as unity thus

$$Q_A/Q_B = (t_A/t_B)^{3/2} \tag{4}$$

[Actually (f_B/f_A) is proportional to $(Q_A t_A/Q_B t_B)$ and slightly emphasizes the conclusions to be drawn from eq. (3).]

If $t_A > t_B$ as initially assumed, then

$$Q_A > Q_B \tag{5}$$

and unequal flow is anticipated in contrast to equal flow assumed in the Miller model. Further, from eq. (4) velocity can be expressed as a function of channel thickness

$$V_A/V_B = (t_A/t_B)^{1/2}, \tag{6}$$

and since $t_A > t_B$

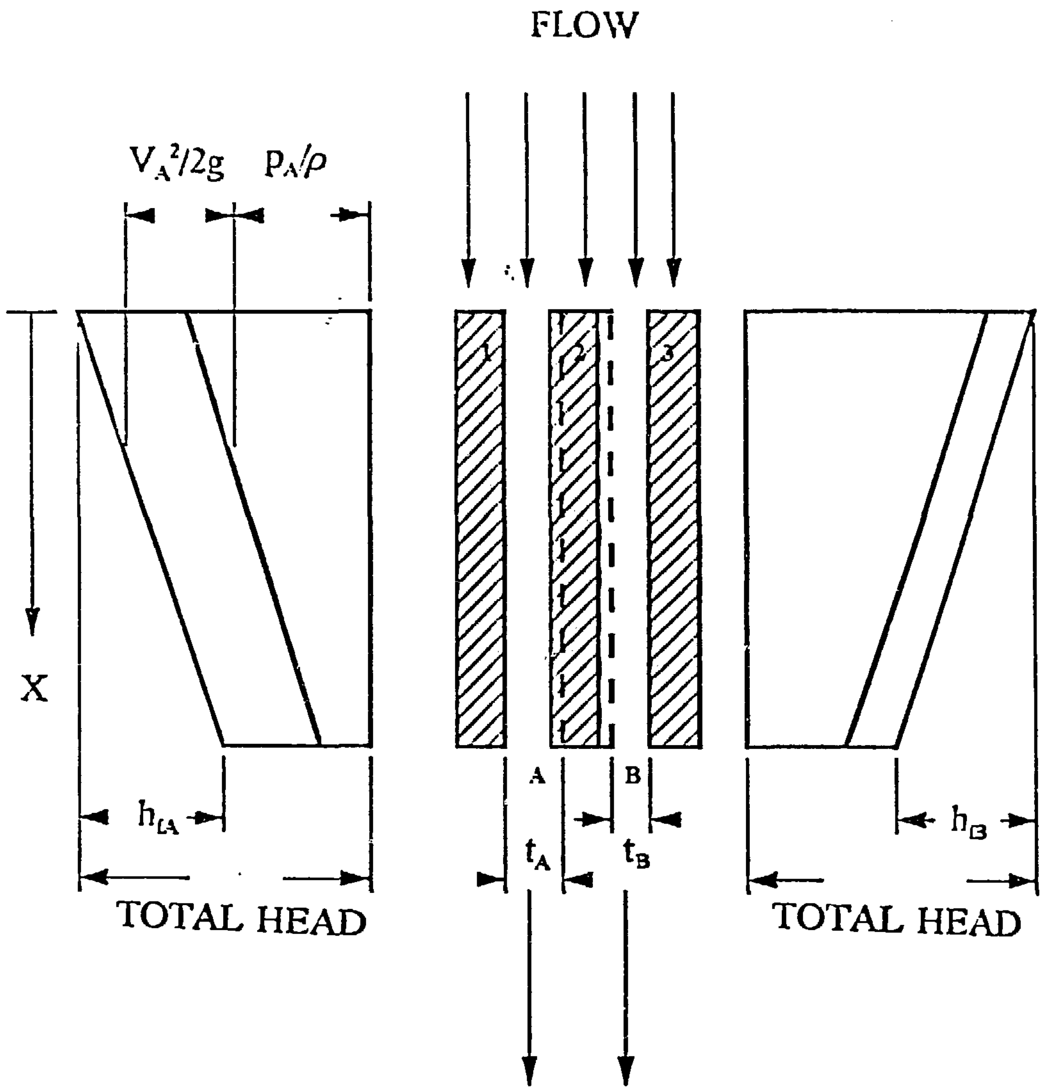

Fig. 2. Parallel and Unequal Flow

$$V_A > V_B. \quad (7)$$

Equation (7) indicates that the flow velocity magnitude is larger in the larger channel than the smaller channel because it carries more fluid. At any x (Fig. 2) the head in each channel is equal

$$p_A/\rho\,|_x + V_A^2/2g\,|_x = p_B/\rho\,|_x + V_B^2/2g\,|_x \quad (8)$$

or

$$(p_B - p_A)/\rho = (V_A^2 - V_B^2)/2g \quad (9)$$

Thus, $p_B > p_A$ and plate 2 tends to equalize the channel dimensions t_A and t_B. The underlying conclusion is that this model predicts stable flow. If the model is used to describe plate response to flow, eq. (9) becomes an important design equation. The limiting pressure differential across the plate would occur when V_B approaches zero, in which case

$$(p_B - p_A)\,|_x = (\rho V_A^2/2g)\,|_x \quad (10)$$

(the dynamic pressure at location x). Like most limiting cases too much should not be drawn from the illustration. For example if the entrance to channel B (Fig. 2) were blocked, V_B would go to zero and the static pressure in channel B would become the exit static pressure. This situation would cause a large pressure difference in the entrance region across the plate and collapse