

FIGURE 2. Pericyclosis.

3 illustrates the mitosis or erratic shattering of a cancer cell as its means of reproduction. Gurel has related this to saddle point solutions to the differential equations of motion.

#### Differential Games

The theory of differential games, according to the initiator of the theory, Isaacs [9], is an area of mathematics which is significantly different from classical mathematical analysis. One can interpret most of classical mathematics in terms of one player game theory. The mathematical analysis involved in the application of differential game theoretic concepts involves, according to Isaacs, thinking that transcends the concepts traditionally dealt with by classical mathematics.

Basically a differential game is a mathematical model of an evolving conflict

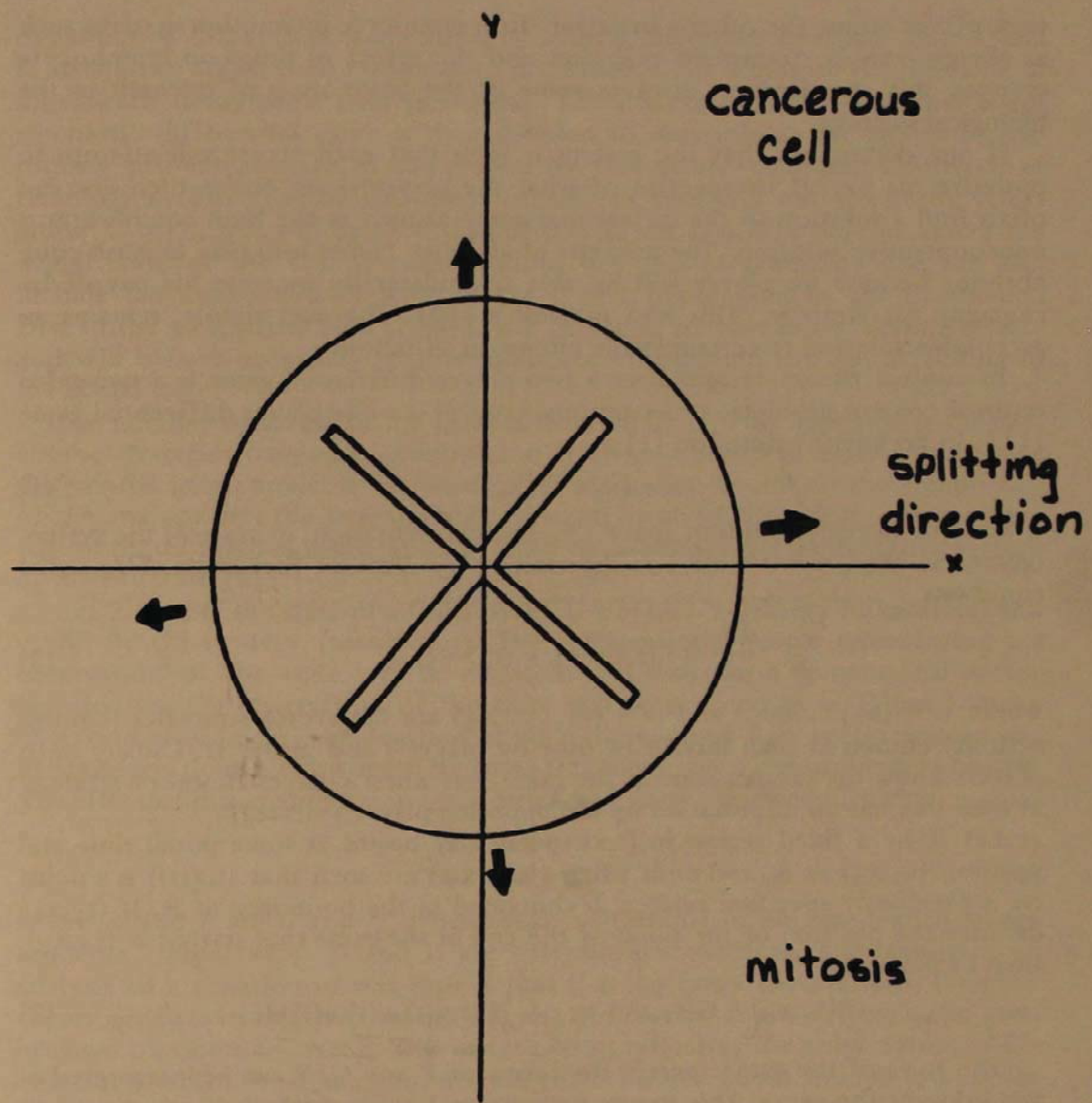


FIGURE 3. Mitosis.

situation [3]. In formulating the model one may specify that each player endeavors to minimize a parameter describing an aspect of the state of the system. On the other hand, one may set up the game so that, given a payoff  $P$  that is well defined, one player's objective will be to maximize  $P$ , while the other's objective will be to minimize  $P$ .

A good deal of research on differential games in the U.S. and U.S.S.R. has been devoted to military problems. Typically, one player will be a ballistic missile and the other will be an anti-ballistic missile. The state of the system is the relative positions of both missiles. The strategy (controls) of the anti-missile will be designed to minimize the intercept time and the strategy (controls) of the missile will be designed to maximize the intercept time. Thus each player's strategy will be directed toward obtaining an extreme value of the payoff while taking the other player's strategy into account.

In differential game theory one usually specifies the assumptions made by

each player about the other's behavior. In lymphocyte interaction systems such as allergy, cancer, transplant rejection and the effect of drugs on lymphocyte systems this specification involves some of the basic areas of research in the biological sciences.

If one determines that the system is such that each player will attempt to optimize his payoff irrespective of what the player(s) are doing, then one can often find a solution to the differential game known as the Nash equilibrium; a noncooperative solution. The concept of stability comes into play in Nash equilibrium, because no player will be able to unilaterally increase his payoff by changing his strategy. This idea of Nash's [10], although simple, remains an acceptable solution to certain stable biological situations.

In control theory terminology a two player differential game is a two-sided optimal control problem, or an optimal control is a one player differential game [11]. In Berkovitz's notation [1]

$$x = (x_1 \dots, x_n) \quad (1)$$

is a vector in real Euclidean space  $E^n$ . The configuration, or state of the system (game) at the present time  $t$  is determined by a set of first order differential equations

$$\frac{dx_i}{dt} = f_i(t, x, u, v), \quad x_i(t_0) = (x_i)_0 \quad (2)$$

where  $u = (u_1, \dots, u_p)$  and  $v = (v_1, \dots, v_q)$  are the vector strategies (control actions) chosen at each instant of time by player I and player II. Usually both players know the present state of the game, but when a player chooses a strategy at time  $t$  he has no information on the opposing player's strategy.

Let  $R$  be a fixed region in  $(t, x)$  space. Play begins at some initial time and position  $(t_0, x_0)$  in  $R$ , and ends when  $t$  and  $x(t)$  are such that  $(t, x(t))$  is a point on a previously specified surface  $\Sigma$  contained in the boundary of  $R$ . If  $(t_1, x_1)$  denotes the position of the point at the end of the game that started at  $(t_0, x_0)$ , then I's payoff is

$$P(t_0, x_0) = G(t_1, x_1) + \int_{t_0}^{t_1} F(t, x(t), u(t), v(t)) dt \quad (3)$$

The rules of the game specify the forms of  $F$  and  $G$ .  $P$  can be interpreted as the value of the game. This means that player I has a method of selecting  $u$  so that the game can be terminated within a given time no matter what II does, while II has a method of selecting  $v$  such that the game will not end in the same given time.

### Lymphocyte System Games

To apply differential game theory to realistic biological situations on the microscopic level requires one to consider a theory of imperfect information differential games. It is possible to describe some aspects of the cancer-lymphocyte interaction phenomenon by means of a multistage, discrete time stochastic differential game model. The concept of the biodynamic field of the cancer cell as postulated by Gurel [6] plays a central role in this discussion. The field is assumed to be the mechanism whereby the cancer cell develops immunity to attack by lymphocytes. Thus the cancer cell,  $C$ , will attempt to maximize its immunity and hence to maximize its biodynamic field. The lymphocyte,  $L$ , on the other hand, seeks to destroy  $C$  and thus to minimize the field effect. The

dynamics of C-L system is described by a linear difference equation. Both C and L attempt to adjust their responses to maximize (C) or minimize (L) the value of a quadratic biodynamic field functional. The analysis of the discrete multistage stochastic differential game is then devoted to determining the effects of corrupting the actual state of the system by treatments—chemical, electrical, or radiological. The type of treatment considered here will not physically effect either C or L, but will be such that neither C nor L will be able to detect the actual state of the C-L system. Without any loss in generality one can also include the destruction of parts of the C or L populations by the treatments. Due to the treatment, both C and L will detect an additive noise corrupted state and will behave according to this corrupted information and not according to the actual state.

The number of stages in the game is denoted by  $N$ . This implies that C and L choose strategies (responses, controls) at  $N$  distinct points in time. A multistage differential game model is extremely difficult to handle due to the complexity of the analysis and the large number of terms involved. Therefore, a single stage stochastic differential game model is often considered to get a qualitative picture of the situation [2].

Let  $Z$  denote the state of a C-L system.  $U$  will be L's strategy (minimizer) and  $v$  will be C's strategy (maximizer). The  $q$ -dimensional vector representing L's observation of the state will be denoted by  $x$  and the  $q'$ -dimensional vector representing C's observation of the state will be denoted by  $y$ . C and L make observations of linear combinations of the  $n$ -dimensional state vector  $z$ , however, their observations are corrupted by some treatment, say a chemotherapeutic one. The effect of this chemotherapy is independent noise sequence such that

$$x = GZ + \eta \quad (4)$$

$$y = HZ + \xi \quad (5)$$

where  $\eta$  and  $\xi$  are  $q$  and  $q'$ -dimensional realizations of an independent noise sequence, respectively.  $G$  and  $H$  are deterministic matrices. The results of an analysis of a situation of this type is that if L has noisy observations, then the theory predicts its control strategy will not be identical to the deterministic case, because L's optimal strategy will involve terms reflecting the noisy nature of C's observations. On the other hand if L has perfect observations and has knowledge of C's observation, then L's optimal strategy will consist of the deterministic case plus a term proportional to the error in C's estimate of the true state.

### Example

Let the boundary that determines the end of the game  $\Sigma$  be greater than zero and let  $R$  be the strip  $-\epsilon < t < \Sigma$  with  $G < 0$ . Let C's strategy, denoted by  $u = u(t,x)$ , be its field strength intensity normalized so that

$$0 \leq u(x,t) \leq 1 \quad (6)$$

L's strategy, denoted by  $v(t,x)$ , will be devoted to detecting C and will also be normalized

$$0 \leq v(t,x) \leq 1 \quad (7)$$

The C-L system of behavior will be governed by

$$\frac{dx}{dt} = |u-v| x(0) = x_0 \quad (8)$$

Play will terminate at  $\Sigma$  due to death or destruction of all elements in C. The payoff P is given by

$$P(0, x_0, u, v) = \int_0^{\Sigma} x dt \quad (9)$$

where C wants to maximize (11) (the field effect) and L wants to minimize it. This is a case where a saddle point solution does exist, viz

$$\text{Max}_u \text{Min}_v P \neq \text{Min}_v \text{Max}_u P \quad (10)$$

Thus it makes a difference who makes the first move, C or L, and a mixed strategy must be played.

In a given case, say L can equalize C's field effect, then from (8)

$$\frac{dx}{dt} = 0 \text{ on } [0, \Sigma] \quad (11)$$

Integrating (11) get  $x(t) = x_0$  and substituting into (9) yields,

$$\int_0^{\Sigma} x dt = x_0 \Sigma \quad (12)$$

Therefore,

$$\text{Max}_u \text{Min}_v \int_0^{\Sigma} x dt \leq x_0 \Sigma. \quad (13)$$

Also, since L will only respond to the level of C's field by (8),  $x(t)$  will be a nondecreasing function and one must have

$$\int_0^{\Sigma} x dt \geq x_0 \Sigma \quad (14)$$

for any pair of strategies  $(u, v)$ . It follows that

$$\text{Max}_u \text{Min}_v \int_0^{\Sigma} x dt = x_0 \Sigma. \quad (15)$$

Thus if C plays first, L can always minimize the integral by equalizing the field effect by some means.

If, on the other hand, L plays first, i.e. is sensitized to C before C appears, then C can choose  $u$  such that

$$\begin{aligned} u(t, x) &= 1 \text{ if } v(t, x) \leq \frac{1}{2} \\ u(t, x) &= 0 \text{ if } v(t, x) > \frac{1}{2} \end{aligned} \quad (16)$$

Thus if L is sensitized to greater than one-half the level of the maximum field strength C is capable of attaining, C will remain dormant. However, if L is sensitized to less than one-half of the maximum field strength, then C will attempt to attain that level of immunity.

This guarantees that

$$\frac{dx}{dt} \geq \frac{1}{2} \quad (17)$$

and

$$\text{Min}_y \text{Max}_u \int_0^{\Sigma} x dt \geq x_0 \Sigma + \frac{1}{4} \Sigma^2 \quad (18)$$

for C's strategy of  $v = 1/2$  and for any  $u$ ,  $\frac{dx}{dt}$  will be less than  $1/4$ , thus

$$\text{Min Max } \int_0^{\Sigma} x dt = x_0 \Sigma + \frac{1}{4} \Sigma^2 \quad (19)$$

and the game has no value.

This points out the value of preventive treatments.

### Conclusion

Instead of describing the conclusions reached by the author it is more profitable to discuss the conclusions the author hoped the reader would elicit from the paper.

One basic concept the author desired to impart to the reader is that the immunological aspects of Lymphocyte behavior are not restricted to the production of chemical compounds and the affects of these compounds as they interact with the agents that have induced the immune response. In fact, there is a mechanical aspect of the immune response as described in this paper that may play an important role in preventing and retarding cancerous growths. The importance of presenting this concept in this paper can be better understood by looking at almost any book on immunology. In these books one can not find any discussion of the mechanical aspects of the immune response.

The second central idea in this paper is that the concepts and formalizing of differential game theory can be profitably applied to biological problems. Here some aspects of cancer immunology have been analyzed within the framework of differential game theory. From the description of the game theoretic techniques and applications, it should be clear that there are many problems in the biological sciences that are amenable to analysis by this theory. For example, predator-prey relations and general interactions among and between species lend themselves to description and analysis by means of the theory of differential games.

The third and final basic objective of this paper is to publicize the lack of experimental data and observations in the area of the physical interaction between cancerous cells and lymphocytes. It is hoped that this paper may be read by an experimentalist who would develop an interest in doing the necessary basic research in this area. Related to this is the hope that theoreticians will adopt differential game theory as a tool for the analysis of biological systems.

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## **Agricultural Weather in West Virginia The Unusual Growing Season of 1972**

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### **Abstract**

Typical weather and climate conditions from March through November 1972 are reviewed. West Virginia has a varied climate due to its topography. The State's growing-season climate is comfortable for both man and beast. Farm operations during the 1972 growing season, with its cool summer and excessive rainfall, were not as badly affected as during the drought years of 1963-1966.

### **Introduction**

Weather is probably the greatest factor farmers have to be concerned with and yet there is little he can do to change it. He has to make the best use possible of the varying weather conditions. With the experience and equipment utilized in forecasting much can be done to forewarn farmers of inclement weather, but that is about all that can be done.

Due to its geographic location and topography, West Virginia weather is extremely variable. This multiplies the Mountain State Farmer's risks in attempting crop production. Weather and climate as it affects the agriculture of West Virginia is discussed in the remainder of this article, and is compared with the weather that actually occurred during the growing season of 1972. Monthly effects and progress of 1972 farm operations are also noted.

Typical weather in April and May results in a continuation of soil moisture surplus. Crops and gardens usually have to be planted and the first hay cutting harvested, during dry periods, which occur sporadically during both months. Long-term precipitation records show the month of March to have a secondary precipitation maximum, due to the cold air outbreaks from Canada becoming progressively weaker as winter ends and the return flow circulation of tropical air becoming stronger. These two air masses frequently become stationary over West Virginia and to the south, with a weak cold front lying along the western or northwestern slopes of the Appalachian or Allegheny Mountains. We saw this type of cold-season rainfall in June 1972 when the circulation around hurricane

"Agnes" drew down extremely cold air from Canada, and caused major floods in the coastal states and even in parts of West Virginia.

#### *Summary of April 1972 Weather*

April was a cool rainy month. It was the sixth wettest April in Huntington's 80 year record with over 6 inches of rain recorded. There were 2 six day rainy spells among the month's 20 rainy days. Temperature averaged below normal for the month.

#### *Summary of April 1972 Farm Operations*

Farming operations were restricted by wet soils for much of April. Most spring plantings are two-three weeks later than normal. Pastures and hay crops are about normal but would improve considerably with a let up in the rain and some warm sunny days. Farm activities have been primarily fill-in jobs while waiting for the ground to dry enough to work it. Many farmers who had plenty of hay continued feeding cattle much of April.

#### *Summary of May 1972 Weather*

Sections west of the higher mountains had less than 3 inches of rainfall during May, although showers were abundant the first 3 weeks. The higher mountains and Eastern Panhandle had large areas which received over 5 inches of rain during the month. Temperatures averaged below normal for the month and were highest during the dry spell which occurred the fourth week.

#### *Summary of May 1972 Farm Operations*

Farming activities were restricted for the first three weeks of May because of wet soils. A break in the weather for the remainder of the month resulted in increased farm activity. Planting of corn, preparation of land for other crops, cutting of the first hay crop and general farm maintenance were the main farm activities.

*Pasture* condition as of June 1 averaged 91 percent of normal, the highest on record for that date. Abundant rainfall and moderate weather were contributing factors for the record high.

The average date in spring of the last occurrence of 32°F or lower is about April 15 in the southwestern part of the State, which includes the Williamson, Charleston, and Huntington areas. In the north-central sections and the Eastern Panhandle the last date is about May 1, and in the mountain areas from May 15 to May 30. Canaan Valley has recorded 32°F or lower all months of the year. One of the latest freezes at many stations in the northern half of the State and higher elevations in the southern mountains occurred June 11, 1972 and damaged many crops and gardens. Many stations had record low June temperatures then, and particularly low for so late in the spring.

#### *Summary of June 1972 Weather in West Virginia*

June was a very cold and wet month, the coldest of record at most stations. Ten plus inches of rainfall at Morgantown during June was the second highest amount of rain recorded for the city in the past 100 years. Many Eastern Panhandle stations received more than ten inches of rain. Most of this occurred during June 19-24 as a result of Hurricane Agnes. Temperatures on June 11 were

the lowest June temperatures ever, for many stations. Freezing temperatures occurred over much of the State on June 11.

*Summary of June 1972 Farm Operations—June Weather Unfavorable*

Weather during June, for the most part, was unfavorable for crop development and field work. Surplus soil moisture, persistent rain, and below normal temperatures prevailed throughout most of the month. Crop development and field work were more than two weeks behind schedule for a normal year. The weather was most uncooperative for the harvesting and curing of the first crop of hay. Pastures are providing ample grazing in most sections of the State. Most livestock are making good gains.

June 1972 weather illustrates in a startling manner two deviations which farmers have to cope with, mostly unsuccessfully: a record late freeze and excessive rain (even some flooding) at a time when crops and gardens should be in full development. June usually shows an increase in moisture in more concentrated short-duration forms due to greater frequency of thunderstorms. Average temperatures increase (the exception of course is June 1972) and give the heat necessary for plant growth.

July is the warmest month of the year, being slightly warmer than June. It also has a slightly greater frequency of thunderstorms than June. July is the month of maximum precipitation for West Virginia, except for the Eastern Panhandle. Occasionally a one- or two-week dry spell occurs in July that results in crop damage.

Let us follow through a typical July day—July because this month is usually the warmest and best illustrates typical summer days. The sun rises at about 6 a.m. Eastern Daylight Time. Temperatures may be quite cool: about 60 degrees F. generally but nearer 50 degrees F. at elevations above 2000 feet. Valley fog may form about sunrise, if it has rained recently and if moisture is abundant. This fog is usually "burned off" by the heat of the sun by 8 a.m. At this time the sky is generally a bright blue and clear of clouds. The air is quite still until about midmorning, after which gentle breezes begin, induced by the heat of the sun. By noon the sky is about half-covered with cumulus clouds, which gradually extend to greater heights during the afternoon and by then cover about 70 percent of the sky. About every fourth or fifth day on the average, these towering cumulus clouds cover the entire sky and develop into a thunderstorm, usually of short duration, whose time of occurrence is usually between 1 p.m. and 10 p.m. The highest temperature of the day occurs in the afternoon about 3 o'clock EDT, depending on the amount of cloud cover. A few afternoons may have oppressively high humidity, which is more noticeable in the lower elevations of the larger cities. However, afternoon breezes, particularly near the hilltops and in the countryside, are dependable and exert a comforting influence, although their speeds are seldom above 12 miles per hour. By sunset, at about 8:45 p.m. EDT, temperatures have lowered perceptibly and the sky is less than half-covered with clouds. The first few hours after sunset temperatures fall rapidly and a gentle movement of cool air from the mountains or hilltops slowly descends into the valleys. Nights which are comfortable for sleeping are the rule.

*Summary of July 1972 Weather in West Virginia*

This was a cool July except for the humid heat wave July 18-26, which brought the summer's warmest weather. Rainfall totals were variable but general-

ly near normal, particularly in the higher mountain elevations and the Northern Panhandle.

#### *Summary of July 1972 Farm Operations*

*Crops Late.* Growth and harvest of the Mountain State's crops were two weeks or more later than normal. Frequent rain slowed harvest and caused considerable lodging in small grains. Excessive rain, however, benefitted pastures and the second growth of hay. Soil moisture in July was mostly adequate or surplus. Outside of the last week in July, very few reports of short soil moisture were received. Rain the first week in August should have alleviated this condition. Japanese beetles and other insects have been a particular problem in gardens because of the cool, wet weather. The condition of all growing crops was fair-to-good.

August is usually drier than July, as rainfall begins its slow decrease to its annual minimum monthly values in October. In the Eastern Panhandle the month of August shows the rainfall maximum because this is the month of maximum hurricane frequency. The remnants of hurricanes cause large rainfalls even as far inland as the Eastern Panhandle and the eastern slopes of the Mountains. Of more importance to the orchard industry is the fact that high winds may penetrate inland and shake fruit off the trees.

#### *Summary of August 1972 Weather in West Virginia*

Most of the state had evenly spaced near normal rainfall. Monthly temperatures continued below normal. An early cold spell occurred August 8-12. There were very few occurrences of temperatures 90°F. or above.

#### *Summary of August 1972 Farm Operations—Weather Favors Harvest*

Mountain State farmers experienced favorable weather conditions during August for harvesting their crops. Throughout most of the month, farmers were active baling hay, combining small grains, filling silos, gathering vegetables and, toward the end of the month, cutting tobacco.

Corn remained in mostly fair-to-good condition. The crop was maturing rapidly after getting off to a rather slow start. As of September 8, 92 percent of the acreage was in or past the dough stage. Farmers began filling their silos the last week in August.

Nearly all the small grains were combined. Land preparation and seeding of winter wheat and barley was well underway.

Hay making was extremely varied this year. A few farmers were still trying to harvest first cuttings while others, as of September 8, had harvested about 20 percent of the third cutting.

With the late summer decrease in rainfall and cloudiness, sunshine increases. The shortening days are almost as warm because of this decreased cloudiness but the longer nights bring lower minimum temperatures, particularly in September and October. The average length of the growing season is about 200 days in the southwestern part of the State, and about 150 to 175 days in the balance of the State except in the mountains it varies from 90 to 110 days. The average date for the first occurrence of 32°F or lower in fall is about September 15 in the mountain areas, and between October 1-10 in the balance of the State except for the southwestern areas where it does not occur until about October 30. These

dates for both spring and fall are general and vary considerably within each area mentioned due to differences in elevation and other microclimatic variations, in addition to any yearly variation due to the large-area regional circulation.

#### *Summary of September 1972 Weather in West Virginia*

September had about average rainfall and temperatures. The heaviest amounts of rain occurred during the last week of the month.

#### *Summary of September 1972 Farm Operations*

*General* Hay making dominated farm activities in the Mountain State throughout September with harvest of tobacco, small grains and silage also being very active. Most of the State had adequate soil moisture during September with the exception of the Eastern Panhandle where it was getting dry at the end of the month. Light, scattered frost occurred October 1-2 with a general frost reported October 10.

*Hay Production Over Million Ton Mark* Growth of hay has been excellent this year, but frequent showers during the harvest reduced quality. The hay crop is expected to total 1,005,000 tons, up 9 percent from 1971 and 15 percent from 1970. If this production is realized it will be a record high for the State. The increased production is due to an increase in yield for hay other than alfalfa.

#### *Summary of October 1972 Weather in West Virginia*

The lowest average temperatures of record for October were recorded in many areas. Record low temperatures for October occurred in several locations on the 20th. Rainfall was above normal in the higher elevations and Eastern Panhandle but below normal along the Ohio River. Many October snowfall records were broken October 19.

#### *Summary of October 1972 Farm Operations*

*General* Mountain State weather through October was mostly cold and wet. The rain, heavy at times, kept the ground too wet for most farming operations such as plowing and seeding small grains. October's weather pattern slowed the pace of corn harvest and reduced yields of late corn for grain. Some late corn for grain was diverted to silage. There were still apples on the trees when the October 20 freeze occurred.

*Pastures* Pasture condition on November 1 was 83 percent of normal, 10 points below the record high level for November 1971, but 10 points above the 1961-70 average. Pastures have been very good most of this year due to an abundance of moisture.

The State's growing-season climate is comfortable for both man and beast and reflects to a large degree the effects of the topography—the mountains, hills, and valleys—on the regional weather. It should be remembered that the most important aspect of West Virginia's climate is its diversity, which is created by the generally rugged and hilly terrain, and is further accentuated by the temperature and precipitation differences between valley and mountain locations. The State's varied topography considerably modifies the latitudinal climate controls and also results in diversified farm activities.

Despite the late start due to wet fields, the cool summer, and the wet fall, total production was not too bad. There were more complaints about the lack of rain during the drought years of 1963-1966. It would seem that a record cool

and wet summer and fall does not affect West Virginia farm operations as much as do hot dry summers.

## International Conflict—A Basis for Prediction and Systems Analysis—

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### Abstract

The objective of this paper is to gain insight into an important problem in the area of operations research. The problem is the analysis of arms races and the prediction of armed conflict. This rigorous quantitative approach is developed by analogy with theoretical mechanics. The two-nation problem is considered first and general relations describing the behavior of these nations involving a set of ordinary linear differential equations are obtained. It is shown that these relations reduce to the well known and widely accepted equations of L. F. Richardson (*Arms and Insecurity*, Boxwood Press Pittsburgh, 1960). By means of this theory one can calculate the optimum proportion of resources that should go into defense.

International relations involve complex processes where nations act and react toward each other. The objective of this study is to obtain insights into and to provide an analysis of one important aspect of international relations: armed conflict. To this end a general theory is developed from basic concepts. This generality is needed to provide adequate quantitative descriptions of the frequent changing of nation's policies, technologies, populations, attitudes, ideologies, moralities, affluences, etc. [21], [7], [4], [20].

Another advantage of this general approach is that the formalism is valid for all types of conflict such as: civil disorders [5], labor-management interactions [6], [16], familial conflict, man-machine interaction. For this purpose Schouborn's definition of conflict is adopted [14]. "A situation in which the conditions, practices, or objectives of various parties are incompatible and therefore compel parties to neutralize, injure, or eliminate each other." Most problems involving group or individual conflict are amenable to analysis by the techniques developed here.

There are two basic categories into which all approaches to international relations may be subsumed. The first includes rigorous and quantitative theories characterized by the work of Richardson [11], [12] and post-Richardson extensions [1], [9], [2], [8]. The second category includes most of the published work in the area of international relations and will be called the *intuitive* approach. There are three basic subclasses involved in this approach to international relations to be found in the literature [13]. The first is the *historical*

*tack* based on diplomatic history. The second is independent of historical accounts and is based on vague concepts of the *national interest* and *balance of power*. The third involves the *verbalization of systems analysis techniques* by political scientists unschooled in mathematics and unaware that the power of systems analysis is in its mathematical reasoning and methods. There is no need to dwell on the advantages of quantitative and mathematical systems approaches as this is done in most works in the first category (see [11] in particular).

### Definitions

The basic *elements* to be considered in a study of international conflict are *nations*. However, depending on the particular situation an element may take forms other than national such as societies, religious groups, institutions, international corporations, racial groups, or even individuals. The specification of the elements is the first step in rigorously developing a system [10]. The set of elements (nationals) taken into consideration in the analysis is called the *international system*.

The complete specification of the international system involves determining the *modes of interaction* of the elements within the system. The analysis of these interactions leads to a set of *constitutive relations* which serve to represent the basic properties of the elements. It is these relations along with the *governing differential equations* of the system that allows one to predict conflicts.

To determine the modes of interaction of the elements the assumption is made that the primary motivation of each element in international relations is the continuation of its functions and its existence. To accomplish this the element must be supported and maintained. *Sustenance* is defined as that which is required by an element in the system to exist and function. Sustenance need not correspond to the actual needs of the element. It can be, and often is, what the element believes it needs to exist and function. Sustenance can therefore assume various forms and among them are currency, energy, raw materials, power, hate, loyalty, peace, war, markets, arms, ideology, racism, etc. Obviously an element will require a large number of sustenances of various magnitudes. However, in analyzing a particular system at a given time a small number, or even a single sustenance may dominate the behavior of the element.

### Two Element Interaction

In a two element or two national problem the interaction is a function of the sustenance required by each element. In this interaction the elements influence each other in direct proportion to the sustenances involved. The *influence*  $I$  exerted by an element  $\alpha$  on an element  $\beta$  is defined as

$$I_{\alpha:\beta} = N_{\beta} A_{\alpha} \left[ \sum_j A_j \right]^{-1} \quad (1)$$

where  $N_{\beta}$  is the sustenance *desired* by element  $\beta$ ,  $A_{\alpha}$  is the sustenance *available* from  $\alpha$  and  $\sum A_j$  is the *total* sustenance available from all sources including  $\alpha$  and  $\beta$ . This relation adequately describes the two extreme cases of influence in a two element interaction: a) the sustenance available from  $\alpha$  is zero, equation (1) then implies that  $\alpha$  has no influence on  $\beta$ . b)  $\alpha$  is the only source of sustenance for  $\beta$ , equation (1) then tells us that the influence of  $\alpha$  on  $\beta$  is the sustenance desired by  $\beta$ .

The *unbalance* (international unbalance of influence) between element  $\alpha$  and element  $\beta$  is the influence difference

$$\Gamma_{\alpha:\beta} = I_{\alpha:\beta} - I_{\beta:\alpha} \quad (2)$$

a change in the imbalance  $\Gamma$  implies that changes are occurring in the relative influences of  $\alpha$  and  $\beta$ . In some cases the imbalance will remain constant at a time when the influences will be changing rapidly.

The *force* (international force)  $F$ , exerted by element  $\alpha$  on element  $\beta$  is the rate of change of imbalance

$$F_{\alpha:\beta} = \frac{d\Gamma_{\alpha:\beta}}{dt} \quad (3)$$

Thus large imbalances do not necessarily lead to forces being applied to elements; it is the *change* in imbalances that leads to increased forces and eventually to conflict.

The *inertia*  $m$  of an element is a weighted measure of population. In certain cases  $m$  will reduce to the actual population of a nation. In others it will be the population multiplied by the average yearly income, or the number of military personnel multiplied by the square root of the number of aircraft, etc. The choice of the measure of inertia is determined by the dominant sustenance in a given situation. Thus there will be one method of calculating the inertia if economic considerations are dominant, another if hatred is dominant, and yet another if territorial desires are dominant, etc. Even in cases where a single sustenance is dominant over a period of time the inertia will often be variable.

The *state* of an element (international state),  $s$ , is the condition or status of the element measured with respect to a reference state. The state is generally expressed in terms of the inertia, sustenance need and self sufficiency.

$$s_{\alpha} = s_{\alpha}(m_{\alpha}, N_{\alpha}, A_{\alpha}) \quad (4)$$

The *instability*  $c$  of an element (international instability) the time rate of change of its state

$$c_{\alpha} = \frac{ds_{\alpha}}{dt} \quad (5)$$

or

$$c_{\alpha} = \frac{\partial s_{\alpha}}{\partial m_{\alpha}} \frac{dm_{\alpha}}{dt} + \frac{\partial s_{\alpha}}{\partial N_{\alpha}} \frac{dN_{\alpha}}{dt} + \frac{\partial s_{\alpha}}{\partial A_{\alpha}} \frac{dA_{\alpha}}{dt} \quad (6)$$

Finally using the instability one may define the *power* (international power) an element  $\alpha$  has over and element  $\beta$ ,

$$P_{\alpha:\beta} = F_{\alpha:\beta} c_{\beta} \quad (7)$$

The power  $\alpha$  has over  $\beta$  depends on the force exerted by  $\alpha$  on  $\beta$  and also the state of  $\beta$ . In other words the power depends on external and internal factors.

## Stresses and Strains

The *stress* (international stress)  $\sigma$  that an element  $\alpha$  imposes upon an element  $\beta$  is

$$\sigma_{\alpha:\beta} = \frac{F_{\alpha:\beta}}{m_{\beta}} \quad (8)$$

The use of the term "stress" to describe certain aspects of political or social interactions is not new. However, in most cases it has been introduced as an intuitive concept, whereas here it has been developed from certain basic assumptions. Nevertheless the concept of stress as developed here bears certain similarities to the *societal stress* discussed by Terrell [18].

The stress applied by  $\alpha$  and  $\beta$  induces a *strain* (international strain)  $\epsilon$  on  $\beta$ . The strain is a measure of the ability of the element  $\beta$  to receive and resolve the conflicting demand placed on it by  $\alpha$ . Thus the instability  $c$  is a measure of internal stability of  $\alpha$  as it depends only on  $\alpha$ 's state and the strain  $\epsilon$  is a measure of the instability of  $\alpha$  due to the forces applied by  $\beta$ . Succinctly  $c$  is a measure of internal stability and  $\epsilon$  is a measure of external stability [3], [17], [15], [19].

The relation between stress and strain is called the (international) *constitutive relation*. In general, the constitutive law relates the stress to the strain through a history dependent process. The state of strain at the present time in an element is determined by the entire past history of the stress applied to that element. Mathematically this is expressed by writing (in Volterra's notation) [19].

$$\epsilon_{\alpha:\beta}(t) = \Omega[\sigma_{\alpha:\beta}(\tau)]_{\tau=0}^{\tau=t} \quad (9)$$

This says that the strain in  $\beta$  due to  $\alpha$   $\epsilon_{\alpha:\beta}$ , is a functional  $\Omega$  of the stress  $\alpha$  applies to  $\beta$ ,  $\sigma_{\alpha:\beta}$ , from some initial time,  $\tau = 0$ , to the present time,  $\tau = t$ .

The simplest case of (9) occurs when  $\Omega$  reduces to a constant. Then

$$\epsilon_{\alpha:\beta}(t) = K \sigma_{\alpha:\beta}(t). \quad (10)$$

In equation (10)  $k$  is a constant and the past history has no influence on the present.

### Application

In many applications one can reduce the (societal) stress and (international) strain to the force (3) and the state (4), respectively. In this case the general relation (9) can be written as

$$F_{\alpha:\beta}(t) = \Omega[s_{\beta}(\tau)]_{\tau=0}^{\tau=t} \quad (11)$$

This relation states that one can determine the force exerted by nation  $\alpha$  on nation  $\beta$ , at the present time, if one knows the past history of the state of  $\beta$ .

The well known and widely quoted Richardson model [11] will now be shown to be a very special case of (11): If a linear relation exists between  $F$  and the time derivatives of  $s$  then (11) can be written as

$$F_{\alpha:\beta} = \sum_{i=0}^n m_{\beta} \frac{d^i s_{\beta}}{dt^i} \quad (12)$$

for  $s = s(t)$ .

Consider the case where only the  $i = 2$  term is non-zero, that is the Newtonian case:

$$F_{\alpha:\beta} = m_{\beta} \frac{d^2 s_{\beta}}{dt^2}. \quad (13)$$

Let the influence (see (17)) be of the form

$$I_{\alpha:\beta} = \frac{N_{\beta} A_{\alpha}}{A_{\alpha} + A_{\beta}} \quad (14)$$

Now  $\Gamma$  (See (2)) can be expressed as

$$\Gamma_{\alpha:\beta} = \frac{N_{\beta} A_{\alpha}}{A_{\alpha} + A_{\beta}} - \frac{N_{\alpha} A'_{\beta}}{A'_{\alpha} + A'_{\beta}} \quad (15)$$

where  $A'_{\alpha}$  and  $A'_{\beta}$  represent the availability of sustenance (in the case security is equivalent to sustenance) for  $\alpha$  from  $\alpha$  and  $\beta$ . Therefore from the constitutive relation (13) and (3) one obtains

$$m_{\beta} \frac{ds_{\beta}}{dt} = \frac{N_{\alpha} A_{\beta}}{A_{\alpha} + A_{\beta}} - \frac{N_{\alpha} A'_{\beta}}{A'_{\alpha} + A'_{\beta}} \quad (16)$$

### Derivation of Richardson's Equations

In Richardson's model  $s_{\alpha}$  and  $s_{\beta}$  represent the armament or the nation's defense posture. Thus the insecurity of  $\alpha$ — $\alpha$ 's need for security—will be proportional to the state of the enemy's armament,  $s_{\beta}$ , and inversely proportional to its own armament state,

$$N_{\alpha} = G_{\alpha} \frac{s_{\beta}}{s_{\alpha}} \quad \text{and} \quad N_{\beta} = G_{\beta} \frac{s_{\alpha}}{s_{\beta}}, \quad (17)$$

where  $G_{\alpha}$  and  $G_{\beta}$  are constants. Now, consider the availability functions. Consider first  $A_{\beta}$ . The smaller the state  $s_{\beta}$ , the greater will be the pressure to divert the nation's resources to security (armaments). The military and their supporters will raise the hue and cry denouncing the nation's weak defenses and then convincingly call for increased military expenditures. Conversely, the greater the state  $s_{\beta}$ , the more difficult it will be to convince the nation to divert more of its resources into the armament sphere. In the U.S. this takes the form of contention between military supporters and people who feel the nation's primary con-

cern should be social and urban problems. In the U.S.S.R. this takes the form of a "guns or butter" controversy.

Next, consider  $A_\alpha$ . Nation  $\beta$ 's sustenance (security) increases as  $\alpha$ 's armament state decreases. Hence, the sustenance available for  $\beta$  from  $\alpha$   $A_\alpha$  will be inversely proportional to  $s_\alpha$ . The above conclusions can be succinctly stated as

$$A_\beta = \frac{H_\beta}{s_\beta}, \quad A_\alpha = \frac{H_\alpha}{s_\alpha} \quad (18)$$

where  $H_\alpha$  and  $H_\beta$  are constant.

Substituting (17) and (18) into (16) leads to,

$$m_\beta \frac{ds_\beta}{dt} = G_\beta \frac{s_\alpha}{s_\beta} \frac{(H_\alpha/s_\alpha)}{(H_\alpha/s_\alpha) + (H_\beta/s_\beta)} - G_\alpha \frac{s_\beta}{s_\alpha} \frac{(H'_\beta/s_\beta)}{(H'_\beta/s_\beta) + (H'_\alpha/s_\alpha)} \quad (19)$$

Equation (19) can be expressed as

$$m_\beta \frac{ds_\beta}{dt} = G_\beta s_\alpha \left[ \frac{H_\alpha}{H_\alpha s_\beta + H_\beta s_\alpha} \right] - G_\alpha s_\beta \left[ \frac{H'_\beta}{H'_\beta s_\alpha + H'_\alpha s_\beta} \right] \quad (20)$$

and the equivalent expression for  $m_\alpha \frac{ds_\alpha}{dt}$  is

$$m_\alpha \frac{ds_\alpha}{dt} = G_\alpha s_\beta \left[ \frac{H'_\beta}{H'_\beta s_\alpha + H'_\alpha s_\beta} \right] - G_\beta s_\alpha \left[ \frac{H_\alpha}{H_\alpha s_\beta + H_\beta s_\alpha} \right] \quad (21)$$

These relations are more general than Richardson's equations. They reduce to Richardson's equations when: a) the armament states are changing relatively slowly, i.e.,

$$s_\alpha = s_{0\alpha} + s_\alpha^* \quad \text{and} \quad s_\beta = s_{0\beta} + s_\beta^* \quad (22)$$

where  $s_{0\alpha}$  and  $s_{0\beta}$  are constants and  $s_\alpha^*$  and  $s_\beta^*$  are small in comparison to the constants; when: b)  $\alpha$ 's influence over  $\beta$ , then the influence  $\beta$  has over  $\alpha$ . This implies that

$$I_{\alpha:\beta} \gg I_{\beta:\alpha} \quad (23)$$

Hence (20) becomes

$$m_{\beta} \frac{ds_{\beta}^*}{dt} = G_{\beta} H_{\alpha} (s_{0\alpha} + s_{\alpha}^*) [H_{\alpha} s_{0\beta} + H_{\beta} s_{0\alpha} + H_{\alpha} s_{\beta}^* + H_{\beta} s_{\alpha}^*]^{-1} - G_{\alpha} H'_{\beta} (s_{0\beta} + s_{\beta}^*) [H'_{\beta} s_{0\alpha} + H'_{\alpha} s_{0\beta} + H'_{\beta} s_{\alpha}^* + H'_{\alpha} s_{\beta}^*]^{-1} \quad (24)$$

$$= \bar{G}_{\beta} (s_{0\beta} + s_{\alpha}^*) [1 + (\bar{H}_{\alpha} s_{\beta}^* + \bar{H}_{\beta} s_{\alpha}^*)]^{-1} - \bar{G}_{\alpha} (s_{0\beta} + s_{\beta}^*) [1 + (\bar{H}'_{\alpha} s_{\beta}^* + \bar{H}'_{\beta} s_{\alpha}^*)]^{-1} \quad (25)$$

where the barred quantities are new composite constants.

Applying the binomial expansion and neglecting higher order terms yields,

$$\frac{ds_{\beta}^*}{dt} = \bar{G}_{\beta} (s_{0\alpha} + s_{\alpha}^*) [1 - \bar{H}_{\alpha} s_{\beta}^* - \bar{H}_{\beta} s_{\alpha}^*] - \bar{G}_{\alpha} (s_{0\beta} + s_{\beta}^*) [1 - \bar{H}'_{\beta} s_{\alpha}^* - \bar{H}'_{\alpha} s_{\beta}^*] \quad (26)$$

or

$$\frac{ds_{\beta}^*}{dt} = J_1 s_{\alpha}^* [1 - J_2 s_{\alpha}^* - J_3 s_{\beta}^*] - J_4 s_{\beta}^* + J_5 \quad (27)$$

where the  $J_i$  are new composite constants. The equivalent relation for  $s_{\alpha}^*$  is

$$\frac{ds_{\alpha}^*}{dt} = J'_1 s_{\beta}^* [1 - J'_2 s_{\beta}^* - J'_3 s_{\alpha}^*] - J'_4 s_{\alpha}^* + J'_5 \quad (28)$$

Equations (27) and (28) are Richardson's most general two nation equations in Richardson's terminology.  $J_1$  and  $J'_1$  are called the defense coefficients.  $J_2$  and  $J_3$  are constants representing the national submissivenesses.  $J_3$  and  $J'_3$  are taken to be equal to  $J_2$  and  $J'_2$  by Richardson.  $J_4$  and  $J'_4$  are representative of the national fatigue and the expense of maintaining the defenses.  $J_5$  and  $J'_5$  represent national grievances and ambitions.

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## Influence of Ultrasonics on the Flow of Polymer Melt

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### Abstract

Under conditions simulating injection molding, the flow rate of a polymer melt was found to be increased by the application of ultrasonic radiation. Other variables included in the study were temperature and pressure. The temperatures used ranged from 185 to 200°C which is the injection molding temperature range for the polymer used. The pressures used varied from 425 to 1420 psig. Ultrasound having a frequency of 20 kHz was applied with input intensities of 45 to 105 watts. The effect on the polymer melt was measured by the distance of polymer penetration into a stainless steel tube. An increase of up to 60% was measured. It is conjectured that the ultrasonic radiation was preferentially absorbed near the metal-polymer interface, which could either induce sliding friction of the polymer at the metal wall, by modifying frictional bonds between phases or could induce a reduced polymer viscosity by changing the polymer morphology. The apparent reduction in viscosity,  $\frac{\mu(u.s.)}{\mu(initial)}$  ranged from 0.35-1.0.

## Introduction

There are presently few commercial applications of ultrasonic energy in the chemical industry. In particular, ultrasonic sealing of plastic is widely used in plastic industries. Some of the research work reported in the literature includes 1) Application of ultrasonic energy to compression molding,<sup>(1)</sup> 2) Correlation of changes in the electrical and thermal conductivities to ultrasonic radiation input,<sup>(1)</sup> (It was reported that an increase in the conductivities at high frequencies was observed but remained practically the same as the power input was changed.) 3) Acoustically augmented drying,<sup>(2)(3)</sup> 4) Polymer viscosity reduction and control,<sup>(4)(5)</sup> 5) Ultrasonic acceleration of liquid flow through porous media.<sup>(6)</sup> An important conclusion in this latter work was that ultrasonic energy reduces the adhesive forces at the liquid-solid interface.

It should be noted that two main characteristics of ultrasonic energy account for the bulk of applications or potential applications which use ultrasound. One characteristic is the ability of ultrasound to affect the frictional bonds between dense phases in contact. The second characteristic is the absorption of energy by scattering, where the waves get scattered in the body of the system (either solid or fluid) by simultaneous reflection or refraction.

Very little work has been done on what effects ultrasound has on extrusion or the injection molding cycle of polymers. However, considerable work has been done on the effects of ultrasound on extrusion of the nonnewtonian flow of clays and ceramic materials.<sup>(7)(8)</sup> Ultrasound was found to accelerate flow. The present work was undertaken to investigate the effects of ultrasound on the flow of polymer melt. The conditions used were similar to that found in molding to simulate possible effects on moldability. Moldability can be described as the ease with which polymer melt can flow into a mold without creating strain in the final solid. Moldability affects the efficiency of the molding operation and depends on the thermal and rheological properties of the plastic. If ultrasound could bring about a change in thermal and rheological properties of the polymer, the entire molding operation can be improved.

## Experimental Program

**Apparatus:** To study the effects of ultrasonic energy on polymer flow an apparatus simulating injection molding was constructed. It consisted of a cylinder, plunger and an extruder tube mounted on a jack of variable pressure (Figure 1). Pressure required to inject molten polymer was supplied by a nitrogen tank. The nitrogen tank was attached to the jack by a brass tube. The cylinder had an opening deep enough for a thermocouple to measure the temperature of the polymer melt. Heating was done by an ordinary bunsen burner, fitted horizontally next to the cylinder 1½" away in order to achieve uniform heating. The flame was broad enough to achieve uniform heating.

**Procedure:** A number of slugs of the polymer (polymethyl-methacrylate Lucite-bead polymer, Dupont, composition: AU, NC-99) were prepared by heating the polymer powder to a specific temperature, subsequently compressing the polymer in the major cylinder. Upon cooling, a polymer slug, (clear and without bubbles and impurities) was formed which fits the cylinder cavity. Such slugs were used for subsequent experimental runs.

For an experimental run, a slug was placed in the cylinder. The cylinder is then heated to the required temperature. The polymer melt is injected into an extruder tube at a specified pressure, once without ultrasonic energy, once with

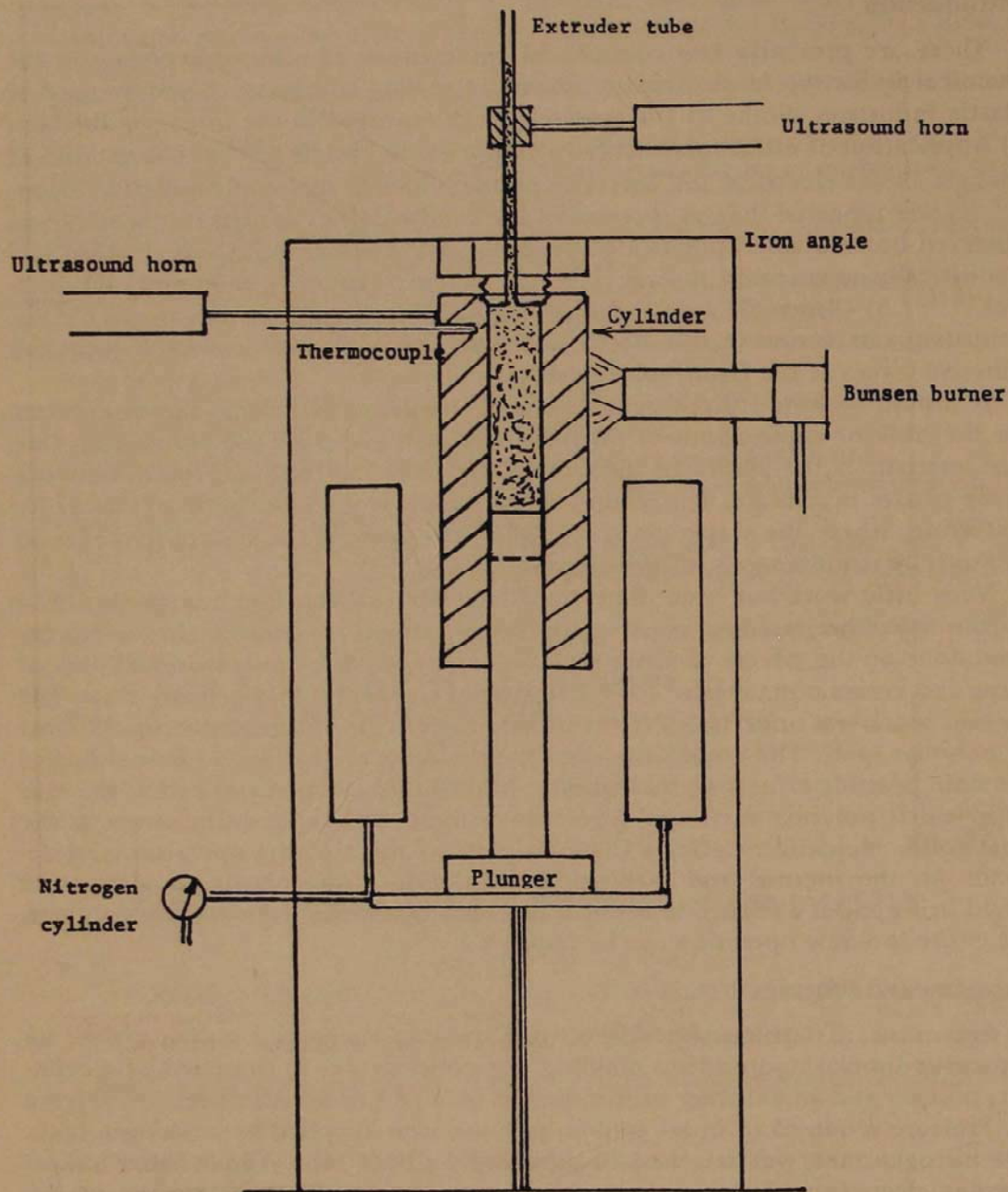


FIGURE 1. Assembly of the Apparatus.

ultrasonic energy. Ultrasonic energy could be applied at two places, on the cylinder at the entrance of the polymer to the extruder tube and on the extruder tube (Figures 1 and 2). Readings were to be taken for separate or simultaneous application at these two places. The penetration of the polymer up the extruder tube was measured for ultrasound application. The difference in the readings are a measure of the effect of ultrasonic energy on melt flow.

The temperature range for the experiments was 185-200°C. Plunger pressure and ultrasonic ranges were 425-1420 psig and 0 - 105 watts at 20 kHz respectively.