of the plate would occur. On the other hand if eq. 10 is interpreted as the limiting pressure difference (dynamic pressure) between two channels with flow conservative design information can be found. Plate failure would be predicted when plates deflect and touch at mid-channel causing large pressure changes as noted above. When this model is compared with existing experimental data some points are noted.

- The experiments by Groninger and Kane[5] and Smissaert[6] had stable plates that deflected in proportion to the flow velocity up until rapid oscillations (flutter) occurred. This condition seemed to occur when plates began to touch and was at about 1.9 to 2.0 times the Miller critical velocity. The dynamic pressure model would predict deflection in proportion to the flow velocity. If the flat plates are assumed to touch at half channel deflection, the dynamic pressure model would predict a critical velocity at 1.5 times the Miller critical velocity.

- Pressure differential between two adjacent channels varied along the length of the plate. It was usually of opposite signs near the center and entrance regions of the channels.

- The maximum measured pressure differential between two adjacent channels was generally about half of the dynamic pressure but the measured pressure differential did reach as much as 80% of the dynamic pressure in some instances. Comparison of the dynamic pressure results with some of Smissaert's reported data shows this model to be an upper limit for use in design. (Fig. 3)

- Comparison of the dynamic pressure model with data from a single involute plate test done at ORNL shows the model to be reasonable until non-linear effects become significant. (Fig. 4)

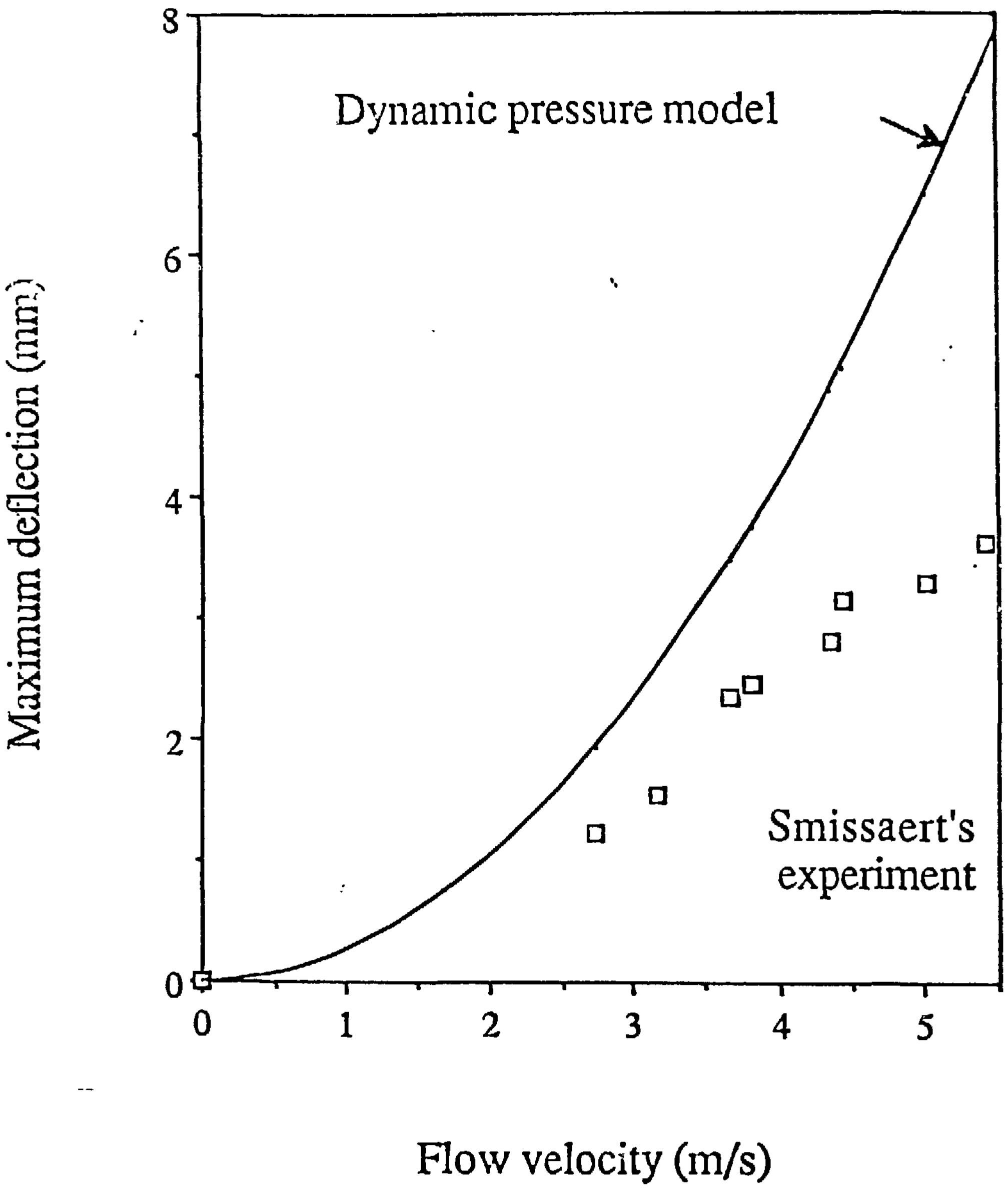

Fig. 3. Comparison of Dynamic Pressure Model With Smissaert's Flat Plate Data

The dynamic pressure model can conveniently be used to evaluate the critical stress regions as a function of flow velocity. For some of the preliminary advanced neutron source reactor plate designs this could be very significant since the flow velocity could be limited by peak stresses in the plates more than by deflection or stability.

In summary the dynamic pressure results in eq. (10) predicts the differential pressure across a plate as a function of flow velocity. The pressure differential can then be used to find the deflection and/or stress of the plate using traditional plate analyses. Instability would occur when plates are touching at mid-channel such that rapid oscillations of pressure can occur. The technique is conservative and gives a design limit for the plate. This model is one of several methods being used in the design of the ANS fuel elements.