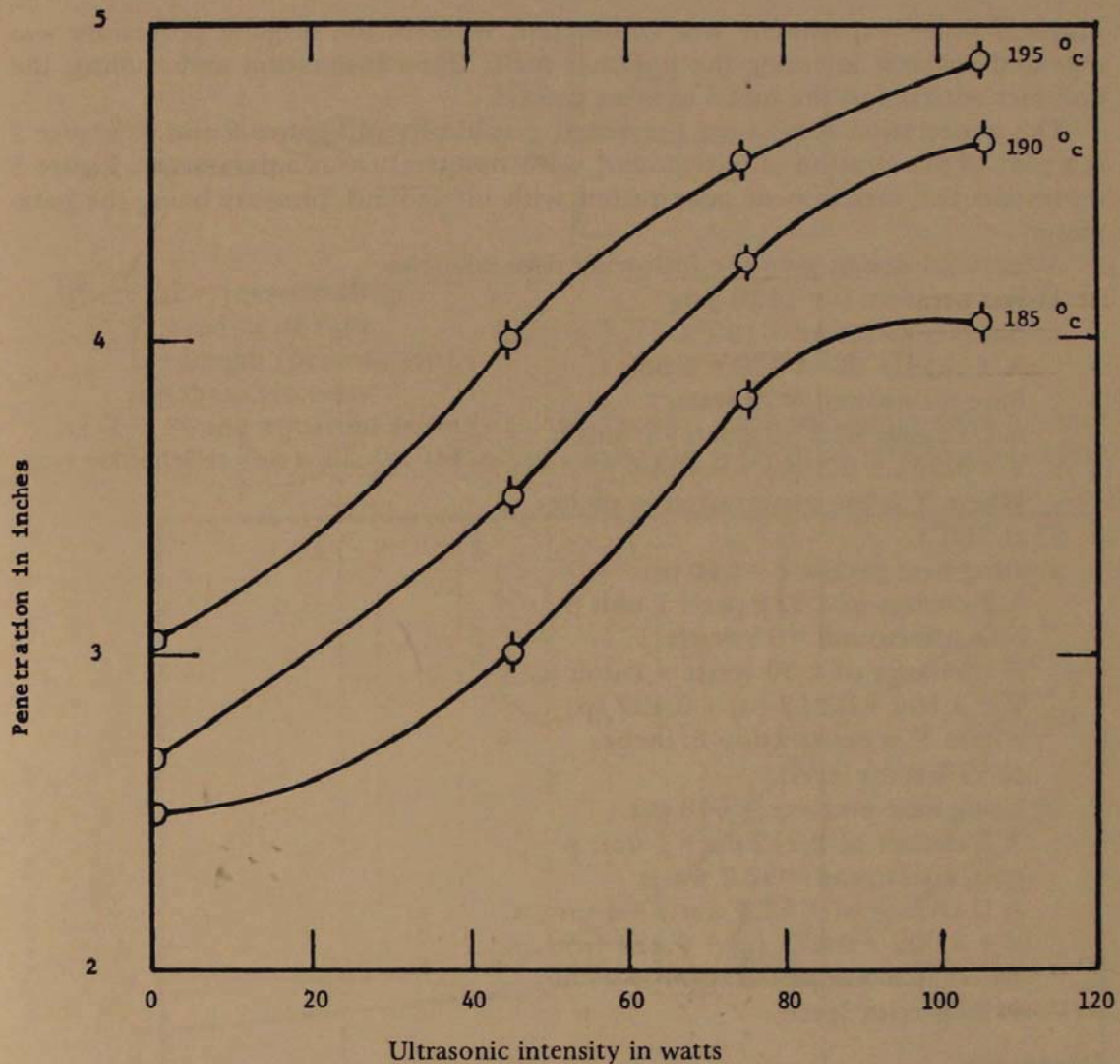


FIGURE 2. Correlation of Penetration with Ultrasonic Intensity. The variation of penetration versus ultrasonic intensity is given at different temperatures. Pressure = 1420 psi.

### Results

Initially, the temperature range used was 150-200°C. It was found that ultrasonic energy had no effect on the penetration between 150-180°C. On the other hand, at 200°C, at pressure above 1000 psi, all the polymer slug was injected through the tube. These limits determined the effective temperature range at 180-200°C.

Application of ultrasonic energy just on the extruder tube produced a negligible increase in penetration as compared to a run without ultrasound. Therefore, further runs at this position were excluded. Varying the position of ultrasound horn on the cylinder did not make a measurable difference in penetration, although significant increased penetration was obtained.

At the end of an experimental run, the residue of polymer slug was easily removed when ultrasound was *not* applied. For a run using ultrasound, the slug residue adhered to the cylinder and had to be heated to be removed. This suggested a relationship between melt-metal adhesion and ultrasonic radiation. A

supplementary experiment was conducted, wherein the original procedure was repeated *without* injecting the polymer melt. Upon insonation and cooling, the polymer adhered to the metal in most cases.

The penetration results are presented graphically in Figures 2 and 3. Figure 2 is a plot of penetration vs. ultrasound, with temperature as a parameter. Figure 3 represents the variation of penetration with ultrasound, pressure being the parameter.

A factorial design gave the following dependencies.

- 1) For pressure  $p = 1420$  psig  
Base temperature =  $190^{\circ}\text{C}$   
A T change of  $\pm 5^{\circ}\text{C} = 1$  unit  $t$   
Base ultrasound = 75 watts  
A U change of  $\pm 30$  watts = 1 unit  $u$   
 $Y = 3.961 + 0.5(u) + 0.408(t)$   
Where Y is the penetration in inches
- 2) at  $200^{\circ}\text{C}$ 
  - a) using base pressure = 640 psi  
A P change of  $\pm 212$  psi = 1 unit  $p$   
base ultrasound = 75 watts  
A U change of  $\pm 30$  watts = 1 unit  $u$   
 $Y = 3.106 + 0.217(u) + 0.492(p)$   
Where Y is penetration in inches  
at 99% error level.
  - b) Using base pressure = 640 psi  
A P change of  $\pm 212$  psi = 1 unit  $p$   
base ultrasound = 52.2 watts  
A U change of  $\pm 52.5$  watts = 1 unit  $u$   
 $Y = 3.022 + 0.275(u) + 0.425(p)$   
Where Y is the penetration in inches  
at 99% error level.

### Discussion

It is clearly seen from earlier results that absorption of ultrasonic energy produces an increase in penetration. Figure 2 and the factorial design clearly show that penetration increases (at a certain level of ultrasonic energy input) with an increase in temperature. Increasing the level of ultrasonic energy increases the penetration still further. The factorial design and Figures 3 also show that penetration increases with ram pressure. The factorial design showed a relatively uniform dependance of penetration on the independent variables, temperature, pressure and ultrasonic radiation. Statistics allow no statement to be made as to whether this increase in penetration, with either increasing temperature or ultrasound, is linear or non-linear.

One can explain the results by either assuming (1) that ultrasound facilitates the flow of polymer melt by inducing a slip at the wall of the cylinder (a phenomena which can be characterized by a coefficient of sliding friction,  $\beta$ ) or (2) the apparent bulk viscosity decreases under ultrasound application.

By assuming Newtonian flow calculations for  $\beta$  and viscosities can be made. The average velocity in this case is given by

$$\langle v_z \rangle_{\beta} = \frac{\Delta P R^2}{8 \mu L} \left[ 2 \left( \frac{\frac{2\mu}{\beta} + R}{R} \right) - 1 \right]$$

Where  $\Delta P$  = pressure drop

$R$  = radius of tube

$L$  = length (penetration)

$\mu$  = shear viscosity

At  $\beta \rightarrow \infty$ , the equation reduces to the familiar form of average velocity with zero velocity at the wall. On the other hand at  $\beta \rightarrow 0$ , there will be no friction

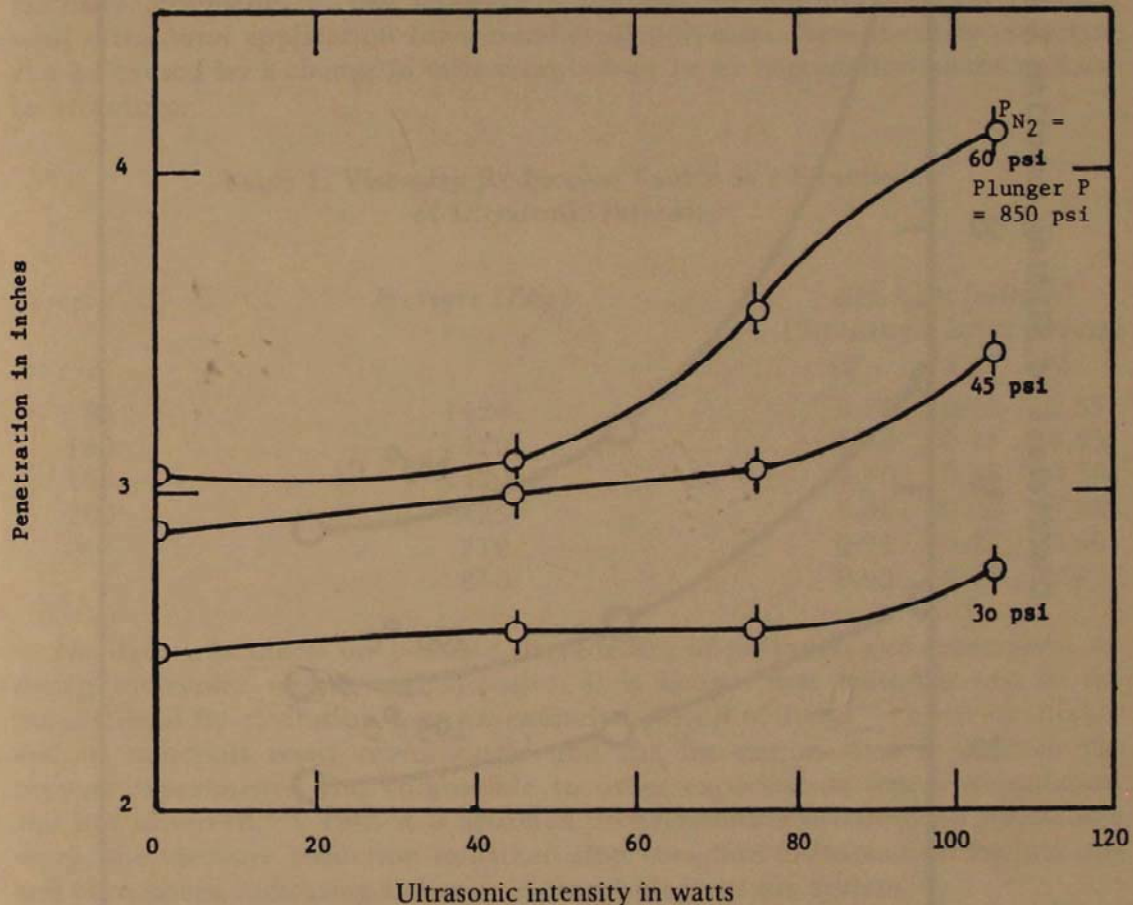


FIGURE 3. Correlation of Penetration with Ultrasonic Intensity. The variation of penetration with ultrasonic intensity is plotted at different pressures. Temperature = 200°C.

and all the melt will slide as a slug. The  $\beta$  calculations result are presented graphically in Figure 4. With an increase in ultrasound,  $\beta$  decreases with a resultant increase in slip.

The decrease in  $\beta$  with increase in ultrasound can be explained by absorption of ultrasound in the polymer melt near the wall. The cylinder as a whole can be regarded as a source of ultrasonic energy radiating waves radially inwards. A

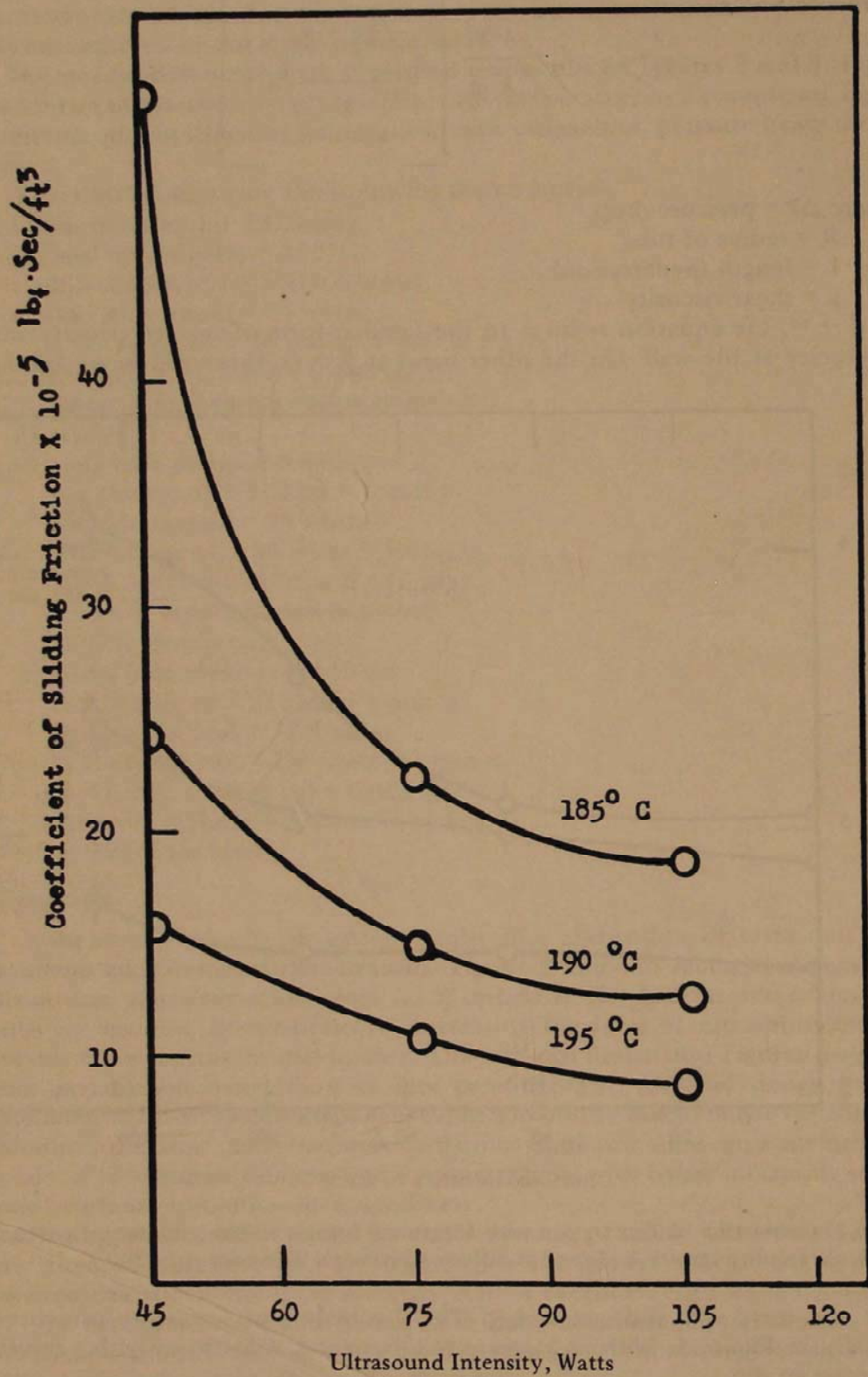


FIGURE 4. Variation of the Coefficient of Sliding Friction with Ultrasound Intensity at different Temperatures (Ram pressure = 1420 PSI).

certain portion of the waves is reflected and refracted. Assuming the continuity of tangential shear stresses of velocities, the refracted wave could move the molecules near the wall either upwards or downwards. With the ram compressing from below, the particles could slide upwards. This is facilitated by the absorption of ultrasonic energy preferentially at the melt metal interface, which appears as heat, reducing the viscosity at the wall. This is manifested by the slip at the wall.

A corollary of the explanation of slip at the wall is the interpretation in terms of the modification of entrance effects into the extruder tube. Ultrasound supplies excess energy at the entrance of melt to the extruder tube. This excess energy is used for the higher velocity gradient near the wall. It is possible that ultrasonic energy modifies the flow pattern, since this is found to be the most effective location for applying ultrasound.

The increased penetration could be caused by a reduction in apparent bulk viscosity. Johnston<sup>(5)</sup> has reported a decrease in polymer solution viscosity with ultrasound application for a number of polymers. Now viscosity reduction can be caused by a change in melt morphology or by degradation of the molecular structure.

**Table 1. Viscosity Reduction Factor as a Function of Ultrasonic Intensity**

Temp. ( $^{\circ}$ C)	Pressure (Psig)	$\mu(\text{u.s.})/\mu(\text{initial})$		
		Ultrasound Level (Watts)		
		45	75	105
185	1420	0.58	0.45	0.39
190	1420	0.59	0.41	0.35
195	1420	0.70	0.43	0.39
200	425	1.00	0.96	0.82
	710	0.91	0.85	0.69
	850	0.92	0.77	0.57

No data was taken on possible degradation of polymer, and subsequent reduced molecular weight and viscosity. It is known that materials can be depolymerized by cavitation over an extended period of time;<sup>(9)</sup> however, highly viscous materials resist cavitation<sup>(8)</sup> and the insonation time is short in the present experiments, and comparable to other experiments where degradation was not observed.<sup>(5)</sup> Thus it is assumed no degradation occurred. In Johnston's work, the viscosity reduction remained after cessation of insonation for minutes and even hours, indicating a change in morphology of the system.

The present system has much higher viscosities than those present in Johnston's work.<sup>(5)</sup> The present range was 30,000-100,000 poise, while Johnston's polymer solutions had a viscosity range of 10,000-14,000 cp, using insonated by frequencies of 47 kHz. Other work by Johnston at 10-880 kHz also demonstrated a viscosity reduction effect, which increased with frequency.

Assuming injection time remained constant with and with out ultrasound, the viscosity reduction is given by

$$\frac{\mu(\text{u.s.})}{\mu(\text{initial})} = \left( \frac{L \text{ initial}}{L \text{ u.s.}} \right)^2$$

The results of these calculations are shown in Table 1.

The reduction in viscosity,  $\mu(\text{u.s.})/\mu(\text{initial})$  was calculated to range from 0.35 - 0.40 to 1.0. This compares with Johnston's work giving  $\mu(\text{u.s.})/\mu(\text{initial})$  as low as 0.3. A decrease in viscosity due to a change in morphology is consistent with previous work,<sup>(5)</sup> and is the most likely cause of the increased penetration of melt.

### Summary

Application of ultrasound at the entrance of the melt to the extruder tube brings about the maximum increase in penetration. This increase can be explained by either

- i) creation of a slip flow at the wall of the cylinder and entrance to the extruder tube
- ii) reduction in apparent polymer viscosity

In conclusion, it can be stated that ultrasonic energy does make a difference in the flow of the melt. To determine the industrial applicability of this effect requires further work in an increasingly sophisticated experimental program.

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# Loss Coefficients in Closely Spaced Sharp-Edged Area Contractions

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## Abstract

An experimental study of flow energy losses in closely spaced sharp-edged area contractions was conducted for pipes of circular cross-section. The percentage reduction in diameter was the same for each contraction. Energy losses were correlated for two different area ratio systems in terms of the spacing between the upstream and downstream contractions. For a contraction diameter ratio of 0.5 at a spacing of 0.75 diameters between contractions, the loss coefficient was reduced by 14% compared to that for a single contraction of the equivalent area ratio. This effect can be attributed to an apparent streamlining of the flow passage. A contraction diameter ratio of 0.75 exhibited no optimum spacing compared to a single contraction. Further investigation is warranted in view of the possible savings in pumping costs for large flow systems.

## Introduction

In industrial systems where a fluid flows through a network of pipes, it is often necessary to incorporate a sudden reduction in pipe size in the design of the flow network. A low mechanical energy loss method of achieving this area reduction is to use a well-designed tapered contraction. However the high fabrication costs and the time involved in designing a tapered contraction, manufacturing it, and installing it has raised questions concerning the use of an alternative method [1] \* of achieving the desired area reduction.

Two closely spaced sharp-edged contractions can be used to achieve the same area reduction. When this method was first considered, it was found that the energy losses were much less than had been expected. The spacing between the contractions apparently had an effect on the amount of energy loss. This report describes an experimental study made on closely spaced sharp-edged contractions to determine the loss coefficient with respect to the spacing between the contractions.

## Theoretical Development

The mechanical energy lost in a sharp-edged contraction is due to the separation of the boundary layers and the formation of regions of recirculation, or eddies [2]. It would seem that two contractions may introduce more mechanical energy losses than one equivalent contraction having the same downstream area. This is known to be the case when the contractions are far enough apart that they act independently of each other. However, when the contractions become closely spaced there may be a streamlining effect of the flow through the contraction system that will reduce the mechanical energy losses. Referring to

\*The numbers in brackets denote references in the Literature Cited.

Figure 1 which illustrates a double contraction system, the spacing between the contractions will be referred to as a ratio of the length (l) over the diameter (d) of the middle section of pipe between the contractions.

By applying the Bernoulli's Equation to a set of double contractions the energy lost due to the contraction system can be found. The mechanical energy at some point upstream or downstream from the contractions is related to the pressure and velocity of the fluid and the elevation of each point with respect to some reference datum. The total energy loss will be that due to friction plus that due to the contractions. Figure 2 shows that the mechanical energy upstream is equal to the sum of the mechanical energy downstream, the losses due to friction, and the losses due to the contraction. The losses due to frictional effects must be calculated and subtracted from the total energy loss to determine the losses due to the contractions alone. The losses due to the contraction will be expressed as a loss coefficient ( $K_c$ ) times a reference condition; namely the downstream velocity, that is:

$$\text{Energy Loss} = K_c \left( \frac{V^2}{2g} \right) = \Delta P / \rho g \quad (1)$$

By measuring the pressure, velocity and dimensions of the test section, the loss coefficient can be found by solving the system equations illustrated on Figure 2.

### Experimental Apparatus

The apparatus used in the experimental program is shown schematically in Figure 3. A constant head tank was used to supply a uniform flow of water. The test section consisted of the double contraction and additional runs of straight pipe. Manometer leads to measure pressure were connected at locations 12 pipe diameters upstream from the first contraction and 12 pipe diameters downstream from the second contraction. A weighing scale, collecting container and timer were employed to determine the flow rate [2, 3]. The contractions were machined from plexiglas. A section of the upstream and downstream pipe was cemented to one side of each of two plexiglas plates. The plates have a recessed groove cut into their other side to fit the variable (l/d) section of pipe between the contractions. The sections were held together by four threaded rods fastened to the edges of the plates forming the contractions.

### Data Acquisition

The data acquisition program is described as follows. A flow was established through the test section. The system was inspected to determine if air pockets were trapped in the contractions or manometers. The flow rate and differential pressure across the manometer were measured simultaneously. Three data readings were taken at each flow rate for various flow rates to determine Reynolds number effects. The data sample for each test section consisted of between 6 to 10 independent data runs for each (l/d) station.

### Results

A double contraction system is one in which two equal diameter ratio contractions are used. Two such contraction systems were studied, the diameter ratios being 0.50 and 0.75, respectively. The analysis of data for the 0.5 double contraction system showed a reduction in overall energy losses. These results are

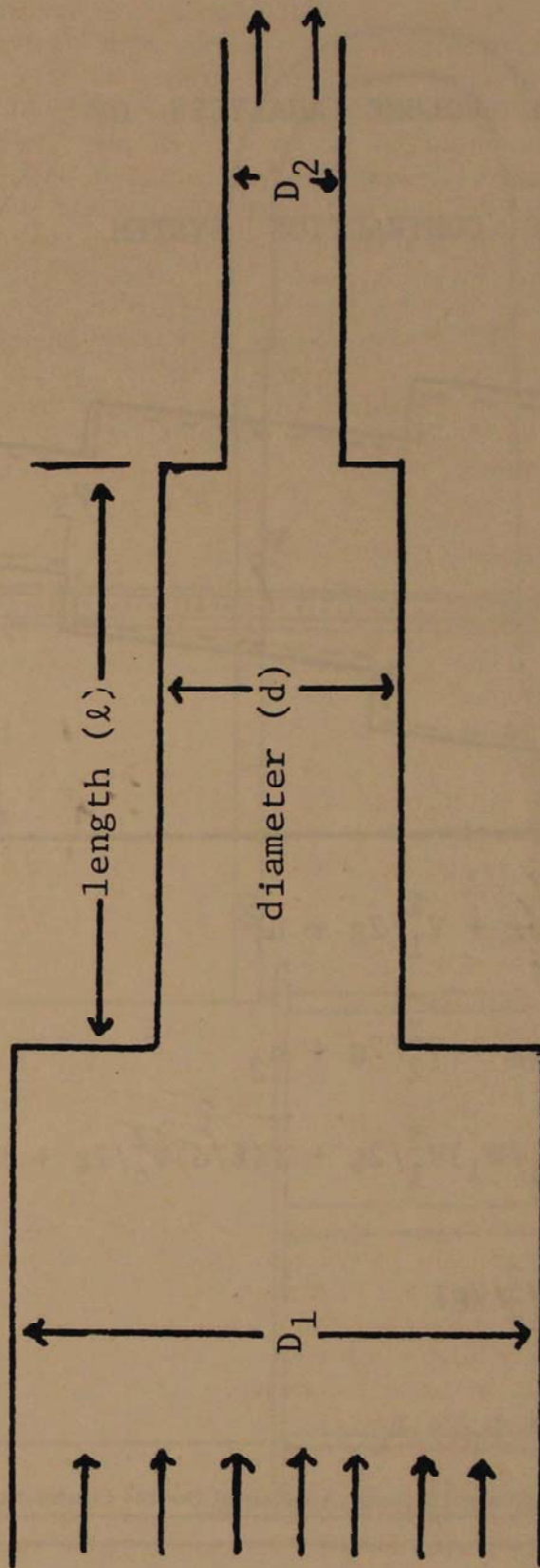
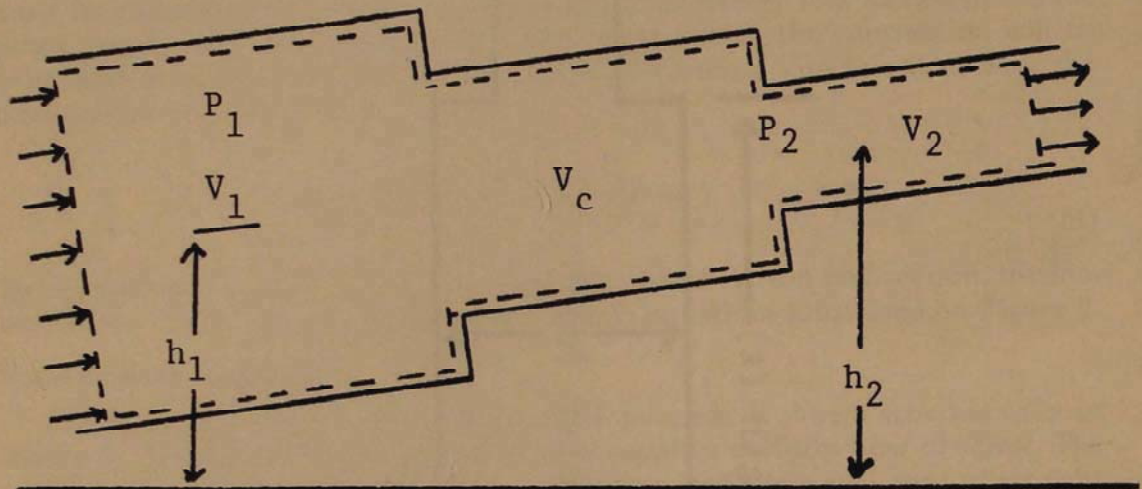


FIGURE 1. Double Contraction System.

CONTROL VOLUME ANALYSIS OF

DOUBLE CONTRACTION SYSTEM



$$E_1 = P_1/\rho g + V_1^2/2g + h_1$$

$$E_2 = P_2/\rho g + V_2^2/2g + h_2$$

$$L_f = f(L_1/D_1)V_1^2/2g + f(l/d)V_c^2/2g + f(L_2/D_2)V_2^2/2g$$

$$L_c = K_c(V_2^2/2g)$$

$$E_1 = E_2 + L_f + L_c$$

FIGURE 2. Control Volume Analysis of Double Contraction System.