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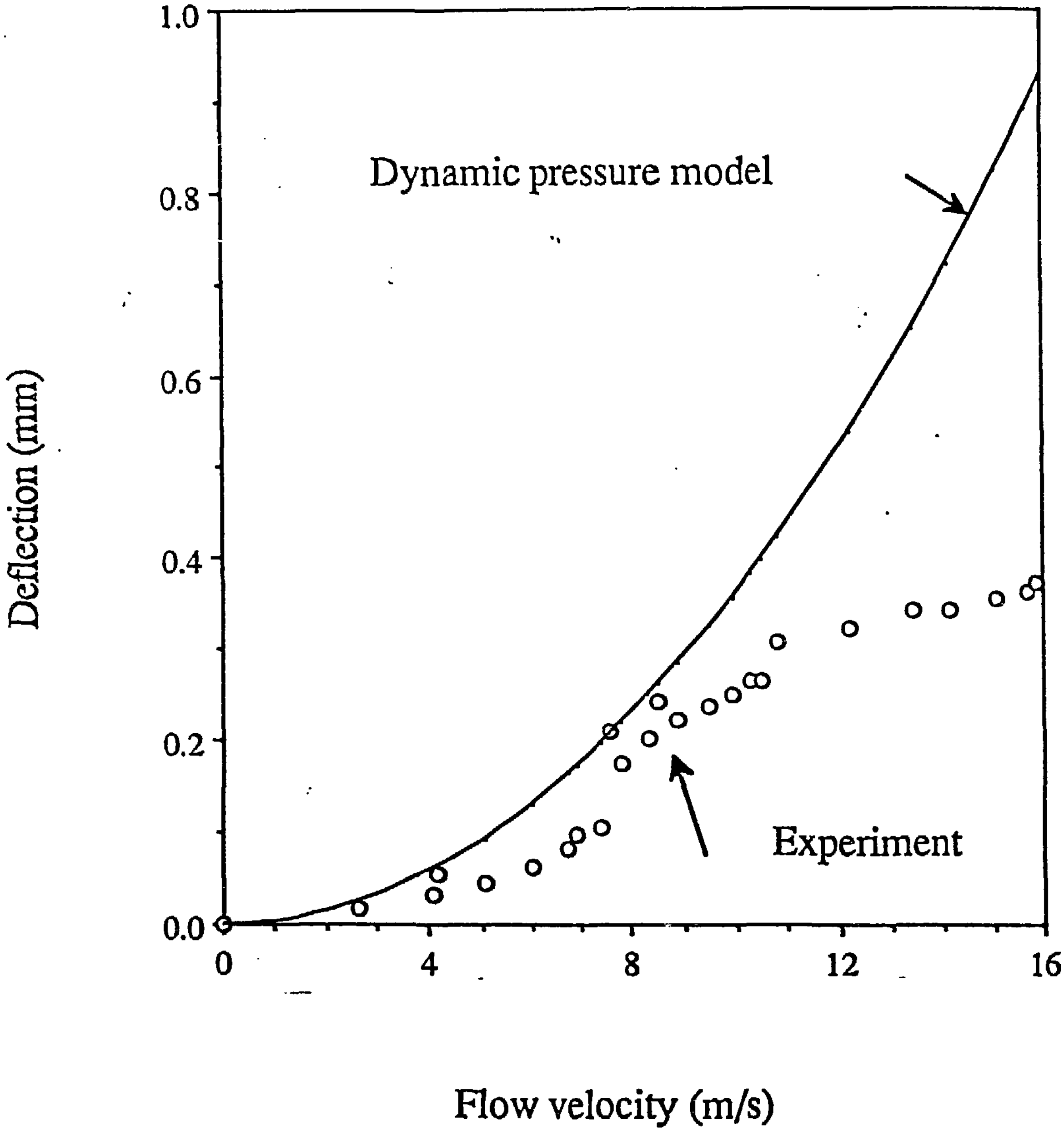

Fig. 4 . Comparison of the Dynamic Pressure Model With Test Data From a Single Epoxy Involute Plate