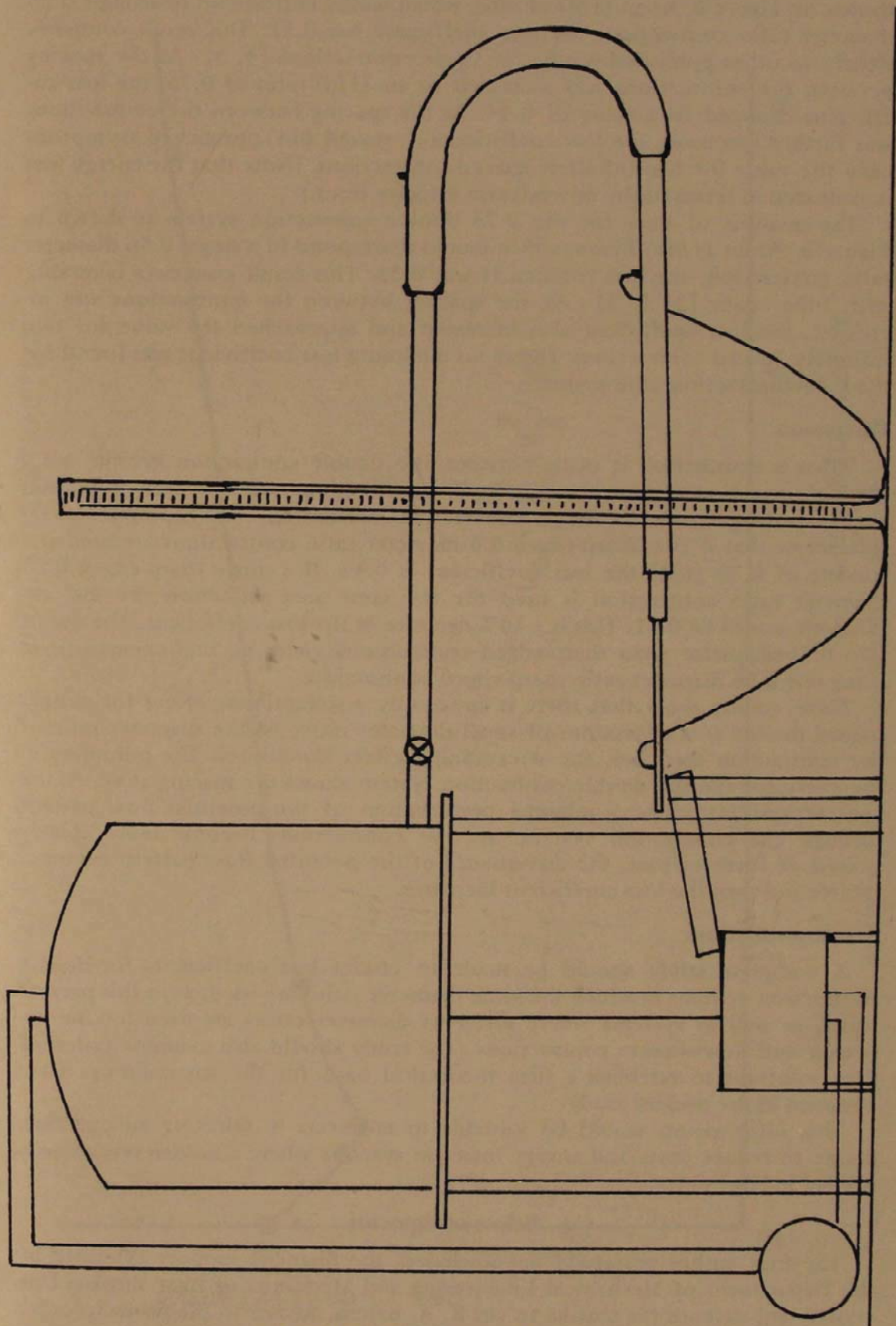


FIGURE 3. Experimental Apparatus.

shown on Figure 4. At an  $(1/d)$  of zero, which would correspond to a single 0.25 diameter ratio contraction, the loss coefficient was 0.51. This result compares closely to other published results for single contractions [4, 5]. As the spacing between the contractions was increased to an  $(1/d)$  ratio of 0.75, the loss coefficient dropped to a value of 0.44. As the spacing between the contractions was further increased, the loss coefficients increased and approached asymptotically the value for two infinitely spaced contractions. (Note that the energy loss is evaluated in terms of the downstream velocity head.)

The analysis of data for the 0.75 double contraction system is shown in Figure 5. At an  $(1/d)$  of zero, which would correspond to a single 0.56 diameter ratio contraction, the loss coefficient was 0.32. This result compares favorably with other data [2, 4, 5]. As the spacing between the contractions was increased, the loss coefficient also increased and approached the value for two infinitely spaced contractions. Hence no minimum loss coefficient was found for the 0.75 contraction ratio system.

### Discussion

When a comparison is made between the double contraction system and a single contraction system, the 0.5 double contraction system is seen to possess some advantages over the single contraction installation. The experimental results show that if two sharp-edged 0.5 diameter ratio contractions are used at a spacing of 0.75  $(1/d)$  the loss coefficient is 0.44. If a single sharp-edged 0.25 diameter ratio contraction is used for the same area reduction the loss coefficient would be 0.51. This is a 14% decrease in the loss coefficient. The use of two 0.75 diameter ratio sharp-edged contractions yields no improvement over using one 0.56 diameter ratio sharp-edged contraction.

These results show that there is apparently a streamlining effect for closely spaced double area reductions of small diameter ratio. As the diameter ratio of the contraction increases, the streamlining effect diminishes. The minimum in the curve for the 0.5 double contraction system shows the spacing at which the contractions introduce a minimal perturbation of the potential flow pattern through the contraction system. As the contractions become more closely spaced or further apart, the disturbance of the potential flow pattern becomes greater and thus the loss coefficient increases.

### Recommendations

A complete study should be made to obtain loss coefficients for double contraction systems in which the same diameter ratios are used, as in this present study, as well as systems where different diameter ratios are used for the upstream and downstream contractions. The study should also examine potential flow solutions to establish a firm theoretical basis for the streamlining effect observed in the present study.

This information would be valuable to engineers in selecting an optimum design to reduce costs and energy losses in systems where a sudden reduction is needed in large pipes.

### Acknowledgments

The first author gratefully acknowledges the financial support extended by the Department of Mechanical Engineering and Mechanics of West Virginia University and extends his thanks to Dr. R. A. Bajura, adviser to the project, for his help and discussions during the course of the study.

$K_c$  vs  $l/d$  FOR 0.50 DOUBLE CONTRACTION

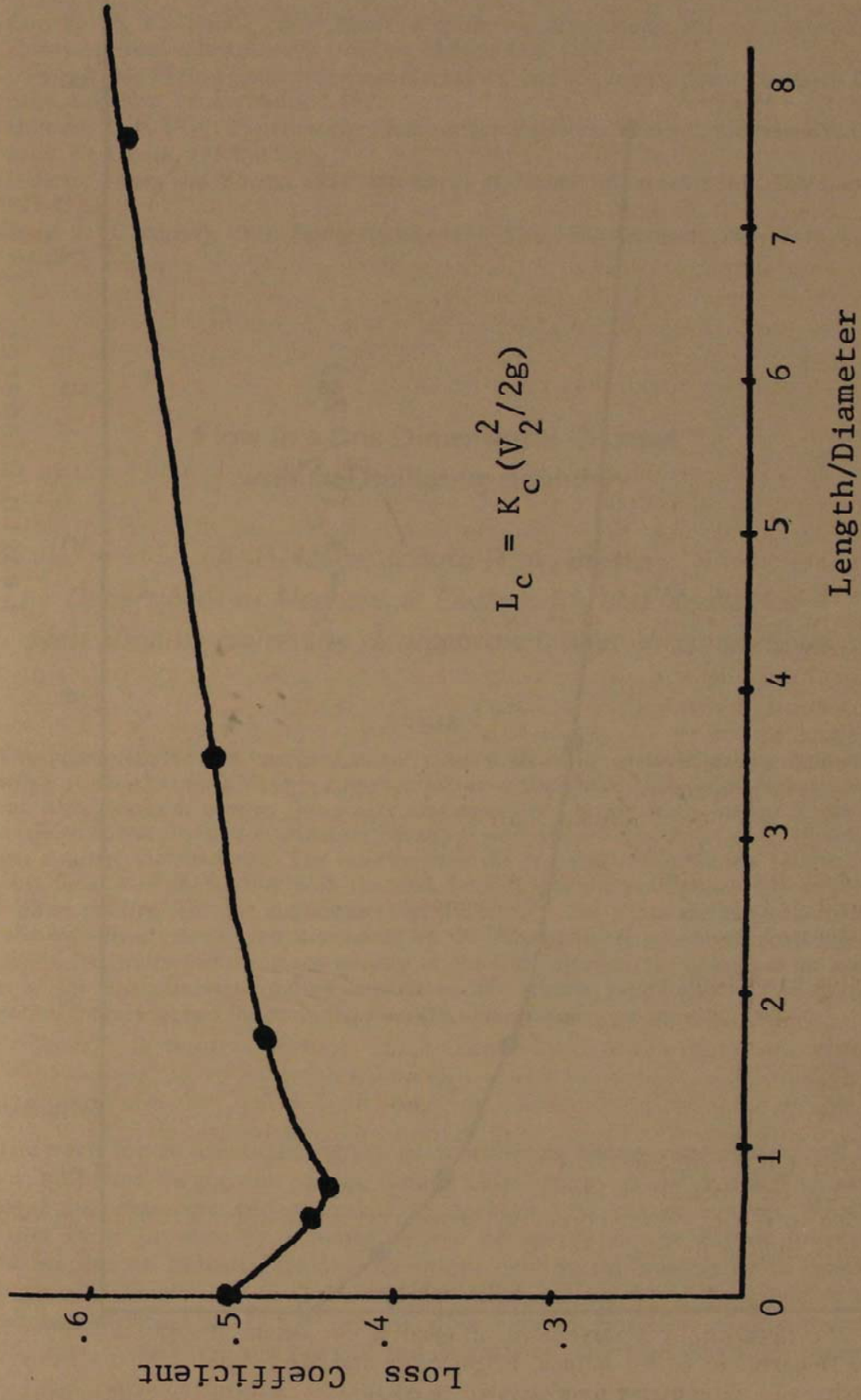


FIGURE 4. Loss Coefficients for 0.50 Double Contraction.

$K_C$  vs  $L/d$  FOR 0.75 DOUBLE CONTRACTION

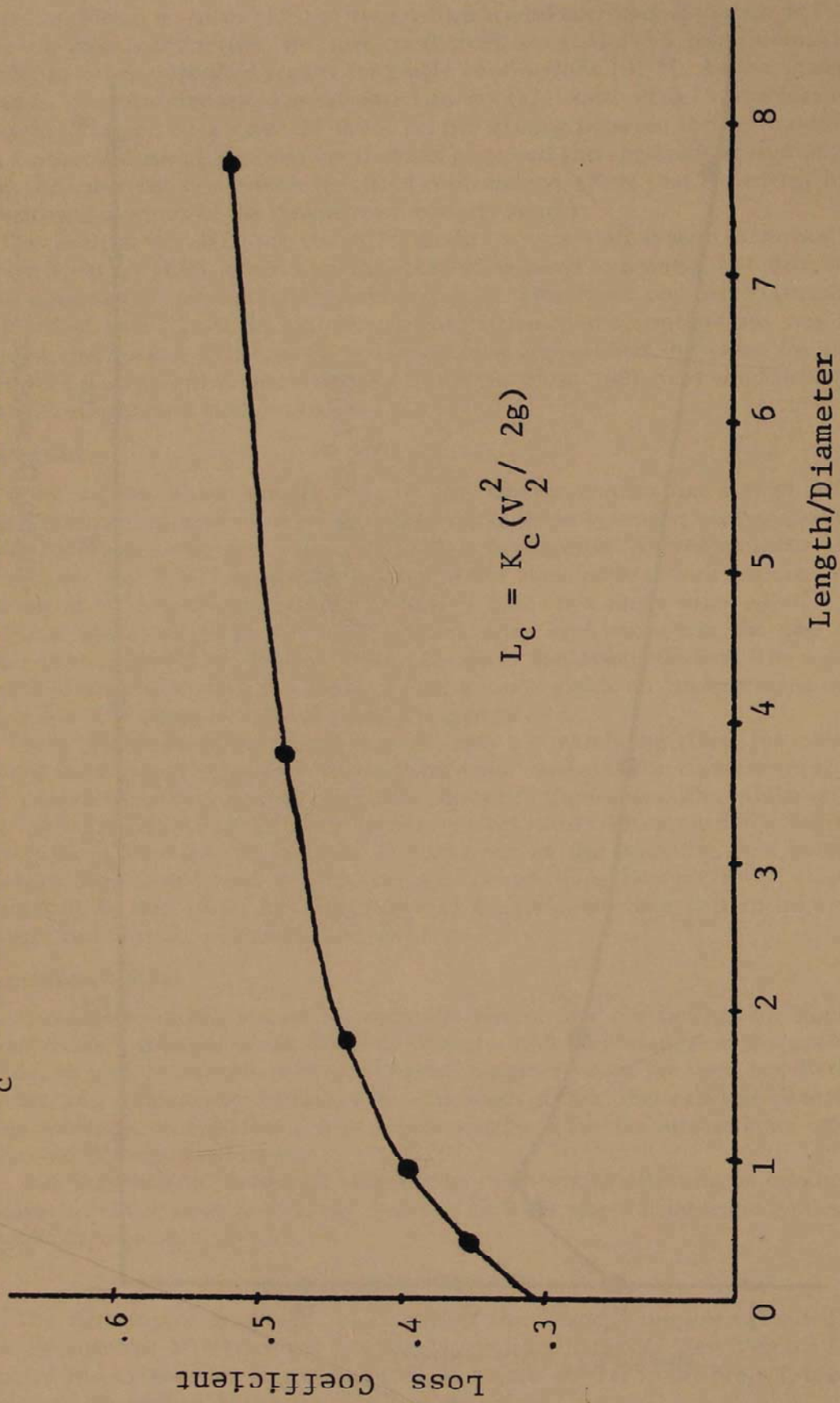


FIGURE 5. Loss Coefficients for 0.75 Double Contraction.

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## Flow in a One Dimensional Channel with an Oscillating Boundary

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### Abstract

This paper describes the results of an analytical study of the pressure loading imposed on a surface resulting from a vibratory motion of the surface itself. Effects of dynamic loads due to high Reynolds number flows were also considered. Analytical solutions to the one dimensional continuity and momentum equations were obtained for a flat plate vibrating in a high density, viscous fluid. The solutions for the resulting dimensionless velocity and pressure fields have shown that both the peak velocity and the peak pressure force vary in their phase relation with the displacement of the surface. The phase and the magnitude of the dimensionless velocity are dependent on the dimensionless parameters involving the excitation frequency and the mean velocity of the flow; whereas, the phase and the magnitude of the dimensionless pressure depend on the relative magnitudes of the friction, excitation frequency, and the mean flow velocity dimensionless parameters.

### Introduction

The need for an abundant supply of economical energy sources is one of the major problems facing our nation today. This "energy crisis" has put extreme pressure on engineers and scientists to develop new energy sources. Nuclear reactors show promise as a major source of energy in the future; however, problems due to fluid-structural interactions exist in the nuclear field. Damage to reactor internals due to flow induced vibrations has been described in the literature. Wambsganss (5,8)\* reports flow excited vibration of the thermal shield, fuel assemblies, and control rod assemblies. The high Reynolds number

\*The numbers in parentheses denote references in the Literature Cited.

flow of a high density, nearly incompressible fluid that occurs in a nuclear reactor is the source of this problem which is related to the interaction of the working fluid and the various structural elements.

Among other areas of engineering application which involve the problem of fluid-structure interaction are high velocity cross flow in the tube banks of heat exchangers (4), flutter of aircraft wings (6), wind loading on buildings (1), vibration of ship hulls (7), and high Reynolds number flows in thin walled pipes (2). A large body of literature exists pertaining to both acoustic excitation and turbulence excitation of plates, shells, beams, and cylinders. Obviously, the problem of flow induced vibrations is pertinent to a variety of engineering applications.

There are several types of surface loads which may force a structural response that results from the presence of a moving fluid interacting with a structural component. Surface loadings may be classified as hydrostatic pressure loading, acoustic pressure loading, turbulence excitation, static shear loading, dynamic shear loading, and an induced pressure loading due to the motion of the surface.

This paper presents an analytical model useful in understanding the induced pressure loading due to the motion of a bounding surface of a flow channel. As a structure vibrates, it must move fluid out of the way; hence, an induced pressure force results on the surface of the structure due to the force required to displace the ambient fluid. It should be noted that as a fluid approaches the incompressible case, the induced pressure resulting from the vibration of a structure increases. Hence, the induced pressure loading is greater for high density fluids such as water than for low density fluids like air. There is no induced loading due to a fluid for a structure vibrating in a vacuum, and this case of vibration *in vacuo* is the viewpoint adopted in elementary textbooks in the study of vibrations.

### Analytical Approach

An analysis is presented here with the purpose of observing the effects of the sinusoidal vibration of a flat plate on the characteristics of the flow field in the region between the plate and a rigid wall. Figure 1 shows the geometry of the model, the coordinate system, and the control volume used in the analysis. Consider a flat plate which vibrates near a rigid wall where the region between the plate and the wall contains an incompressible fluid with a mean velocity component. The flow is one dimensional in the x direction. The station  $x = 0$  is a plane of symmetry for velocity fluctuations. Edge effects of the plate are neglected.

For the general case of arbitrary motion of the surface, the continuity equation is

$$\frac{\partial}{\partial x} [v(x,t) h(x,t)] = - \frac{\partial}{\partial t} [h(x,t)] \quad (1.1)$$

For the case where  $h(t) = h_0 + a (\sin(\omega t))$  and  $V(x,t) = V_0 + v(x,t)$ , the continuity equation results in

$$V(x,t) = V_0 - \frac{a \omega}{h(t)} x \cos \omega t \quad (1.2)$$

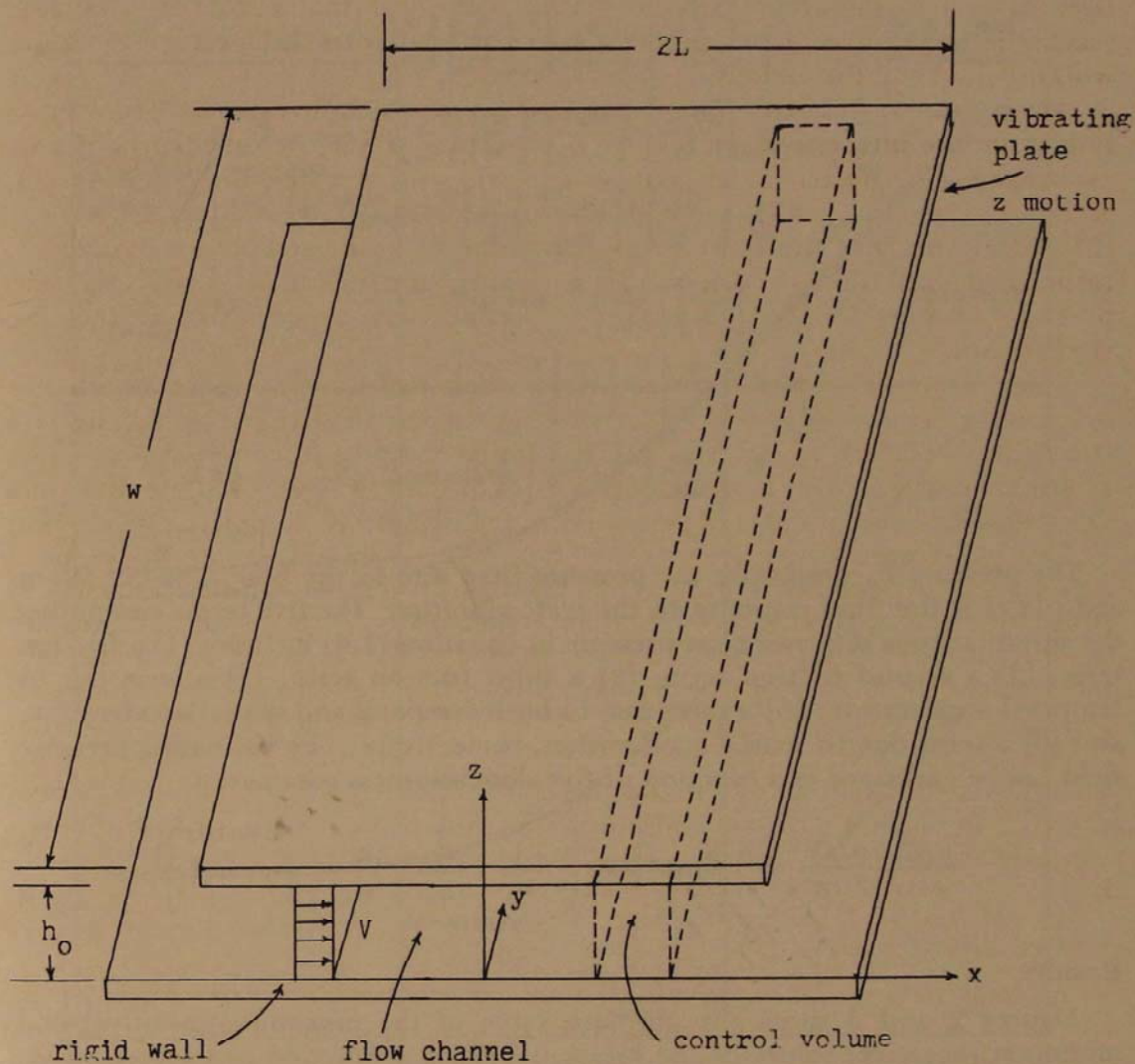


FIGURE 1. Geometry of the Model and the Control Volume.

The term  $h_0$  designates the mean separation between surfaces and the term  $(a)$  denotes the amplitude of the plate oscillation. In this example the entire plate vibrates as a rigid body. The velocity  $V_0$  denotes the base flow in the channel and  $v(x,t)$  is the fluid response to the vibration of the plate.

The momentum equation is for the general case

$$-\frac{1}{\rho} \frac{\partial P(x,t)}{\partial x} - \frac{z \tau_w}{\rho h(x,t)} = v(x,t) \frac{\partial v(x,t)}{\partial x} + \frac{\partial v(x,t)}{\partial t} \quad (1.3)$$

For the case of simple vibration discussed above with  $P(x,t) = P_0(x) + p(x,t)$ , the momentum equation yields the solution

$$\frac{p(0) - p(x)}{\rho \omega^2 L^2 / 2} = -\frac{1}{2} \left[ \frac{fL}{h} \right] \left[ \frac{V_0}{\omega L} \right]^2 \left[ \frac{a}{h_0} \right] \left[ \frac{x}{L} \right] \sin \omega t \quad (1) \quad 4$$

$$-\frac{1}{2} \left[ \frac{fL}{h} \right] \left[ \frac{V_0}{\omega L} \right] \left[ \frac{a}{h} \right] \left[ \frac{x}{L} \right]^2 \cos \omega t \quad (2)$$

$$+\frac{1}{6} \left[ \frac{fL}{h} \right] \left[ \frac{a}{h} \right]^2 \left[ \frac{x}{L} \right]^3 \cos^2 \omega t \quad (3)$$

$$+\left[ \frac{a}{h} \right] \left[ \frac{x}{L} \right]^2 \sin \omega t \quad (4) \quad (1.4)$$

$$+2 \left[ \frac{a}{h} \right]^2 \left[ \frac{x}{L} \right]^2 \cos^2 \omega t \quad (5)$$

$$-2 \left[ \frac{V_0}{\omega L} \right] \left[ \frac{a}{h} \right] \left[ \frac{x}{L} \right] \cos \omega t \quad (6)$$

The pressure  $P_0$  designates the pressure field due to the base flow condition and  $p(x,t)$  is the fluid response to the plate vibration. The five terms composing the instantaneous dimensionless pressure in equation (1.4) include: (1) a friction term, (2) a second friction term, (3) a third friction term, (4) a term due to temporal acceleration, (5) a term due to both temporal and spatial acceleration, and (6) a term due to spatial acceleration, respectively. The oscillating pressure field can be expressed as a function of five dimensionless parameters:

$$\frac{p(0) - p(x)}{\rho \omega^2 L^2 / 2} = \text{function} \left[ \frac{fL}{h_0}, \frac{V_0}{\omega L}, \frac{a}{h_0}, \frac{x}{L}, \omega t \right] \quad (1.5)$$

## Results

Figures 2 and 3 show the absolute value of the maximum (positive) and minimum (negative) values of the pressure field as a function of selected values of the dimensionless parameters given in equation (1.5). Figures 4 and 5 show the phase relation with respect to the plate displacement at which the maximum and minimum values of the dimensionless pressure occur. The angles given correspond to the angle ( $\omega t$ ) of the sinusoidal plate vibration. Although the dimensionless parameters are limited to several selected values in the graphs, these graphs serve to illustrate the general results for this analytical model. For a particular geometry, frequency of vibration, and set of flow conditions, the resulting velocity and pressure fields can be calculated from equations (1.2) and (1.4).

Figures 2 and 3 illustrate the pressure maxima and minima at a station located halfway between the plane of symmetry and the exit of the channel (downstream end). The effect of variations in the friction parameter ( $fL/h_0$ ) is small at low speeds, but serves to increase the extremum pressures at high velocity. (The term *high velocity* denotes that the base flow condition is of higher speed than the velocity generated by combining the oscillation frequency with the half-length of the plate. In the high velocity case the flow can be looked upon as being essentially steady with a minor perturbation due to a slight unsteadiness in the flow field. A *low velocity* case is one in which the effects of the vibration are more dominant than the base flow condition. Here the pressure

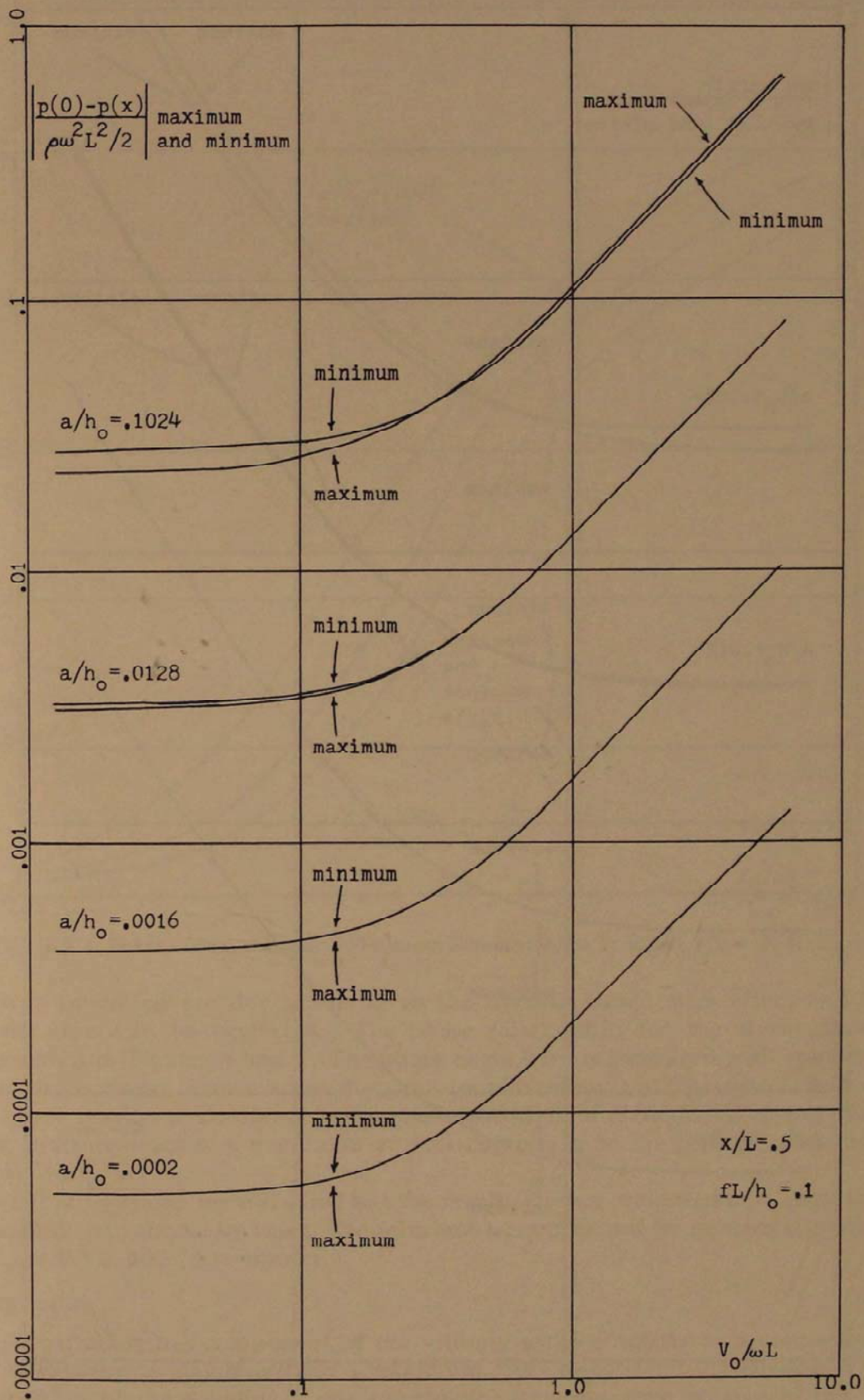


FIGURE 2. Maximum and Minimum Dimensionless Pressure,  $x/L = .5$ ,  $fL/h_0 = .1$ .

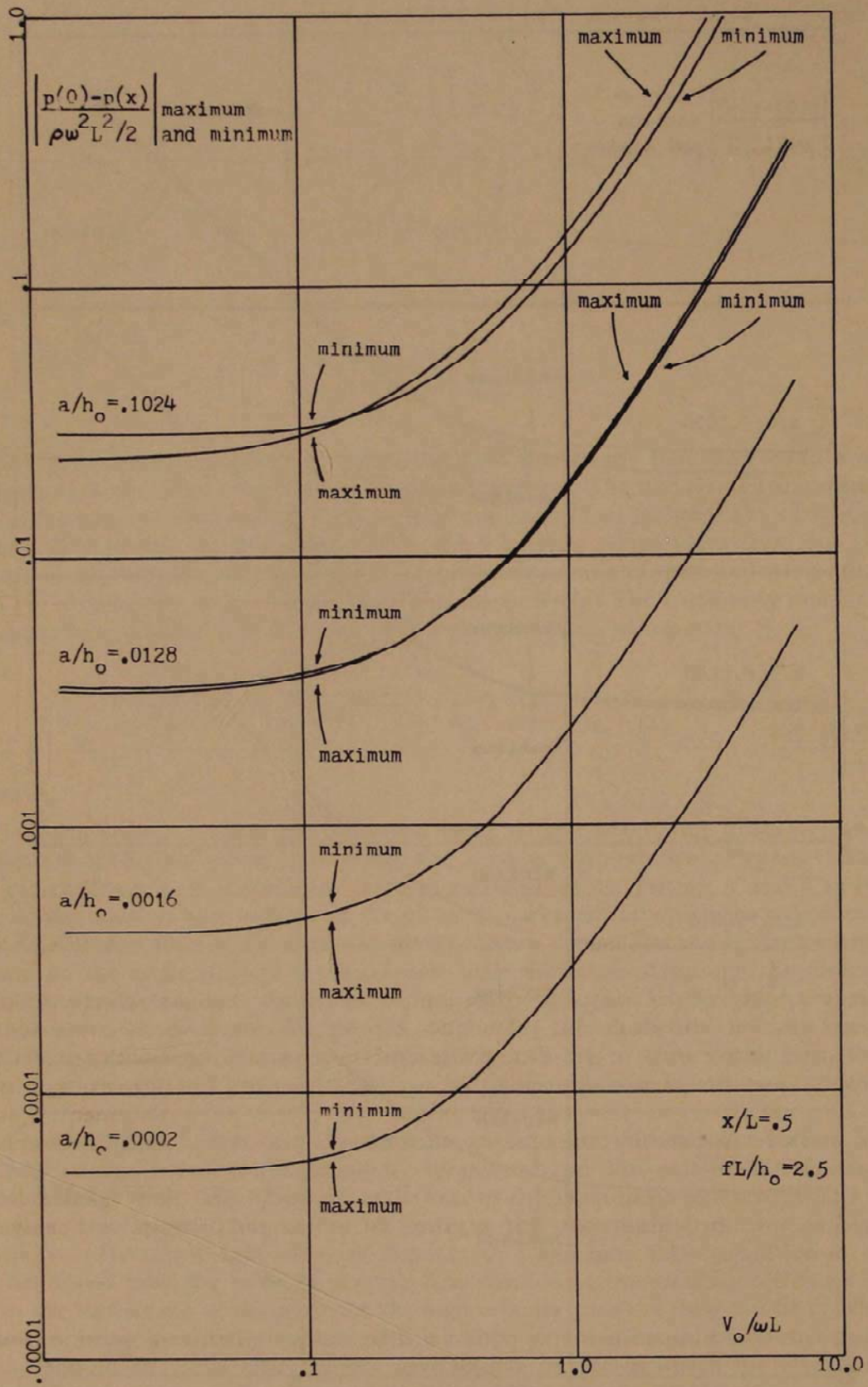


FIGURE 3. Maximum and Minimum Dimensionless Pressure,  $x/L = .5$ ,  $fL/h_0 = 2.5$ .

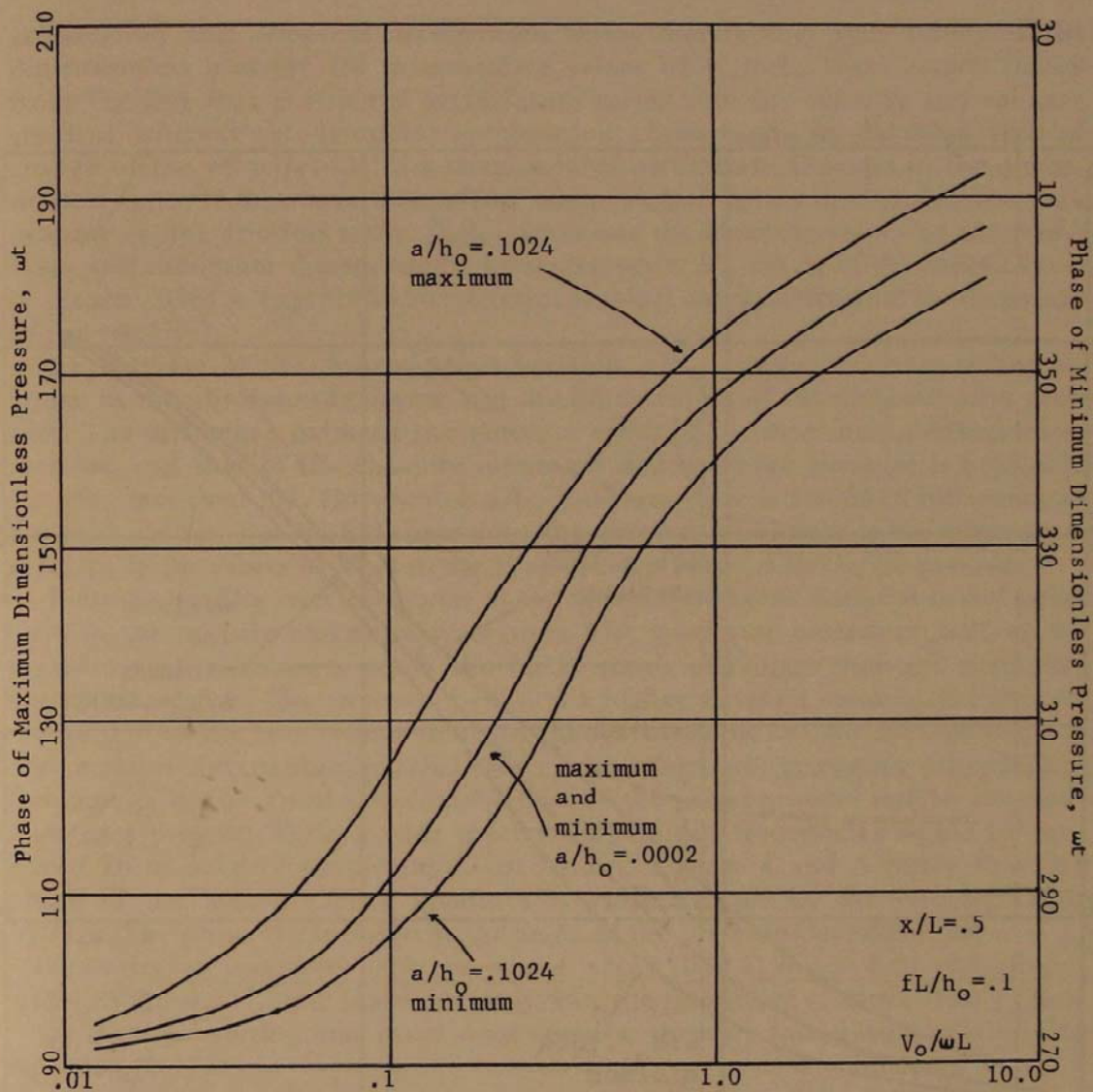


FIGURE 4. Phase of Maximum and Minimum Dimensionless Pressure,  $x/L = .5$ ,  $fL/h_0 = .1$ .

forces generated are due primarily to the hydrodynamic mass effect and the mean flow can be neglected.) The phase relationship for the above cases is presented in Figures 4 and 5. The phase angle here is measured with respect to the displacement. Hence when the pressure maximum is at 90 degrees, then the pressure reaches a maximum at the maximum value of plate displacement. When the pressure reaches a maximum at 180 degrees, then the plate is in its mean position.

Other locations were studied but the results are not presented here since they are similar to the above cases. The solutions were obtained by numerical analysis on the WVU 360-75 computer.

#### Discussion

The fluctuating component of the velocity varies similarly to a cosine function between a maximum and a minimum. (See equation 1.2.) However, the waveform of the velocity is not a symmetrical cosine wave because of the  $a/h$

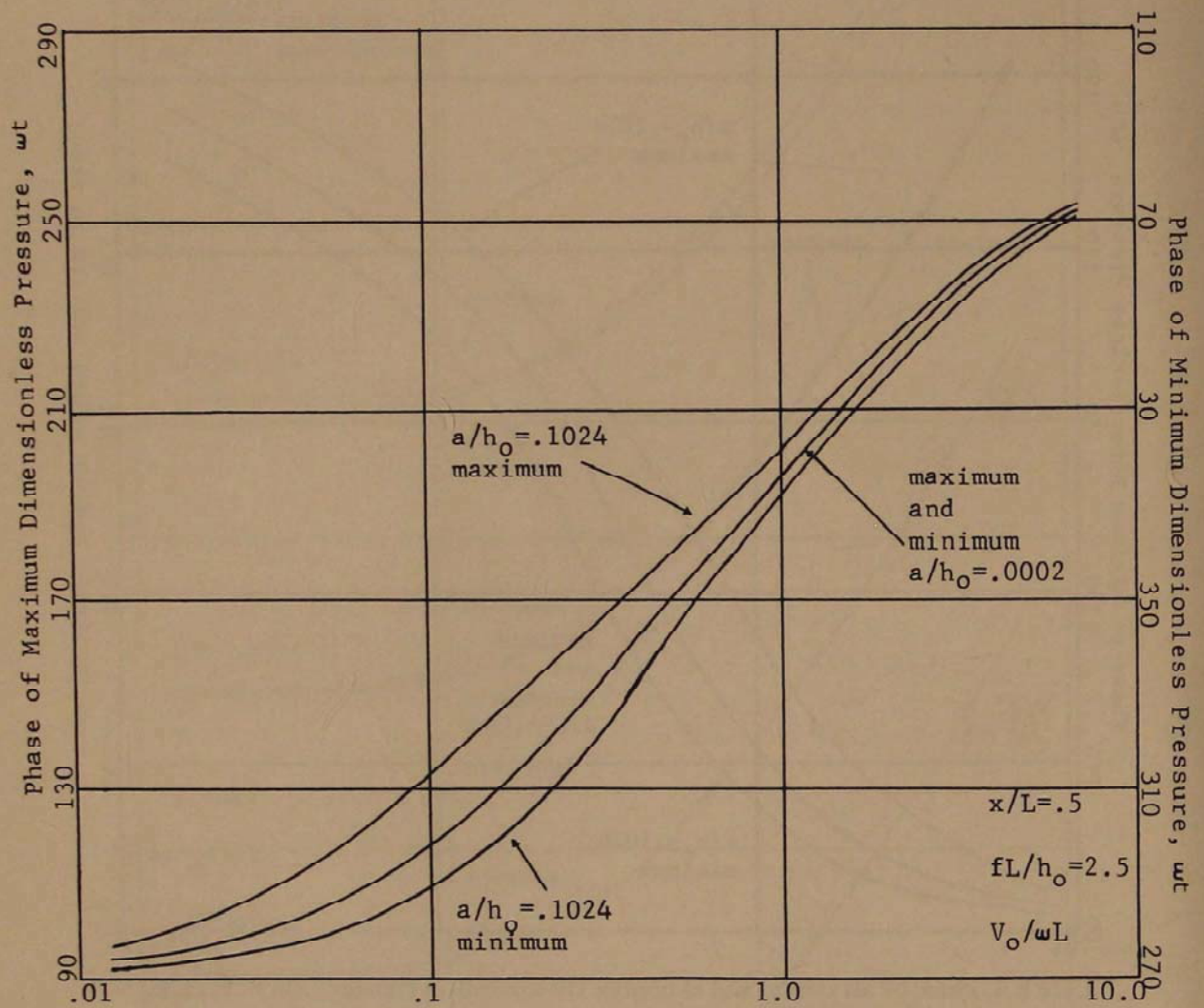


FIGURE 5. Phase of Maximum and Minimum Dimensionless Pressure,  $x/L = .5$ ,  $fL/h_0 = 2.5$ .

dependency. ( $h$  denotes the instantaneous location of the plate.) The dimensionless velocity is a function of three dimensionless parameters,  $V_0/\omega L$ ,  $x/L$ , and  $a/h_0$ .

The dimensionless pressure may exhibit a nonsymmetrical waveform as the parameter  $\omega t$  is varied due to the nonlinearity of the momentum equation solution (equation 1.4). The other four dimensionless parameters vary in terms of their effect on the dimensionless pressure. The most marked effect on the pressure is observed for the dimensionless velocity ratio,  $V_0/\omega L$ . As  $V_0/\omega L$  approaches zero, the absolute maximum and minimum values of the dimensionless pressure approach constant values due to the dominance of the temporal acceleration term. As  $V_0/\omega L$  approaches the order of one and greater, the absolute maximum and minimum values of the pressure increase constantly due to the dominance of the spatial acceleration and friction terms. Both the spatial

acceleration and temporal acceleration terms dictate the peak values of the dimensionless pressure for intermediate values of  $V_0/\omega L$ . These results follow from the fact that the spatial acceleration varies with the velocity and velocity gradient whereas the temporal acceleration corresponds to the time rate of change of the velocity, i.e., the frequency of oscillation. Changes in the dimensionless ratio,  $fL/h_0$ , have little effect when  $V_0/\omega L$  is less than .1. However, an increase in the friction term,  $fL/h_0$ , increases the absolute values of the maximum and minimum dimensionless pressures when  $V_0/\omega L$  is of the order of one or greater. This is expected since frictional losses are proportional to the square of the velocity.

An increase in the dimensionless variable,  $a/h_0$ , causes a corresponding increase in the absolute maximum and minimum values of the dimensionless pressure. The difference between the absolute value of the maximum dimensionless pressure and that of the absolute minimum dimensionless pressure is negligible for  $a/h_0$  less than .01. However, as  $a/h_0$  increases there is a marked difference in the peak values. For  $V_0/\omega L$  near zero the absolute minimum is the larger pressure; for larger values of  $V_0/\omega L$  the absolute maximum is the larger pressure.

Pressure profiles over one cycle show that the pressure does not spend equal time in the positive and negative regions. The maximum extremum half of the pressure profile becomes much shorter in terms of radians than the minimum extremum region. The pressure peaks at a higher absolute value in the shorter region due to the area requirement for the fluctuations, i.e., the average value of the pressure fluctuations is zero. Hence, this effect will introduce other higher frequencies in the Fourier decomposition of the pressure wave due to the nonlinearities present. Thus, a wide spectrum of output frequencies would be produced from a fairly simple input oscillation. Figures 4 and 5 verify that the phase of the absolute peak pressures is most affected by the velocity ratio,  $V_0/\omega L$ . The phase is expressed as the angle of the plate displacement,  $\omega t$

Consider an example problem where  $x/L = 1.0$ ,  $fL/h_0 = 2.5$ , and  $a/h_0 = .1024$ . Suppose  $V_0$  and  $L$  are constant, but the frequency  $\omega$  varies. For  $V_0/\omega L = .0125$ , the resulting maximum dimensionless pressure found from maximizing equation (1.4) is

$$\left| \frac{p(\omega) - p(x)}{\rho \omega^2 L^2 / 2} \right|_{\text{maximum}} = .0930 \quad (1.6)$$

Similarly, for  $V_0/\omega L = 6.4$ , the maximum dimensionless pressure is

$$\left| \frac{p(\omega) - p(x)}{\rho \omega^2 L^2 / 2} \right|_{\text{maximum}} = 6.189 \quad (1.7)$$

The ratio of the dimensional pressures for these two frequencies is

$$\frac{|p(\omega) - p(x)| \text{ for } \frac{V_0}{\omega L} = .0125}{|p(\omega) - p(x)| \text{ for } \frac{V_0}{\omega L} = 6.4} = \frac{.0930 (6.4)^2}{6.189 (.0125)^2} = 3.9 \times 10^3 \quad (1.8)$$

This result shows that although the dimensionless pressure is higher at low frequency than at high frequency, nevertheless the actual pressure can be much

larger at high frequency than at low frequency whenever all other parameters are held constant. This fact is due to the appearance of the frequency  $\omega$  within the dimensionless pressure definition. The mode shapes of a dynamic system in general have more closely spaced nodes and smaller amplitudes of vibration for the higher harmonics than for the lower harmonics. Thus, the largest amplitudes of vibration and the largest node spacings for a structure are usually associated with the lowest natural frequency of the structure. For the present example, then, the length  $L$  denoting a wavelength of the oscillation would decrease as  $\omega$  increases and tend to offset the increase in pressure determined above.

The present approach of looking at the pressure induced by a structural vibration is important because it considers the mean motion of a fluid. Most investigators consider only the vibration of a structure in a fluid which would be quiescent without the structural motion. The results show that the mean flow is a significant factor in shaping the pressure wave and therefore should be included in an analysis of the induced pressure. The present approach appears to be unique in considering the combined effect of vibration and fluid motion.

The dynamic pressure resulting from the plate displacement results in dynamic stresses in both the plate and the rigid wall. Since this model is one dimensional, the same pressure is felt by both the plate and the rigid wall. In addition, depending on the levels of excitation, it is possible that cavitation could occur in some cases. Furthermore, this type of analysis could be extended to cases where the plate displacement is a function of both the spatial coordinate  $x$  and time since the continuity and momentum equations were initially derived for an  $x$  dependency.

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## Psychology and Education Section

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### The Effects of Sulfur Dioxide on Learning and Activity in the Rat

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#### Abstract

This investigation was an attempt to ascertain the behavioral effects of chronic exposure to sulfur dioxide, a major atmospheric pollutant. The behaviors of interest were learning in simple and complex learning tasks and activity. In addition, a progress record of each subject's weight was kept.

The subjects consisted of forty-three male rats which were assigned to one of two control conditions or one of four experimental conditions.

The results indicate that sulfur dioxide alone had no effect on performance. There was, however, a significant trials effect and the interaction between  $\text{SO}_2$  and the number of trials in the maze also proved to be significant. Activity was found to be increased as the  $\text{SO}_2$  concentrations increased. Finally, it was found that the rats living in the higher concentrations tended to be heavier than those in the lower concentrations.

Corresponding with the relatively recent alarm in environmental pollution has been a vast increase in environmental pollution research. This research has become so voluminous that a periodical index, *Pollution Abstracts*, is presently being published to handle the wealth of information being produced throughout the world. Also, accounts of the effects of pollution have increasingly been reported. For example, in London an air pollution disaster in 1952 took 4000 lives. Similar less extensive tragedies have occurred in the Meuse Valley in Belgium; Osaka, Japan; Donora, Pennsylvania and so on (National Air Pollution Control Administration). Sulfur dioxide ( $\text{SO}_2$ ) has been linked as a major cause of these tragedies.

Most of the sulfur dioxide in the air is produced by the burning of high sulfur content coal. Much of this type coal is used by various industrial facilities and power plants. A somewhat smaller, but still substantial amount of SO<sub>2</sub> emissions result from petroleum combustion and the smelting of ores (U.S. Department of Agriculture, 1971).

Hence, research and observer accounts have led to inferences concerning the previously cited air pollution tragedies. That is, there seems to be considerable evidence that sulfur dioxide is a serious threat to human health. Pirila, Kajanne and Salo (1963) reported a clinical study of an individual who suffered from skin eruptions due to sulfur dioxide. Peacock and Spence (1967) found that mice acutely exposed to 500 ppm of sulfur dioxide possessed approximately twice the incidence of lung tumors when compared to a control group. Heyssel et al. found that sprague dawley rats chronically exposed to 32 ppm of SO<sub>2</sub> had a significantly slower growth rate than did control rats. This finding is one which the present authors felt merited further investigation as will be seen later.

A review of the literature (Greenwald, 1954) suggests that various species differ greatly in their susceptibility to SO<sub>2</sub>. Rats are the most resistant of the experimental animals while guinea pigs are the least. However, man is much more sensitive than guinea pigs. This factor must be considered when attempts are made to generalize the findings of this or similar research to human conditions. The previously cited research is by no means exhaustive of the research on sulfur dioxide, but it is fairly representative of the work in this area.

It seems rather paradoxical when one considers the amount of research relating the behavioral effects of SO<sub>2</sub> as compared to biological investigation. One study (Shalamberidze, 1969) found the chronaxial ratio of the antagonistic muscles to be unaffected by sulfur dioxide alone, but it was affected by SO<sub>2</sub> in conjunction with nitrogen dioxide. Chizhikov (1967) attempted to classically condition audiogenic seizures in rats using sulfur dioxide as the conditioned stimulus. Although he was unsuccessful in this respect, he reported the occurrence of several responses that seemed to be brought about by the conditioned stimulus, which generally coincide with audiogenic seizures.

Realizing the physiological nature of Shalamberidze's and Chizhikov's studies, they represent the only psychological investigations that could be located. An extensive literature search revealed no previous research in the areas of learning and activity. This then, is the foundation for the present study.

### Methods and Materials

*Subjects.* Forty-eight male Sprague-Dawley rats were randomly assigned to one of six conditions. During the course of the experiment, however, two animals from condition one, one from condition five and two from condition six died. The remaining forty-three animals were subjects upon which these results were based.

*Apparatus.* The experimental manipulations occurred in environmental chambers constructed of 1/4 inch plexiglas in the shape of a box with external dimensions of 24 1/2 by 16 1/4 by 12 7/8 inches. The subjects inhabited an area of 1/2 inch mesh screen suspended approximately three inches above the floor of the chamber. Temperature within the tanks was regulated by running tap water through copper coils which ran along the inside end of the walls. The subjects were kept away from these coils with 1/4 inch mesh screen barriers. The rear wall was equipped with a drinking water valve and a suspended food basket formed from 1/2 inch mesh screen. The drinking water for all tanks came from a

common reservoir and was available on an ad lib basis. There were two ports in each chamber. One, located on the lower front of the tank, was used for removal of the excreta trays. The other was used for accessibility of the *Es* to the *Ss* and their food. Both types of ports were closed with 1/8 inch cast aluminum and gum rubber gaskets. Petroleum or silicon jelly was used as an added sealant. The port covers were fastened down by bolts with flanges to press against the plexiglas on one end and wing nuts on the other.

The independent variable, sulfur dioxide, was generated by permeation tubes in which liquid  $\text{SO}_2$  was diffused through the walls of teflon tubes at a specific rate, mixing with air that is passed over them. These permeation tubes were connected just prior to the air input tubes of the chambers. A central pump continuously pulled a very slight vacuum on the tanks, drawing air through the permeation tubes where it picked up the  $\text{SO}_2$ , into the chambers, and out toward the pump. Since the air flow was of prime importance, its rate was monitored with flow meters and controlled by needle valves. Using this method, the desired levels of the independent variable were produced. Chambers 3, 4, 5, and 6 received 5, 13, 26, and 56 ppm respectively. Tank 1 received sulfur dioxide free air by passing the air through a sodium hydroxide solution before entering the chamber. Chamber 2 was subjected to air piped directly from outside of the building in which the laboratories were located. It is estimated that the mean  $\text{SO}_2$  level for chamber 2 was approximately .006 ppm.

In order to ascertain the effect of  $\text{SO}_2$  on learning, two mazes were used. The Lashley I T-maze, operationally defined as a simple learning task, consisted of an approach alley with the start box on one end and a perpendicular alley at the other. Lying in the perpendicular alley directly ahead of the start box was an inverted T partition forming a left and right cul de sac. The right cul de sac served as the goal throughout the course of the experiment. A modified version of the Lashley III maze was used as what was operationally defined as the complex learning task. It was composed of nine alleys and eight gates, forming a rather complicated eighteen choice point maze. (See Munn, 1950.)

*Procedure.* All *Ss* inhabited their assigned chamber more or less continuously, being removed only for maze running and system repairs. Although there was slight variation between chambers, the mean length of exposure was 1246.3 hours. Hourly readings were made to monitor air flow rates, tank and room temperature, humidity, and activity. Activity records were made by simply counting the number of *Ss* in each tank while the reading was made. In order to be considered active by operational definition, a *S* must have been on his feet. This was to prevent a *S* restlessly turning in his sleep or lying perfectly still with his eyes open being counted as active.

The six conditions were divided into three equal groups and assigned to a rotating time schedule for the purpose of maze running. Thus, on a given day, one pair of conditions was on an ad lib feeding schedule, another pair was on twenty-four hour food deprivation, and the last pair was running the maze. This schedule made a complete cycle every three days and the cycles were alternated between the simple and the complex maze.

Prior to maze running, the *Ss* were removed from their chambers and placed in a retaining box in the maze room. As a rat's turn came, he was taken from the retaining box and weighed, and placed in the maze. For each trial, a *S* ran three consecutive runs while the *Es* kept records of start box latency and errors made in the maze. Latency was the time in seconds from the opening of the starting gate until one half of the *S*'s body had passed through the gate. Errors were

operationally defined as one half of the rat's body bypassing a gate, making a wrong turn out of a gate, or entering a gate and backing out. Upon completion of a S's trial, he was placed in another retaining box until the remaining Ss in that condition had finished the maze. When this occurred, the Ss were returned to their chamber and the Ss in the other paired condition were subjected to the same procedure. On the following day, two more experimental conditions replicated the previous day's routine and so on, until completion of the cycle.

### Results

All learning data was analyzed by means of four two-way analyses of variance. As shown in Table 1, there was no apparent effect of SO<sub>2</sub> on simple maze latency, nor was there any change in performance over trials. Of course, there were no interaction effects either.

Table 1. Analysis of Variance for Simple Maze Latency

Source	df	MS	F	p
Total	429	—	—	—
Between Ss	42	—	—	—
Conditions	5	6912.64	.05	N.S.
Error <sub>b</sub>	37	115604.48	—	—
Within Ss	387	—	—	—
Trials	9	16918.88	1.54	N.S.
Trials x Conditions	45	7009.62	.64	N.S.
Error <sub>w</sub>	333	10932.39	—	—

Table 2 shows that sulfur dioxide, trials, and interaction effects were all non-significant for complex maze latency.

Table 2. Analysis of Variance for Complex Maze Latency

Source	df	MS	F	p
Total	429	—	—	—
Between Ss	42	—	—	—
Conditions	5	23504.25	2.36	N.S.
Error <sub>b</sub>	37	9923.37	—	—
Within Ss	387	—	—	—
Trials	9	10284.43	1.42	N.S.
Trials x Conditions	45	9244.34	1.28	N.S.
Error <sub>w</sub>	333	7214.39	—	—

An analysis of simple maze errors also showed no significant effect due to SO<sub>2</sub>. However, there was a significant change in performance due to repeated trials. There was also a significant interaction. The results are shown in Table 3.

Table 3. Analysis of Variance for Simple Maze Errors

Source	df	MS	F	p
Total	429	—	—	—
Between Ss	42	—	—	—
Conditions	5	64.81	.97	N.S.
Error <sub>b</sub>	37	66.28	—	—
Within Ss	387	—	—	—
Trials	9	195.9	9.09	<.001
Trials x Conditions	45	33.05	1.53	<.05
Error <sub>w</sub>	333	21.55	—	—

Table 4 relates to complex maze errors and shows a similarity to the results in Table 3. Although there were no significant effects due to sulfur dioxide, a significant change in performance occurred as a result of learning. The interaction effects between SO<sub>2</sub> and trials were highly significant (p = <.001).

Table 4. Analysis of Variance for Complex Maze Errors

Source	df	MS	F	p
Total	429	—	—	—
Between Ss	42	—	—	—
Conditions	5	543.08	.06	N.S.
Error <sub>b</sub>	37	855.74	—	—
Within Ss	387	—	—	—
Trials	9	2361.69	18.42	<.001
Trials x Conditions	45	237.13	1.84	<.001
Error <sub>w</sub>	333	128.2	—	—

Activity measurement was based on counting data. Since there were unequal numbers of subjects in each condition, it was necessary to convert to the proportion of Ss active in each chamber over a given time period. A comparison of activity for the first ten days versus the last ten days of the research period was accomplished by a test of significance between proportions (Edwards, 1963) for each experimental condition. The results are presented in Table 5.

Table 5. Proportional Activity Level of Subjects

SO <sub>2</sub> Level of Tank	N <sub>1</sub> <sup>+</sup>	P <sub>1</sub>	N <sub>2</sub> <sup>+</sup>	P <sub>2</sub>	z	Probability
1. zero	1256	.357	1128	.273	4.435	.001
2. outside air	1632	.349	1528	.251	6.051	.001
3. 5 ppm	1600	.326	1488	.261	3.978	.001
4. 13 ppm	1624	.294	1376	.257	2.266	.01
5. 26 ppm	1640	.280	1316	.261	1.157	N.S.
6. 56 ppm	1441	.238	1140	.255	-.99	N.S.

<sup>+</sup>1 first 10 days of SO<sub>2</sub> exposure

<sup>+</sup>2 last 10 days of SO<sub>2</sub> exposure

Lastly, observation of the weight data revealed an interesting effect. When the mean final weight of tanks 1, 2, and 3 was compared with the mean final weight for tanks 4, 5, and 6, the latter was found to be significantly heavier than the former ( $t = 4.60$ ,  $df = 41$ ,  $p = .001$ ).

### Discussion

Some interesting generalizations may be derived from the results obtained which have possible application in the human condition. The consistent non-significance found in the latency data for both the simple and the complex mazes may be attributed to one of several explanations. Since there was no significant change in trials in a repeated measures design, it seems most probably that latency was an inappropriate dependent measure for this study.

The main effect of trials for errors (simple and complex) indicated that a change in performance due to learning had occurred. However, sulfur dioxide alone had no such effect. The significant interaction between  $SO_2$  and trials may be due to a type of synergism. That is, while sulfur dioxide does not affect maze performance singularly, its effect becomes significant as a function of the number of trials in the maze. An alternative explanation, however, is that the strong trial effect mathematically "pulled up" the interaction while the behavioral effect corresponding to this actually was not present. Although neither possibility is empirically substantiated, additional research should be conducted using a simpler design and testing for simple effects to discern the possibility of this interaction effect.

Probably the most profound effects occurred in activity. Noteworthy is the decreasing magnitude of  $z$  values as the level of  $SO_2$  increased with the exception of tank 2. This discrepancy in tank 2 is considered to be negligible due to the close  $SO_2$  levels in tanks 1 and 2. Since the study began when the rats were in puberty, it seems likely that the normal lessening of activity due to maturity had less chance to occur as the sulfur dioxide levels increased. Levels above 10 ppm of  $SO_2$  are known to act as an irritant and therefore, probably increased activity. Since the possibility of experimenter bias is evident, this type of study could be facilitated with the use of more precise activity paradigms.

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## Environmental Education: A Broad Spectrum Approach With Emphasis on Role-Playing and Local, Student-Directed Projects

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### Abstract

During the past year, West Virginia University has offered a new environmental education course for teachers and other professionals. The course Basic Environmental Education, is a 3-credit graduate offering taught this spring semester in five counties with an enrollment of 131 students. The course provides a basic update in environmental subject matter, both science and non-science topics. A unique feature is the requirement that enrollees must advise a class of their own students in developing an environmental student-directed project. Role-playing is encouraged as a means of stimulating students' interest in the enrollee's class.

Results of surveys show that the students and their teachers find the projects are enjoyable and interesting. The projects are localized and represent a broad spectrum of environmental subject matter ranging from field ecology to community health surveys and environmental law. A survey of 135 educators representing teachers from six counties revealed that they and their students are ready for a new approach in education. Responses from teachers enrolled in Basic Environmental Education reveal that role-playing by youth who are permitted to plan and direct projects provides new excitement in learning. The teacher also enters the role-playing activity by becoming a participant and resource leader. These personalized projects can be tailored to fit into most schedules and still permit sufficient time for presenting some of the classical textbook material which is also necessary.

Within the past decade, ecology has assumed new dimensions. Concerns for the people problems of overpopulation and misuse of resources have generated

new interest in environmental studies. These studies, called human ecology by some, have been developed into courses in colleges throughout the country including West Virginia. The West Virginia public school system has also provided leadership to encourage more open-ended ecology projects in the classrooms. College, university, and agency personnel have worked closely with public schoolteachers to develop outdoor education and conservation education programs. County school superintendents and their staffs have sponsored numerous in-service programs about environmental education. We are privileged to have had opportunity to participate in these workshops and seminars.

### Materials and Methods

One of the important observations from these workshop experiences was the positive response of teachers to environmental concepts and methods of developing localized projects. Teachers also welcomed ideas about indoor projects that had some orientation to their local community. In October of 1972, West Virginia offered a new, three-credit graduate course with emphasis on localized community-oriented projects. This paper will report the responses of teachers enrolled in this environmental education course which is now in progress in five counties of the state.

The course, Basic Environmental Education, is offered as a special topic and is monitored by the Department of Curriculum and Instruction, West Virginia University.

During the planning of the course and prior to scheduling in each county, talks were held with county superintendents and their staffs to determine interests in environmental education and the course. Feedback from teacher spokesmen was solicited. In general, there was a favorable response from each county and the course schedules were announced for enrollment of teachers and administrators.

The teachers had raised concerns about the large number of catalogues and other publications of environmental literature sent to them from various sources. Many teachers were also concerned about lack of classroom time for additional subject matter. It was decided subsequently that a survey of interests might shed some light on these views as well as on the status of environmental education in schools today. Another question to be answered was: Is there a real need for this course, Basic Environmental Education?

Two groups of teachers were surveyed; one was an in-service group of 26 teachers from Harrison County. The other group represented teachers and administrators from five counties—Raleigh, Fayette, Jackson, Mineral and Hampshire, all surveyed during the first week of class in Basic Environmental Education, C & I 380. The survey consisted of 12 multiple choice questions about teacher and student awareness of environmental education in their schools. In most instances, the question also gave the option of the alternative personal response to be filled in by the responder. Partial results of this survey, answers to 3 of the questions, are given in Table 1 and will be discussed shortly. Another survey was conducted to evaluate the projects of the enrollees' classes. Some of these questions and results are presented in Table 6. The teachers who participated in the surveys represent colleagues who teach kindergarten up through 12th grade. Many principals and other administrators also participated. Geographically, the survey covered school district areas from the south, east, west and central sections of the state. A total of 109 enrollees participated in the

**Table 1. Environmental Education:\* Current Interest in the Public Schools**

<i>Observation</i>	<i>Teacher groups and (percent) who share the observation</i>	
	<i>In-service workshop group (26 teachers)</i>	<i>C &amp; I 380 enrollees, (109 teachers polled)</i>
My students are:		
Keenly interested in E. E.	(40)	(37)
Slightly interested	(35)	(38)
Perhaps interested, I don't really know	(27)	(26)
Absolutely not interested	(0)	(0)
We need a different approach from our present system, one offered through E. E. and other means	(70)	(78)
I want to offer my students more environmental education but:		
I haven't time	(40)	(37)
I don't know how to present the new material	(55)	(52)
Other	(5)	(11)

\*Hereafter referred to as E.E.

initial survey. Only four classes were surveyed the second time and therefore 79 were available for the second survey. A total of 131 had enrolled in the course with none dropping out as of this date.

### Results and Discussions

Table 1 shows that responses from both groups are similar to all questions listed. About 40% of the teachers felt that their students were keenly interested in environmental education although another 25% of each group didn't really know if their students were interested. About 48% of each group reported that their students now receive no environmental education although all teachers believe or think that their students are interested in environmental approaches. Teachers want to increase environmental education in their classes, but most stated they haven't time, and over half of them don't know how to present the material, according to the survey. Quite possibly, these two reasons are inter-related.

Nevertheless, at least 70% of each group feel that new and different approach is now needed, one offered through environmental education and other means.

A course in environmental education for teachers could be useful according to the survey if the course provided opportunities to teach cooperative planning. The survey revealed that teachers want to learn useful strategies to arouse interest in and response by their students.

Role-playing by adults and youth has been previously successful in training programs for many years. Group leaders in industry have used group dynamics and guided design programs to stimulate group interaction and problem solving. It was decided that one of the key portions of this course would be sessions on

project planning and role-playing of the teachers' students. As a requirement for Basic Environmental Education, teachers were asked to guide the development of a student planned and directed cooperative classroom project. Role-playing was to be emphasized with the classes to be subdivided into environmental groups or committees with peer group leadership. A total of 131 classroom projects was to be developed because as Table 2 reveals, a total of 131 teachers and other professionals was enrolled in the 5 sections of Basic Environmental Education. Eight county Extension agents were also enrolled. The 121 teachers and education administrators represent both elementary and secondary schools. Just about all teaching disciplines are represented and corresponding K-12 grades of students. Two class members are professionals in fields other than education.

**Table 2. Basic Environmental Education, C & I 380  
Semester II, 72-73**

<i>Course Location</i>	<i>Enrollment</i>
Beckley	40
Oakhill	28
Ripley	20
Keyser	23
Romney	20

The course is multidisciplined as evidenced by the listing of subject matter in Table 3. Both evening sessions and outdoor field trips were scheduled. Usually most of the instructors were local resource leaders and included county Extension agents and other agency personnel. Exams consist of written and oral reports by the teachers. Table 4 shows a semester sequence flow of the course subject matter. Major emphasis is placed on concepts in environmental education to provide the teachers with updated ideas for classroom projects. Team resource planning (Table 4) provides the enrollees with specific strategy for their classes. As a requirement, much of the planning is to be provided by their students. Projects varied in time from one to sixteen weeks in length.

Their projects also varied in subject matter and environmental focus, as shown in Table 5. Four categories are represented in the table to show the wide spectrum of possibilities for projects. Of the 131 projects, 45 were in wildlife ecology and conservation. Many language arts, speech and social studies classes chose one of the 52 projects listed under environmental arts and crafts or community development. Most projects were open-ended survey and analysis type with gathering of local data an important feature of the project. In fact, all of the projects were community oriented in the sense that they were localized and the project focused on the immediate school-community environment.

Natural relevancy to the local situation perhaps accounts for the overwhelming report of success as shown in Table 6. Informal committee role-playing also was important. With 74 and 69 teachers able to report (some projects are still in progress at this writing), all said the projects were successful. Sixty-eight teachers said their classes next year would have an environmental education project. In contrast, 58 teachers of this group would not have had the classroom project had they not taken this Basic Environmental Education. Presumably, this course has provided some necessary confidence in the teachers who now see local environ-

Table 3. Typical Course Schedule of Basic E. E.

<i>Date</i>	<i>Subject</i>	<i>Instructor</i>
Jan. 22	Objectives and Principles	Anderson
Jan. 29	Suggested K-12 projects	Anderson
Feb. 5	Air, earth, fire, water concepts; team resource planning	Anderson
Feb. 12	Environmental surveys and student directed projects	Ice
Feb. 20	Exam—team project reports	Anderson
Feb. 26	State, regional, local health programs	Merrit Saunders Anderson
Mar. 5	Geology of Jackson County and WV: suggested earth science approaches	Bingman
Mar. 12	Creative Indian arts and craft from nature	McTeer
Mar. 19	Appalachian center and other WVU programs; team resource planning	Black Dague Anderson
Mar. 26	The WV Geological survey; its local and state wide programs in environmental improvement	Woodfork
Apr. 2	Team resource planning and reports	Anderson
Apr. 9	Edible wild plants	Wood
Apr. 14	(8:30 A.M.) Field trip; local industries and utilities	Richardson Black Dague
May 5	Outdoor education labs and local nature trail development	Anderson Christie Breiding Pauley
	Workshop, creative arts and crafts from natural sources	McTeer
May 7	Final exam	Anderson

mental projects as important learning tools and their own roles somewhat changed from floor leader to participant with the students, and their resource leader.

The results presented here strongly indicate that teachers and students are looking for something in education beyond the printed handout and standardized answer sheet. Localized environmental classroom projects are relevant because the children are involved in planning as well as project activity. The project is about them in their own environment. Practice in decision-making is possible through role-playing and formation of committees. Frequently these committees simulate actual committees in the town or county.

Many schools and colleges still are more concerned with presenting past knowledge in an over-crowded semester timetable. About 20% of the teachers surveyed stated that schools are teaching the same subject matter as was taught 50 years ago. Cooley (1973) writes: "In short, the present school system usually emphasizes past knowledge. Environmental courses must explore the unknown, the uncollected and the unsuspected." And he further states: "The major purpose of courses in environmental quality should be to gather new information. Rather than teaching known facts and past experiences, major emphasis should be placed on monitoring the environment."

The same philosophy applies to colleges and universities. Many of the colleges

**Table 4. Rationale of Course Schedule and Subject Matter**

<i>Initial Class Meeting</i>	<i>Semester Time Sequence and Framework</i>	
	<i>1/3</i>	<i>2/3</i>
<i>Update:</i>		
Science and non-science subjects; multidisciplinary concepts in environmental education.		
	<i>Team Resource Planning:</i>	
	Local environmental education projects for school and community; role-playing strategy and project planning.	
		<i>Applied, Local Ecology:</i>
		Project refinement; actual results from community oriented projects with focus on project evaluation.
		Final Exam

**Table 5. Category Distribution of Classroom Projects**

<i>General Topic and Focus</i>	<i>Number of Projects</i>
<i>Pollution, Pollution Control Technology (34)</i>	
Anti-Litter school campaigns	5
Pollution survey and abatement proposal	13
Energy and fuels	2
Water, gas, or soil analysis	7
Math, economics and physical science games	6
Foreign language study	1
<i>Wildlife Ecology and Conservation (45)</i>	
General plant and animal studies	39
Local nature trail or outdoor laboratory development	6
<i>Environmental art, Music, Dance and Crafts (21)</i>	
Arts and crafts	14
Drama, music, or literature	5
Camp craft projects	2
<i>Community Development (31)</i>	
Environmental law	1
Farm or home management	5
Local geography and population study	9
Landscape design	2
Local environmental attitude	10
Environmental health	2
Local environmental attitude survey	2

**Table 6. Students' Environmental Education Projects  
as Reviewed by Their Teachers**

<i>Survey Question</i>	<i>Teacher</i>	<i>Response</i>
	<i>Yes</i>	<i>No</i>
Was 40% or more of the total planning done by <i>your</i> students and not yourself?	51	28
Was their project time span 4 weeks or longer?	41	38
2-4 weeks in length?	32	6
Have you and your previous students ever developed an environmental education project?	19	58
If you had <i>not</i> taken this course, would your students have had an environmental education project this year?	18	58
Was this required project (as required in this course) successful in your class:		
From your point of view?	74	0
From your students' point of view?	69	0
Will you and your students next year have an environmental education project?	68	8

and universities in West Virginia offer some integrated courses and intradisciplinary seminars about ecology. West Virginia University offers field studies in several environmental study areas. Project oriented field work is offered through graduate student internship programs. The Appalachian Center of the University also has an active youth training program in community development offered through its 4-H program. More environmental education courses are needed, however, in public schools, colleges and universities to train the youth who will have to be problem-solvers and decision-makers in the near future.

Results of the surveys reported in this paper support the contention that localized student-directed projects can be educational and extremely interesting. Teachers who have had a true course in environmental education develop confidence that a project can be unstructured and yet be organized into meaningful, efficient, learning experiences. When these learning experiences are planned and developed by youth role-playing committees, adults can participate also without loss of identity as the teachers. In fact, the teacher becomes more highly respected because his or her students realize that all are seeking the unknown answers to local environmental questions and all are not only re-reading lesson plans or lecture notes written by someone outside of the school environment.

Like most other things, one could wrongfully go overboard on environmental education. Each teacher and class of students should decide how much emphasis should be placed on environmental education projects during the semester. To "throw away" the textbooks would be folly because past knowledge is needed for a foundation. Some people claim that all education should be environmental

education. To many, including myself, this is an over-simplification and doesn't justify removal of the "3-R's" from education. On the other hand, short-term environmental projects personally developed by role-playing students conveniently fit into a semester schedule. Responses of those enrolled in Basic Environmental Education support the view that student-directed projects are not a waste of time but give students an opportunity to take a fresh look at their personal environment and, instead of talking about *Man in His Environment*, they are focusing on *Self in their Environment(s)*.

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## On the Nature of the Basic Binocular Disparity Cue in Stereoscopic Vision

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#### Abstract

The stimulus to stereopsis has generally been assumed to be adequately described in terms of the difference in angles subtended at the two retinae by objects seen in depth. It is possible, however, that stereopsis does not depend entirely on relative differences between the images on the two retinae, but, in fact, depends on absolute location of the two images on the retinae, which also varies for the two eyes.

It was predicted, given eye dominance, that if absolute retinal location is important then causing over- or under-convergence, with resulting fixation disparity, should result in a shift in space perception that will be manifest in a two-rod test such as the Howard-Dolman. This hypothesis was tested on fourteen subjects and the prediction was confirmed in twelve of them. Since this result was highly significant statistically it was concluded that the possibility of an absolute retinal location factor is worthy of further study.

From a perceptual viewpoint, binocular retinal disparity (stereoscopic vision) results in an invincible belief in the existence of objects lying in three dimensions, to use the words of Thomas Reid. Ever since Wheatstone demonstrated the phenomenon of stereoscopic vision in 1838, the external operations necessary to produce this effect have been known. However, how the eye and brain function to produce this variety of space perception is a matter in need of further clarification.

Conventionally, and almost universally, it has been said that the stereoscopic cue is due to the difference in angles subtended by the two images of an object at the two retinae (Ogle, 1964; Wheatstone, 1838). In Wheatstone's terms, the cue is due to the different perspective projections of an object as seen by each eye. It has generally been assumed that the pertinent thing about those different perspective projections is angular difference in the longitudinal meridian. It is, in fact, assumed that the strength of the stereoscopic cue can be calculated by the formula  $N = a_2 - a_1$ , where  $N$  equals the strength of the stimulus to stereopsis and  $a_1$  and  $a_2$  are the angles subtended by an object or configuration at the two eyes. Thus, when one image has different dimensional characteristics (is expanded or contracted in the horizontal dimension) relative to the other image, you would have a stimulus for stereoscopic depth. However, no one has ever done an experimental analysis varying relevant parameters to find out exactly what it is about the different views of the world that each eye sees that is used by the eye-brain system to generate three-dimensional perception.

There are two immediately apparent ways that the eye-brain system might process the information available to it in constructing depth perception. One would be to process this information in such a way as to register and make use of differences in size (width) of impingement at the two retinae of the same image. Hereafter this will be called the image dimension theory. Presumably the number of receptors stimulated might be involved here. Exact location of these images on the retina would not be critical. Presumably they would be processed the same way in regard to depth no matter how exact retinal locations might differ. This is the theory that is generally assumed. The other way the eye-brain system might work would be to make use of the information available from exact location of impingement of the two images. Hereafter this will be called the locus of impingement theory. Presumably whichever way the system might function there must be some adaptation and correction mechanisms involved to handle magnification differences in the optical systems of the two eyes that occur by natural biological variation (Engel, 1963, 1964). In the case of the exact retinal location model these adaptation or correction mechanisms would permit some adaptation to heterotropias (fixation disparity) which would alter retinal location and which normally accompany heterophorias or eye muscle imbalances (Ogle, 1967).

One way to test which of the two alternate models of eye-brain functioning in depth perception is correct is to assume one and test to see whether inferences following from this assumption are borne out. Assuming the model that maintains that information about absolute retinal location and not just relative image size is used in constructing depth perception then if we can artificially alter retinal location we should get alterations in depth perception even if relative image size is not varied. Therefore, a way of altering image location on the retina without altering image dimensions was sought for this study.

In normal stereoscopic depth perception fixation plays a key role. Normally both eyes fixate an object of regard and therefore bring it to the same or

corresponding parts of the two retinae. However, most people have heterophorias (eye muscle imbalances) that tend to create small deviations from bifovial fixation known as fixation disparities or heterotropias (Ogle, 1967). These fixation disparities can be created artificially using prisms to displace the visual field horizontally but in opposite directions for the two eyes (Ogle, 1967). Given that both eyes cannot fixate the object of regard there is a tendency for the dominant eye to do the fixating. This is the operating principle of the commonly used ABC test of ocular dominance. What this means in terms of retinal location is that the image of the fixated object will fall on a different position in the non-dominant eye from its normal one. Thus, you have a shift in retinal location without a change in the dimensions of the image. According to the image dimension theory you would have no cue for stereoscopic depth or relative depth differences. However, according to the exact locus of impingement theory there would be depth differential information giving the impression that one part of the object of regard is farther away than the other.

A commonly used test in depth perception is the Howard-Dolman test (Howard, 1919). This involves getting a subject to fixate two rods set close together and placed at a distance from the subject and having him make judgments about the relative distance of the two rods. For the purposes of this experiment the two rods can be regarded as the two sides of an object of regard. Thus, if the exact retinal location theory is right, using oppositely directed prisms before the two eyes to create fixation disparity should, in conjunction with ocular dominance, result in seeing one rod as farther away in the Howard-Dolman situation.

The theory involved in the exact locus of impingement information processing model was inspired in part by two unexplained results already in the experimental literature that would follow naturally given the assumptions in this theory. Luria and Weissman (1968) found that in a dynamic stereoacuity situation (one with a moving object of regard) there was a tendency for most persons with an esophoria (eye muscle imbalance giving a tendency for the eyes to fixate short of an object or regard) to make constant errors in setting one rod closer while exophoria individuals (eyes tend to fixate beyond an object of regard) tended to set the other rod closer. However, there were individuals who tended to do the opposite. Given the exact locus of impingement model and given the fact that most people tend to be right-eye dominant these are the results one would expect, but previously there was no explanation.

Another unexplained result in the literature is that of Scott and Sumner (1949) who found that right eye dominant people tend to set one rod closer while left eye dominant people tend to set the other rod closer. Again there were individual exceptions in the opposite direction. Given the fact that exophoria and esophoria are not equally frequent in the general population these are again results that one would expect given the exact locus of impingement model of the stereoscopic cue. Again we have heterophoria factors (and consequent fixation disparity) interacting with eye dominance factors to produce a displacement of images without dimensional alteration of the images.

Given the above results already in the literature it would seem worthwhile to go ahead with an experimental manipulation of these same phenomena using prisms to create fixation disparities artificially (analogous to those caused by natural heterophorias). If the results show an alteration in depth perception this would strongly support the exact location of impingement model of eye-brain functioning. This could not only tell us a lot about the manner in which the

brain processes sensory information but would have important implications for use of depth perception in many situations as in flying where interactions of phoria and eye dominance factors could produce illusions.

### Materials and Methods

The study was carried out using a final sample of nine males and five females, all between the ages of eighteen and thirty. Only potential subjects who had no known visual defects were tested for suitability as subjects. Subjects were required to meet certain visual and eye dominance criteria. Tests used were the ortho-rater acuity, phoria, and stereopsis tests, a measure of eye dominance based on binocular rivalry, and a standard sighting test of ocular dominance (the ABC test). The criterion on the Ortho-rater phoria test was 1.66 diopters or less. Criteria for stereoscopic acuity was a score of 6 or higher on the Ortho-rater depth slide (disparity angle of  $19''$  of an arc or less). Ortho-rater far visual acuity was required to be at least 20/25 Snellen for each eye (corrected). To meet eye dominance criteria a subject was required to use the same eye to fixate at least seven out of ten of the ABC test cards. The binocular rivalry test was used to confirm the results of the sighting test. The eye whose image dominated on two out of three trials in binocular rivalry was required to be the same as the sighting eye on the ABC test. Agreement was obtained for all subjects. Thirty subjects were eliminated without being tested due to known visual defects. Six more were eliminated for failure to meet one or more of the criteria above, leaving the final sample of eight right eye dominant subjects and six left eye dominant subjects.

The basic equipment for measuring stereoscopic distortion in the experiment proper, as opposed to subject selection, was of the type first described by H. J. Howard (1919). The device consisted of a set of parallel tracks, along which a pair of black, vertical steel rods could be moved. The tracks were 7.5 inches apart. The rod on the right varied in its distance from the subject. The left rod was stationary. The lighting was provided by reflectance from a flat-white surface at a distance of three feet behind the rods. The source of this illumination was two eighteen-inch 20-watt fluorescent tubes mounted just behind and below the platform for the tracks.

The rods were viewed through an aperture that hid their tops and bottoms from view. The aperture was 20 inches in front of the zero point of the rods and its dimensions were six inches high by two feet wide. A shield blocked the aperture between trials. Two sets of screens (occluders) were placed between the observer and the rods to limit the field of view to the rods and eliminate distracting stimuli.

Two prism conditions were imposed for each S, base in and base out. In the base-in condition each rotating prism pair was set at four diopters base in. If the person was unable to fuse the images on the two retinae the dioptric displacement for each side was reduced in small equal steps until a point was found at which fusion could be maintained. In all cases this point was such that there was at least two diopters base in displacement. Then all trials for the base in condition were run at this setting. A similar procedure was followed in the base-out condition with each side being set at four diopters to begin with and if this was not workable each side being reduced in small equal steps until fusion could be maintained, in all cases at least two diopters base out. Thus, considering both right and left prisms, the effective dioptric displacement for a given condition was at least four diopters and the difference between base in and base out

conditions at least eight diopters ranging up to a possible difference of sixteen diopters. It was not considered essential that dioptric displacements be the same for each subject as only directional predictions were made.

When the maximal displacement that still permitted fusion was established and the prisms set at this value (both sides the same) the subjects were asked to look through the prisms, between the occluders and through the aperture at the steel rods.

S's were asked to observe the rods and to say which of the two rods appeared closer. The method of constant stimuli was used. Settings of the variable rod were at one-half inch intervals in both directions from the zero point to a distance of two and one-half inches. The zero point was not used as a setting. S's were told that each trial was completely independent of the preceding ones and that in every case one rod was nearer. Settings were randomized with a total of one hundred trials. For both base out and base in conditions on fifty trials the right rod was at one of five nearer positions and on fifty trials it was at one of five farther positions.

**Table 1. Results in Terms of Number of Right-Nearer Responses for Base In and Base Out Conditions for Each Subject and Categorization of Each Case as Positive or Negative Depending on These Results as Determined by Hering Derived Hypothesis**

<i>Right Eye Dominant Subjects</i>			<i>Positive or Negative</i>
<i>Subject</i>	<i>Base In</i>	<i>Base Out</i>	
1.	42	49	P
2.	51	53	P
3.	38	50	P
4.	44	50	P
5.	50	63	P
6.	53	55	P
7.	47	45	N
8.	42	53	P

<i>Left Eye Dominant Subjects</i>			<i>Positive or Negative</i>
<i>Subject</i>	<i>Base In</i>	<i>Base Out</i>	
1.	60	54	P
2.	61	54	P
3.	46	37	P
4.	49	61	N
5.	46	41	P
6.	56	55	P

Because it is possible that constant errors in rod settings are influenced by individual optical characteristics like aniseikonia (Sloan and Altman, 1933) stereoscopic distortion was assumed to be present only if the base in and base out conditions yielded a difference in constant error and the difference was appropriately related to eye dominance. For right eye dominant subjects the

prediction, based on prism produced retinal disparity interacting with eye dominance, was that the base in condition would result in the right rod being apparently displaced away from the observer as compared with the base out condition. For left eye dominant subjects the prediction was just the opposite, that it would be apparently displaced more toward the subject. This prediction was made regardless of any constant errors associated with peculiarities of the individual subject. The total number of right nearer responses was the dependent measure.

The rotating prisms were always set so that both were base in or both were base out, of equal power, so as to cancel out prismatic effects other than displacement. Thus, the total prismatic displacement was always twice the amount before each eye. This method allowed bypassing of the problems of asymmetric convergence and of differential image magnification.

### Results

The data resulting from this investigation were in the form of responses by subjects stating that either the right rod or the left rod appears nearer. For each subject the right rod was presented nearer exactly the same number of times that it was farther and differences in distance of the two rods were the same in either case so that in the absence of some biasing factor the direction of response should be randomly distributed. However, as discussed earlier, the exact locus of impingement model makes a definite directional prediction. According to this hypothesis for right eye dominant S's the base out situation should result in a greater number of right rod nearer responses than the base in position. This prediction is reversed for left-eye dominant S's. Thus, we have a binomial situation where the exact locus of impingement model predicts  $p > .5$  for certain conditions and the hypothesis of random distribution predicts  $p = .5$ . In five out of the six left-eye dominant subjects the comparison of base in prism and base out prism conditions was in the direction to be expected from the exact locus of impingement model. In seven out of the eight right eye dominant subjects the comparison was also in this direction, making a total of twelve out of fourteen in this direction. This has a probability less than .007 under the null hypotheses ( $p = .5$ ). Thus, the evidence supports the exact locus of impingement model. The results for individual subjects are presented in Table 1 in terms of right-nearer responses. In this table positive cases, those favoring the exact locus of impingement model, are labeled "P" while negative cases are labeled "N".

### Discussion

The relatively strong evidence this study provides for a theoretically new model of eye-brain functioning in stereopsis has a number of important implications. It suggests that the eye-brain organization has a somewhat rigid and probably inborn information processing system for stereopsis which has correctives available to it rather than the inherently flexible system that the relative image dimension model would imply. However, the retinal locus model suggested might permit processing a wider variety of information.

The probable interaction of phoria and eye dominance suggested by this study also has a number of other important implications. It would be of considerable clinical and medical importance in analyzing and diagnosing and perhaps treating anomalies of depth perception in patients. It would also be important to take into account in a wide variety of depth perception studies. And, finally, there are certain situations like night vision or vision in a fog or while flying

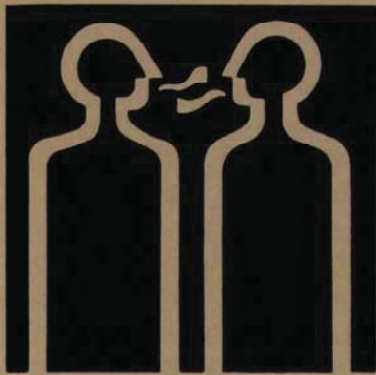
(especially military) where the stimulus to stereopsis is not strong and this interaction could produce significant illusions or distortions.

The findings of this study are significant in clearing up at least two previously unexplained phenomena. The distortions related to phoria factors noted by Luria and Weissman (1960) were previously intriguing but unexplainable. The individual differences in constant errors related to eye dominance noted by Scott and Sumner were also interesting but unexplained. This study shows that both follow logically from the interaction of phoria and eye dominance factors in an information processing system that functions differently than had previously been thought.

The importance of these findings suggest that a more naturalistic study should be carried out to further verify and extend the support for them. A simple and important next step would be to simply take people with strong heterophorias and definite eye dominance and examine their depth perception under conditions of low stimulus for stereopsis to see if the results are the same when retinal disparity is naturally produced instead of experimentally.

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## Social Science

### Testing Women's Attitudes Toward Abortion by Latency-Weighted Responses

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#### Abstract

Recent changes in the legal status of abortion suggest that our society is experiencing a change of attitude on this controversial issue. The change raises conscious/unconscious doubts and conflicts for gynecologists, husbands and wives considering abortion, unmarried women, and a voting public who must ultimately decide on the legality of the issue.

Psychological assessment instruments on abortion are in various stages of development at the present time, but these instruments belong largely to the so-called "paper-and-pencil" type. That means that they depend entirely on subjects' verbal responses to inventories on attitudes toward abortion. Verbal responses to paper-and-pencil tests, coming as they do only from the conscious self-structure, cannot be taken at their face value. As a rule, they do not reflect the subjects' unconscious/unverbalized self-structure. This is especially the case when people face an issue as sensitive as that of abortion. Thus we see the inadequacy of such traditional instruments.

The present investigation attempts to go beyond conscious responses to abortion by applying latency-weighted testing techniques developed by Gilbert originally for the purpose of personality testing.

Results of the study of eighteen women, nine supporting and nine opposing the liberalization of abortion laws, indicate that there is a positive correlation between verbal and latency responses for those who support liberalized abortion laws, while there is no significant correlation for opponents. Our research suggests a greater anxiety level for opponents than for supporters.

The very recent change in the status of legalized abortion, including liberalization of abortion laws in several states and the recent (1973) Supreme Court Ruling which confirms the right of states to permit abortion by consent, possibly reflects and affects a change in attitudes toward abortion in our society. Surveys taken by the Gallup Poll in 1962, 1965, 1968, and 1969 show that there has been "rapidly growing support" (Blake, 1971) both for therapeutic and nontherapeutic abortion. That change is illustrated by the increase in abortions performed in recent years. In California alone the number of therapeutic abortions jumped from about 600 per year prior to new abortion legislation to an estimated 60,000 to 75,000 in 1971 (Overstreet, 1971), and in the United States Tyler (1971) suggests "an increasing demand for abortion services at an estimated 1.7 million annually."

Most of the work done in the field of attitudes has utilized the traditional paper-and-pencil method of testing. Beck (1969) raises the question, "Can women's conscious and unconscious attitudes toward pregnancy be determined and measured? What are the medical/psychiatric indications for abortion?" In studying attitudes toward abortion the present research goes beyond the popular "paper-and-pencil" method of testing, making use of the latency-weighted testing method. This method was found to qualify the verbal responses by giving them a depth dimension.

The rationale of latency-weighted testing is that verbal responses of the conscious, and latency responses from the unconscious self-structure are simultaneously obtained. The higher the correlation between verbal and latency scores, the better is the personality integration or wholesomeness. The lower the correlation, the greater is the incongruence between the conscious and unconscious self-structure. This rationale has been explained and elaborated upon in numerous papers presented by Gilbert to the West Virginia Academy of Science and elsewhere (1961, 1963, 1965, 1966, 1970, and Gilbert and Cable, 1967).

### Materials and Method

In order to test the attitudes under consideration, a special instrument was constructed. Twenty items probing attitudes toward abortion were developed by a content analysis of the discussions on abortion in leading popular books and articles on the so-called "Women's lib movement" (Firestone, 1970; Friedan, 1963; Greer, 1971; Millete, 1970; Oden, 1971; and Westoff, 1971). Each item was worded in such a way that the response "agree" supports the right of women to have an abortion. Examples of the items are: "It is better to have an abortion than to bring an unwanted baby into the world"; "A woman should have full right over her body, including the right to have an abortion"; "A woman should be allowed to have an abortion if she cannot afford to have a baby"; "Abortion is not against the will of God"; and "I do not believe that abortion is murder."

We selected wives of business and professional men living in the college town of Buckhannon, West Virginia. All were white, middle class, parous (child-bearing) women between the ages of 25 and 40. None had had a previous abortion. By interviewing each woman on her stand toward legalized abortion we formed opposite criterion groups. Those who definitely supported legalized abortion were placed in the "positive group"; those who definitely opposed were placed in the "negative group." Each woman was then tested separately. The test items were read to the woman who responded "agree" or "disagree" to each

item. A reaction timer (accurate at 1/100 second) was employed to measure the time delay between the completion of the stimulus item and the verbal response made by the subject.

Thus each test item yielded simultaneously two responses, a verbal and a latency response. For each respondent the verbal response, "agree" or "disagree," was assigned a score of zero or one respectively. As to the latency scores, the test items with the five shortest latency responses (lower quartile) received each a score of zero, while items with the five longest latency responses (upper quartile) were each assigned a score of one. The ten test items with latency scores intervening between the upper and lower quartiles were disregarded, because their intermediary position rendered them diagnostically ambiguous. Each test item now had two scores, a zero or one for the verbal response "agree" or "disagree," and a zero or one for the latency response. This design rendered each test ideographic, for scores were based on each subject's own unique responses.

### Experimental Results

A phi coefficient was then computed for each subject between her verbal and latency response scores. For each criterion group of nine subjects the average phi coefficient was obtained by converting each phi into its respective Fischer's Z statistic and converting the average Z back into a correlation. The average correlation for the group opposed to abortion was +.01 (not significant). The average correlation for the group supporting abortion was +.29 (significant at the .02 level).

Testing procedures were nearly identical to those reported previously to the West Virginia Academy of Science (Warner, Gilbert, and Cable, 1972), and in that report a careful validation procedure was discussed. Validation of the present research method relies on that previous validation.

### Discussion

Our research goal was to investigate the attitude toward abortion of women in the fertility age who are parous and have had no previous abortions. Our investigation revealed that in the group of women who disapproved of abortion there was a greater discrepancy between the conscious and the unconscious self-structure. This was shown by the lack of correlation between the verbalized and the non-verbalized scores in this group. By contrast, the approving group showed a greater correlation between the consciously given attitudes and their unconscious un verbalized reactions.

The lack of congruity between the conscious self-structure, which provides verbalized responses, and the unconscious self-structure, yielding autonomic latency scores, stems from possible cognitive-emotional blocks underlying the verbalized responses, i.e. from mental reservations, fears, anxieties, guilt feelings and the like, underlying the consciously expressed attitudes.

We hold that the method of study of attitudes toward abortion reported in this paper might have application not only in the field of public attitudes, but might also be applied in the study of women who face abortion or those who have undergone the experience of abortion. Surveys of the literature in the field of psychological sequelae related to abortion indicate the widest variety of opinions by authorities as to the extent of emotional disturbances related to abortion. In a survey by Osofsky and Osofsky (1972) the authors find that most of what they consider to be "objective studies" show "markedly negative findings" regarding any psychological sequelae related to abortion. Their own study of

250 women who had experienced abortion corresponds to such "objective studies," namely that emotional complications are quite rare. However, a more recent study of therapeutic abortions for girls in early adolescence shows that 41% had depression, 27% suffered crying spells, 34% showed worrying behavior, and 46% had guilt (Perez-Reys and Falk, 1973).

Thus we are left with rather inconclusive results. Trussel (1973) concludes, in his survey of existing literature, that "the consequences of induced abortion have yet to be reported or perhaps even undertaken." David (1972) writes that it would be very useful to have an easily administered psychological device for predicting with reasonable validity which women are a particularly high risk for psychological sequelae.

We believe that the application of the principle of latency-weighted testing might well provide just such an instrument, and that the application made in our study with women who have never had an abortion might be transferred to a study of those who are in fact considering it or who have already undergone abortion.

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## Changing Locational Trends in Coal Production And Their Relationship to Settlement Patterns

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### Abstract

The past 50 years have witnessed radical changes in coal production—in amount, method and location of the major producing areas. Changes in mining methods have resulted in a decrease in labor inputs in response to mechanization and changes in the scale of production with fewer and larger mines. These changes have rendered the traditional unit of settlement, the company town or coal camp, normally adjacent to the mine, inefficient and unnecessary. The purpose of this paper is to investigate the influence on the settlement pattern of areal shifts in the location of production and regional decreases in labor demand.

On the basis of the investigation it is possible to reach several conclusions:

- 1) There is near universal decline in population in areas dependent on mining, regardless of recent production increases.
- 2) Selective processes influencing settlement abandonment and decay are in progress, apparently somewhat independent of local resource exhaustion.
- 3) Traditional coal settlements suffer greatest decline.
- 4) Location and condition of transportation facilities is only partially relevant to survival of older settlements.
- 5) Communities with higher housing standards survive longer.
- 6) Auxiliary function, whether sales, services, or industrial, do not insure town survival or population stabilization.
- 7) New mining settlements are not necessarily located near mines but tend to be located on or near better highways to insure maximum accessibility to work, retail, and service functions.
- 8) A high degree of overall settlement inertia exists in the study area.

### Introduction

Despite production fluctuations, the overall trend in coal mining has been upward over the past 60 years. At the same time, there has been a decrease in

the demand for labor resulting from increased mechanization. Until 1947, net production increases almost balanced the labor demand. Afterward, rapidly increasing automation and commensurately increasing productivity per man-day resulted in the decrease of the total mining work force to less than one-third its peak level. Competitive pressures and marketing conditions have encouraged consolidation of small companies into progressively larger concerns. The average size of mines has increased as well under a variety of cost conditions which create economies of scale in larger units.

In the historical past mines were often small; each unit was the nucleus for a small settlement owned by the company and housing active mine workers. This company town (or coal camp) was the traditional, basic unit of settlement. Outside the company store and offices, a school or church, and perhaps a series of taverns at the peripherac, there were none of the usual urban functions. Regional service centers or nearby established towns provided any alternative or necessary functions for a group of coal camps.

The combination of decreasing labor needs, increased size of establishment, migration of production to new resources some distance from traditional areas, and the decline or absence of service functions has rendered the traditional coal camp obsolete and often isolated. Consequently, they are being replaced to a degree by a new kind of mining settlement, composed of individually owned homes or trailers located on or near a highway to increase mobility of the individual and maximize access to work, shopping, and service alternatives. The overall population decline in the study area is exhibited in Table 1, but intra-regional movement data was unobtainable from conventional sources. Housing, therefore, rather than population figures has been chosen to illustrate these changes.

Table 1. Population of the Study Area

<i>Population (1000's)</i>	1900	1920	1940	1950	1960	1970
Greene County	28.3	30.8	44.6	45.4	39.4	36.1
Cumberland—twp.	1.7	3.3	7.3	7.8	6.6	6.2
Carmichaels—boro.	0.4	0.5	0.8	0.9	0.8	0.6
Monongahela—twp.	0.7	1.7	2.3	2.6	2.0	1.8
Greensboro—boro.	0.4	0.5	0.6	0.7	0.5	0.4
Dunkard—twp.	1.3	1.2	3.9	3.7	2.7	2.5
Greene—twp.	0.5	0.5	0.6	0.5	0.5	0.4
Whitely—twp.	0.9	0.7	0.7	0.8	0.7	0.6
Perry—twp.	1.1	0.8	1.0	1.7	1.5	1.1
Wayne—twp.	—	—	—	—	1.3	1.3
Monongalia County	19.0	33.6	51.3	60.8	55.6	63.7
Battelle—dist.	2.8	2.1	1.9	1.7	1.3	1.2
Clay—dist.	3.1	2.4	2.9	3.1	3.0	2.9
Blacksville—town	0.2	0.2	0.3	0.2	0.2	0.3
Grant—dist. (total)	2.1	4.8	9.9	11.5	10.0	9.4
(without Westover city or Granville town)				6.2	4.5	3.3
Cass—dist.	1.4	3.2	6.7	6.0	4.1	3.3
Osage—town					0.6	0.3

The study area chosen consists of parts of two counties in the Northern Appalachian Coalfield—Greene County, Pennsylvania and Monongalia County, West Virginia (see figure 1). These counties are notably similar in terms of physical size, reserve structure, yearly production, age and type of mining, as well as physical environment. Mining is still extremely important to the local economy of both counties and represents development confined primarily to the last fifty years. The region includes both indigenous mining development and expansion from neighboring Fayette (Pa.) and Marion (W. Va.) counties. Therefore, some data for those areas are included in the study. Only the western portion of Monongalia County, and the southeastern portion of Greene County have received detailed study in order to keep the field to a reasonable size, to avoid unnecessary duplication, to minimize the factors of resource exhaustion, and to reduce the incidence in the area of previously established, non-coal settlements.

Yet, the study area includes the entire range of conditions: completely abandoned towns, declining towns, and stagnant towns among traditional coal settlements, as well as a series of expanding settlements of the "new" coal mining type. Expansion of coal mining into new areas in the most recent 15 years has resulted in the inclusion of agricultural areas in the mining region, and coal related settlement often takes the form of addenda to existent, previously declining, traditional farm service centers.

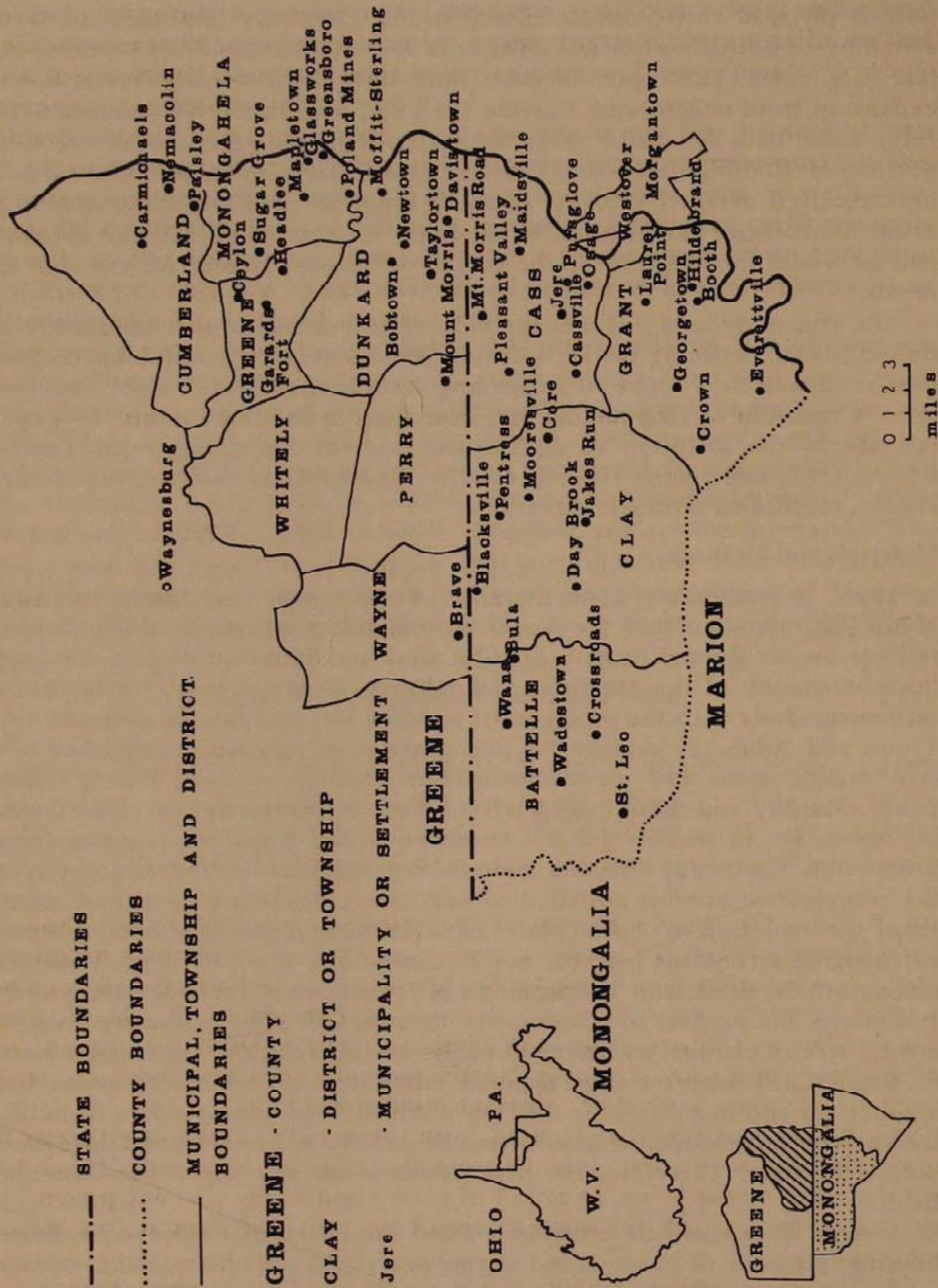
### Materials and Methods

There is remarkably little literature dealing with coal mining settlement. Munn (7) points out that the American coal industry is poorly documented and reflects on the general paucity of solid academic literature dealing with coal in his bibliography of the American coal industry. Most non-academic literature on settlement deals with the problems of building and maintaining company towns. Tryon and Albin (2) analyze the phenomenon of regional in-migration to new coal mining areas and the commensurate creation of coal mining company towns. Murphy and Spittal (6) briefly discuss the phenomenon of the commuting miner, but in another era and unrelated to the migration of actual physical production. Carter (2) discusses stranded communities but makes no analyses of the comparative survival potential of coal towns. Karaska (4) has done an analysis of the evolution of central places in coal mining regions but does not relate it to changing settlement patterns nor to community survival. T. M. Thomas (9), among others, deals with the problems of congestion in the coal valleys of Wales and relates the survival to government investments, while evaluating the governmental role in planned resettlement of the unemployed and migrating miners. A. E. Smailes (8) analyzes intra-regional migration in coal mining areas, but in another era and in a distinctly different (British) coal mining milieu from that in the current American situation. Given the paucity of literature, field work is the only alternative. Therefore, the basic research for this paper was done in the field.

A series of automobile traverses yielded data on relative age and condition of housing, presence of business and service functions, availability and condition of transportation facilities, and allowed for perceptual assessment of the relative degree of accessibility of individual settlements.

Field observations on age and value were correlated with county and township tax records and the proposed county plan (3). Occasional historical sources were used, but most data on housing decline were obtained from field observa-

FIGURE 1. LOCATION OF THE STUDY AREA



tion, interviews with long-time and former residents, and comparisons among topographic maps for the periods 1892-1905, 1925-1938, 1945-1954, and the most recent editions.

Three classes of housing were ascertained on the basis of conditional appearance. Class 1 (new or old) included houses or trailers in obviously good repair with reasonably well kept grounds; structures were larger than two rooms and appeared to have indoor plumbing or well kept outhouses. Houses of this class were to have a market value of over \$8,000 even in depressed housing markets. Class 2 housing was unmaintained of any age, but still reasonably livable. It included many one or two-room houses in relatively good repair, houses of fair to poor condition, and houses with cluttered or unsightly property and/or out-buildings. Class 3 housing was extremely poorly maintained with visible signs of decay such as broken windows, listing, or shoddy patchwork. Data for abandoned housing were collected as a separate category, but for this paper, Class 2 and 3 housing plus abandoned structures are combined into the category "sub-standard." Housing totals in Table 3 include both occupied and unoccupied as

**Table 2. Production and Mine Employment by County**

<i>Coal Production (million tons)</i>							
	1900	1920	1940	1950	1960	1970	Peak Year
Greene	—	2.1	5.2	10.3	10.0	12.7 (69)	12.8
Fayette	5.8	30.7	22.2	10.0	22.2	0.8 (69)	35.6
Monongalia	—	3.2	8.0	9.6	7.0	12.5	12.5
Marion	1.8	4.5	8.1	8.6	9.0	9.1	15.1
<i>Employment in Coal Mining (1000's)</i>							
	1900	1920	1940	1947	1958	1968	
Greene	—	2.3	3.4	8.5	5.6	3.5	
Fayette	10.3	27.7	12.8	12.3	2.1	0.3	
Monongalia	0.1	3.2	4.0	6.3	1.9	3.0 (70)	

well as obviously abandoned houses. The settlement type of "company town" is easily discernable and differentiation into mixed categories was only necessary in a very few instances (see figure 5). Settlement types and abandoned communities were defined and mapped on the basis of individual units identified by a name and/or by physical separation from other settlement clusters. For statistical purposes and some mapping, certain multiple units have been created by combining contiguous or obviously related individual units.

Population statistics were derived from various U.S. Censuses (10) and coal production statistics were obtained from the Minerals Yearbook (11) and the Keystone Coal Annual (5). Location of portals and mines, past and present, was ascertained in the field and with the use of old maps and various coal industry publications.

Certain preconceptions have led to and influenced this project. Among them is the fact that the economic cycle for a coal community is inherently different than that for other types of settlement (12). Previous studies by the author have indicated that transportation accessibility is only one variable in the continued

existence of a coal town (13). In these studies it was ascertained that several original communities were destroyed or reduced in size by construction of roads, cleaning plants and railroad yards. Failing water supplies, subsidence, and fires were other major causes. The totality of company ownership, the absence of legal restrictions, site congestion and proximity to the mine made settlement decline not only possible, but likely.

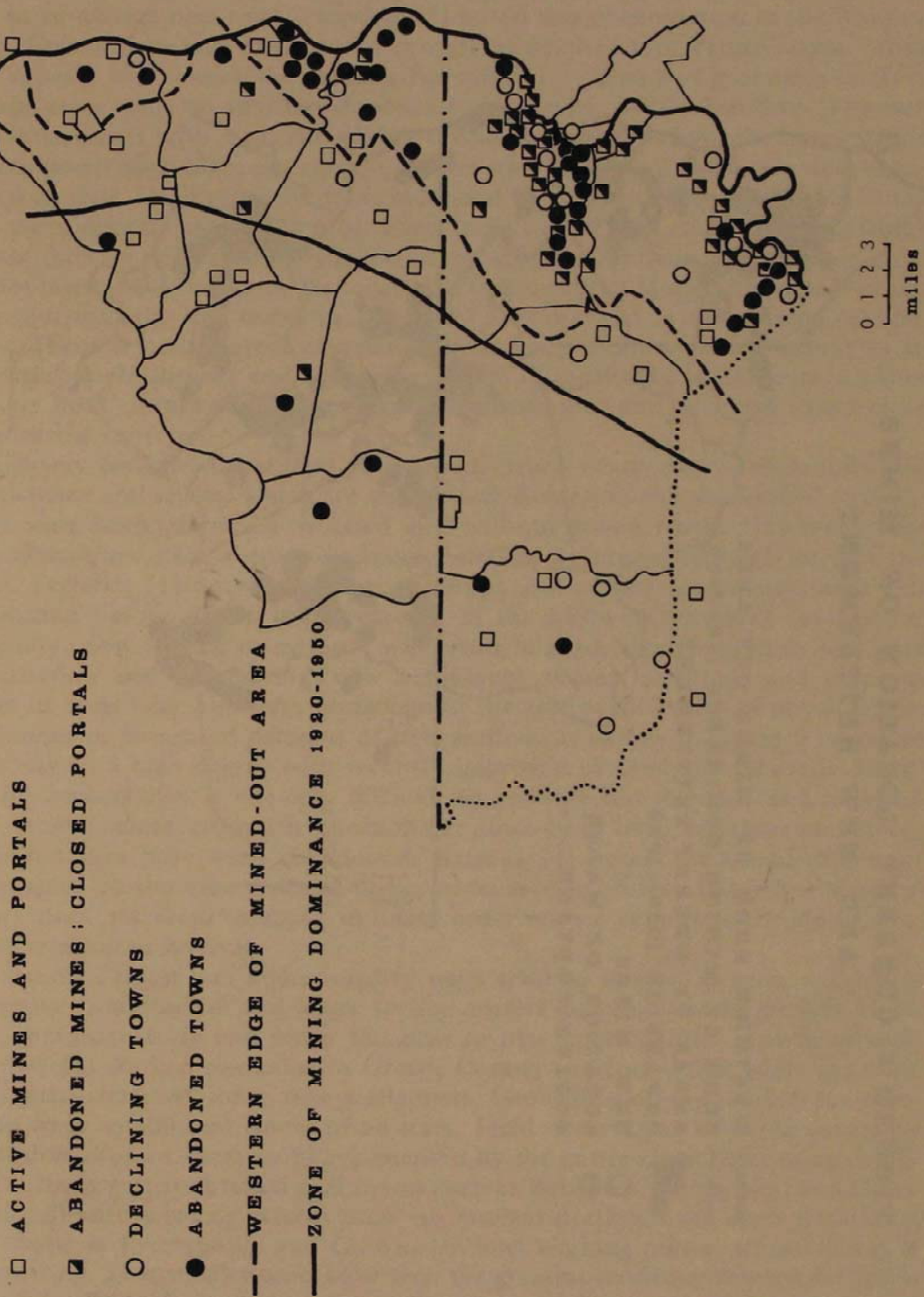
### Results

The study typifies national trends, with currently increasing production but population and employment decline. Within the region itself, however, there has been a moderate relocation of peoples and a general tendency for settlement to shift westward, together with the movement of active mining, though not in a consistent and directly attributable, cause-effect fashion. Table 1 indicates the changes in population of minor civil divisions within the county. Table 2 shows the changes which have occurred in mine employment and coal production on a county wide basis. Data on mine size and number of concerns have not been included but great reduction in the number of companies and individual mines engaged in active mining have taken place within the study area. In figure 2 it is evident that three zones of exploitation emerge: one in which mine abandonment, together with settlement abandonment and decline, are both heavily evident; a second in which advanced states of resource exhaustion and recent portal abandonment have had relatively little negative effect on settlement; and a third in which new mining is only beginning to have some effect on local settlement. The unusually high incidence of abandoned mines and towns in the district nearest the river reflect the changes in scale of production as well as resource exhaustion, in that small mines and small towns were the norm at the time of the inception of settlement.

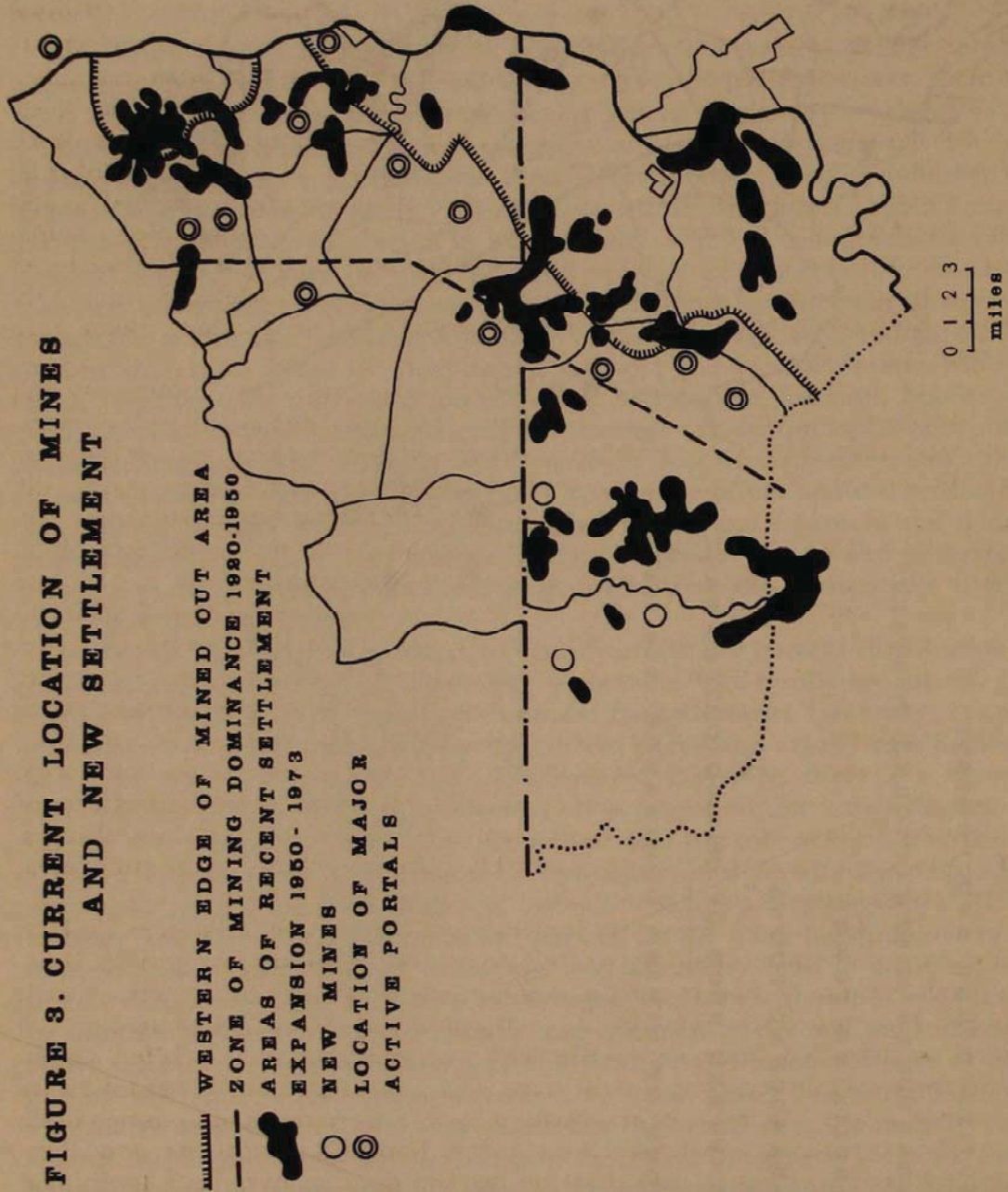
In figure 3 there is an attempt to visually relate the current distribution of active mining and portals to expanding settlement. The results are mixed. Certainly the portal itself no longer concentrates the settlement. Generally, the new settlement is at some distance from the current portal and usually on a highway. There are several reasons for this phenomenon. Certainly, there is a time lag involved, but this is difficult to measure. It is suggested that other factors can explain this tendency. Labor is locally mobile and the role of the automobile is obvious. Portals open and close with frequency, and layoffs and temporary shut-down are normal. This degree of instability favors a location which affords mobility and access to other mines and portals. On the other hand, union regulation, increased skills required in mining, and familiarity tend to stabilize work forces, and miners' jobs migrate to some degree together with mines and portals. In addition to home ownership, family and community ties will tend to keep a miner resident in his former area while difficulties and inconveniences of commuting will tend to encourage movement to areas nearer the portal. Whereas availability and price of land may determine the actual site, the mobility with regards to job and urban service functions determine the general location. Ferree (1) noted the dominance of highways in concentrating post 1939 housing in the Greene County area, relating the choice of home location to both these phenomena.

Auxiliary functions as a key to community growth and survival were examined. Lower level census unit data are not compatible with community designations, because unincorporated areas are often divided among enumeration districts which frequently use roads and streets as borders. Few data are available

**FIGURE 2. MINE AND SETTLEMENT ABANDONMENT**



**FIGURE 3. CURRENT LOCATION OF MINES  
AND NEW SETTLEMENT**



for unincorporated units, and industrial statistics are either unavailable or unreliable. Generally, declining towns had declining business functions as well. Settlements with established retail and services functions tended to become regional centers after coal exploitation began and to expand those functions as well as to attract new ones. Ferrebee (1) noted this phenomenon in the Waynesburg, Uniontown, and Masontown centers of southeastern Pennsylvania. While this appears to enhance the chances for survival, it does not guarantee it. Too, certain areas with no auxiliary functions can survive. While Ferrebee (1) noted that settlements with a purely mining economy tended to have the heaviest rate of settlement abandonment, certain centers with additional functions were abandoned as well. Until recently, most industrial functions that existed in the study area were directly related to coal. Even today, those few small factories which are not directly related to the coal economy account for little in the way of total employment. Most factories are located in metropolitan Morgantown or Waynesburg. Surprisingly few males in the study area worked in non-mining occupations. There is no apparent correlation between proximity of settlement to an industrial establishment and decline or growth of individual settlements in either county. Both counties contain examples of abandoned and declining towns close to industrial centers.

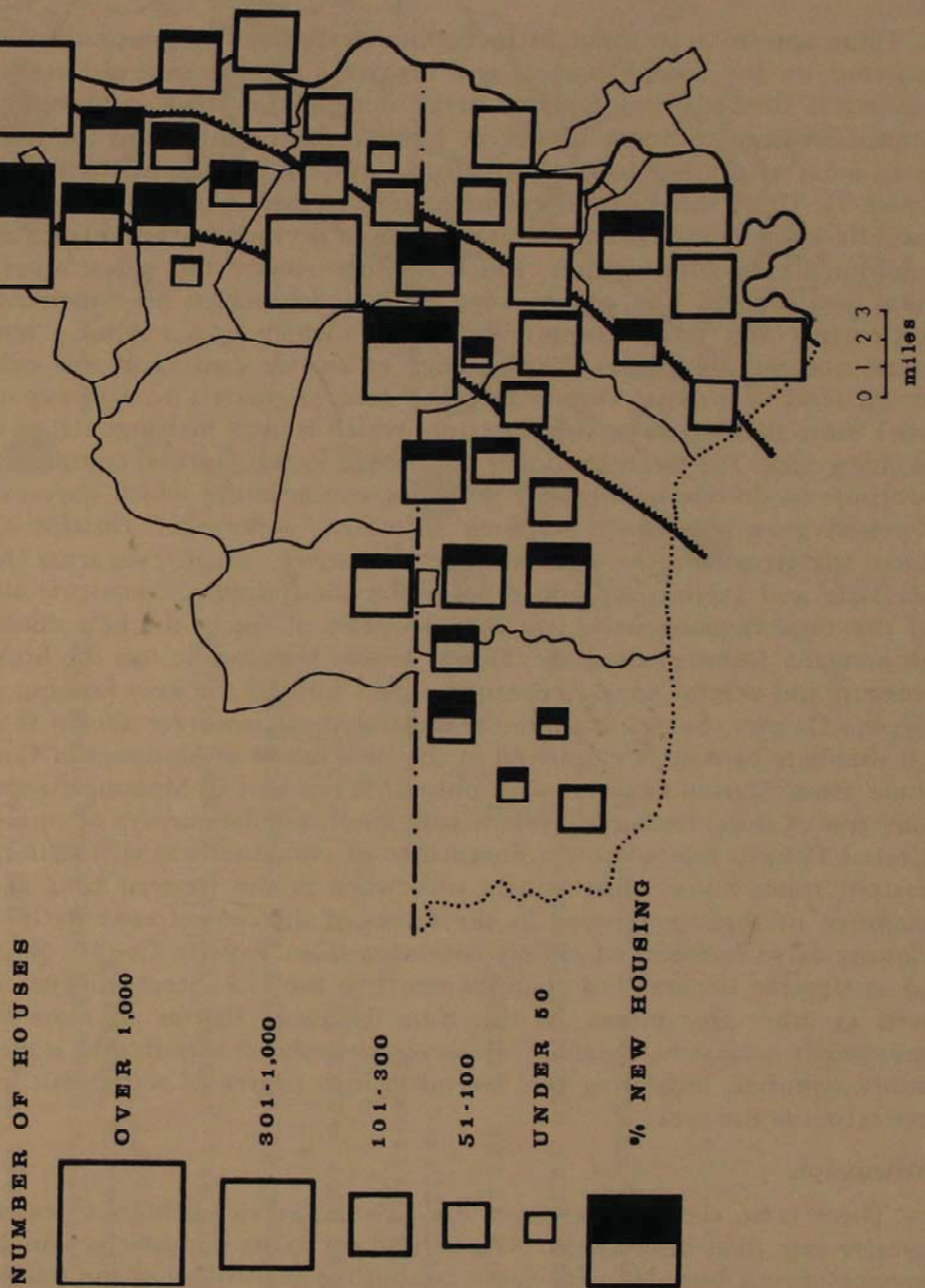
Highway facilities (or at least paved roads) reach nearly every community still in existence and several which are abandoned. Several of the abandoned communities were both physically isolated and without paved roads. However, these were abandoned or in a state of advanced decline before paved roads became the norm. Ferrebee (1) noted that service centers and mining settlements were well established before major improvements in the highway networks took place. Generally, new mining investment will result in road improvement to facilitate construction and commuting; new settlement comes later (14) and tends to locate in areas near highways regardless of the ease or difficulty of physical site. The linear or elongated patterns of new settlement shown in figure 3 correlate positively to a high degree with recently improved or newly paved roads. Physical site accessibility is not only difficult to measure but its value as a determinant in settlement survival is questionable since both level, spacious and steep, congested sites have been abandoned. Karaska (4) noted the broad effects of topography on the emergence of higher order service centers, but physical accessibility does not seem to apply to lower order service centers in the study area, nor to settlement survival.

Generally, larger and higher quality units tend to survive, as seen in Table 3. Attractive communities and larger service centers do exhibit some growth. However, communities in bad repair but near to new mines exhibit growth as well. Ferrebee (1) studied one mine in Greene County and found that while the mine apparently attracted some new settlement, two-thirds of the work force commuted from established towns of all sizes. Field observation of those towns by the author showed them to be represented by the entire range of housing conditions. The largest traditional coal towns such as Bobtown, Nemaocolin, and Glassworks (all with working mines) show no marked decline. Even such traditional coal towns as Everetttsville and Crown, without working mines, are surviving, if not growing. That smaller units have seen the greatest tendency toward decline is evident in Table 3. In terms of growth, as opposed to survival, the case is less clear; both small and large units have grown. New housing (defined here as less than 15 years of age) in relation to community size is illustrated in figure 4, and no definite pattern emerges.

Table 3. Housing Conditions in the Study Area

	# of dwellings	% new	% sub-standard	% visible abandoned housing
<i>Selected Communities—Greene</i>				
Carmichaels-Cumberland-Fairhope	1014	44	7	1
Nemacolin	340	1	5	3
Paisley-Little Chicago	112	38	27	8
Mapletown	170	43	10	1
SugarGrove	56	50	12	4
Greensboro	170	15	27	6
Glassworks	117	19	17	4
Mofitt-Sterling (Nassar's Store)	63	16	56	12
Poland Mines	60	3	75	17
Headlee Heights	54	65	18	2
Bobtown	320	1	4	1
Newtown	68	23	53	20
Davistown	35	23	37	10
Taylorstown	63	25	27	7
Mt. Morris-Martinsville	385	43	16	2
Garrard's Fort	39	13	31	10
Brave-Spraggs	123	16	17	4
Ceylon-Bailey's Crossroads	198	73	9	2
<i>Selected Communities—Monongalia</i>				
Wadestown	47	25	17	4
Wana-Hunting Hills	50	48	12	6
Bula-Miracle Run	59	27	39	12
Crossroads	58	39	17	7
Pentress	111	21	22	4
Blacksville-MacDale	237	38	19	5
Mooreville	65	39	18	6
Jakes Run (Statler)	60	21	40	8
Cassville-Newhill	199	18	39	3
Osage-Chaplin Hill-No Name City	126	6	78	8
Everettville	105	8	71	19
Crown	74	4	48	10
Laurel Point	85	45	31	5
Booth	113	9	37	3
Hildebrand (Dellmar)	96	15	45	8
Jere-Bunker-Shriver	202	6	62	10
Pursglove-Liberty	104	11	71	24
Daybrook	147	38	9	2
Core-Pedlar	80	18	45	8
St. Leo	53	9	48	15
Maidsville	59	7	80	13
Mt. Morris Rd.	127	50	29	8
Georgetown	67	37	36	9
Pleasant Valley	38	71	28	3

**FIGURE 4. NEW HOUSING IN SELECTED COMMUNITIES**



The single factor that all expanding units have in common is a good highway location. The norm is a continuous row of houses on both sides of the road with an occasional widening at minor cross roads or in the form of trailer courts. The heavy incidence of trailers among new housing reinforces the choice of highway location as well as giving the impression of impermanency and recency of movement.

There appear to be three distinct concentrations of housing expansion. One is centered on the service centers and highways of east central Greene County, another is formerly unpopulated areas along major roads converging near the Grant-Cass-Clay common border in Monongalia County, and the third in scattered areas of the heretofore agricultural western portion of the study area (see figure 3). Three zones of settlement pattern emerge in figure 5. The eastern zone exhibits a tendency toward the dominance of declining, stagnant and abandoned traditional coal communities, which in turn occupy the oldest areas of settlement and mining. The central zone finds a dominance of expanding highway settlements and stable communities (rural) which now exhibit a tendency to house commuting miners. The absence of service centers in this central zone would tend to indicate that in this, the zone of greatest housing expansion, it is work more than urban service functions which is most instrumental in the choice of living area. The western zone is dominated by agricultural communities which continue to decline or formerly declining communities which have experienced renewed growth in direct response to miners' settlement. Outside a very few areas, the growth in the western zone is relatively small. Two areas (Blacksville-MacDale and Daybrook) with no great service function, constitute almost 50% of the total housing units less than 15 years of age in the new mining area of Monongalia County; similarly, Mount Morris-Martinsville (on the border of the western and central zones) constitutes over 60% of the new housing in western Greene County. Survey of union membership records have shown that the largest numbers of miners employed in the new mines in Monongalia County commute from Marion County, with only 35% resident in Monongalia County and very few of those from the western zone itself. Similar surveys of employment in Greene County mines show a dominance of commuters as well. The central and eastern zones house most miners who work in the western zone as well as a majority of those employed in the mines of the central zone itself. In Greene County large numbers of miners commute from Fayette County (itself an area of settlement decline and abandonment) to the U.S. Steel Robena complex as well as other area mines. At this time the exact figures on cross-county line movement cannot be obtained. However, the relative importance is great in both study counties, indicating that overall a high degree of settlement inertia is in operation in the area.

### Discussion

There is no clear cut tendency for existent service centers to expand at any greater rate than other areas. New settlement exists not only in association with service centers but also with some established coal towns of the traditional type and in clusters where no previously established settlement existed. It is therefore not only reasonable to assume that mobility with regard to work is the prime determinant in new housing locations, but that this tendency does not necessarily attract even a majority of mine workers away from established settlement areas. It can be further assumed that net areal population decline in response to

**FIGURE 5. CLASSIFICATION OF SETTLEMENTS**

**TRADITIONAL COAL COMMUNITIES**

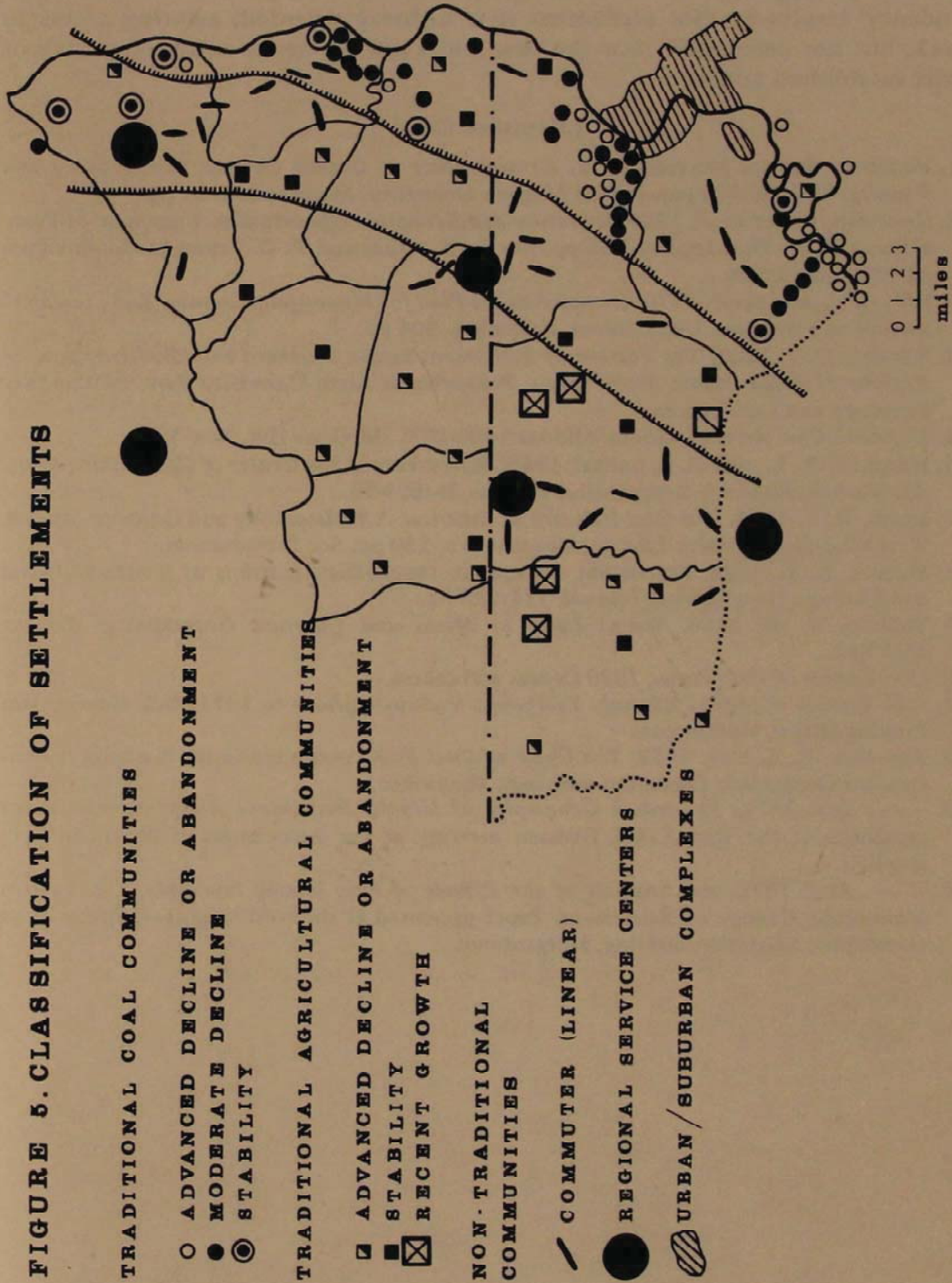
- ADVANCED DECLINE OR ABANDONMENT
- MODERATE DECLINE
- ⊙ STABILITY

**TRADITIONAL AGRICULTURAL COMMUNITIES**

- ▣ ADVANCED DECLINE OR ABANDONMENT
- STABILITY
- ⊠ RECENT GROWTH

**NON-TRADITIONAL COMMUNITIES**

- COMMUTER (LINEAR)
- REGIONAL SERVICE CENTERS
- ▨ URBAN / SUBURBAN COMPLEXES



a decline in employment opportunity has been the primary cause of precipitous population decline and settlement abandonment in the eastern zone. There exists no more than a limited tendency for settlement to follow the opening of new mines and portals to the newer western areas of coal production. Where this tendency results in new settlement it is highway oriented, assuring access to work, but not necessarily near the new mines nor the newly activated portals of older established mines.

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