TOWARDS A STRUCTURAL VIEW OF RESILIENCE

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The notes which follow were put together to serve as background material for the IIASA Workshop on Hypotheticality, Resilience and Option foreclosure. A familiarity with the papers of Holling (1973) and Holling and Clark (1974) is presumed.

The result of resilience is persistence: the maintenance of certain characteristic behavioral properties in the face of stress, strain and surprise. But the origins of this resilient behavior lie in the structure of the systems which concern us. Our need as policy analysists may only be one of comparative measures: Which system is more resilient? But as active designers - as engineers, managers, or responsible policy advisors - we need to be able to say what mechanisms or relationships make a system resilient, and what actions we can take to make it more or less so.

This need for a causal view of resilience led us to a search for persistence-promoting (or "resilient") mechanisms and relationships in a variety of natural and man-made systems.

Three general and inclusive classes of such mechanisms emerged from our studies. We have, somewhat optimistically, labeled these emergent classes the "Components of Resilience". In the pages which follow we describe these components, first at an abstract overview level, and then in some detail through reference to particular examples.

A few prefatory comments are in order, however. First and foremost, our classification of components is in no way unique. The cited examples could doubtlessly be grouped in several other ways. We have provisionally adopted the present classification because of its attractiveness from a design (or, alternatively, a natural selection) point of view.

At present the classification scheme still tends to ring a bit hollow if looked at too closely. A disconcerting number of our empirical mechanism examples could plausibly be placed in more than one of the proposed component classes. Our intuitive feeling is that the ambiguities, though troublesome, are less serious than they might at first appear. The reason is that we have little interest in the classificatory scheme per se. We are interested in it primarily as a tool to help in the articulation and understanding of alternative resilient policy designs. This is not the place to detail their usage in that context, but the general intent is that they be employed as a criterion axis in a version of the so-called "morphological" approach to alternative policy articulation (MacCrimmon 1975).

The important clients for the components notions are not taxonomists and librarians, but rather engineers. Although we are hardly insensitive to the desirability of conceptual elegance and clarity for its own sake, our primary criterion of utility remains a practical rather than esthetic one. The critical question we pose to readers of this note is whether these are types of persistence promoting mechanisms excluded from the present scheme or, somewhat less seriously, whether any of the proposed classes could be decomposed further in a useful and relatively unambiguous manner.

We do not yet understand the resilience components ideas clearly enought to pose them in a single comprehensive and integrated package. Instead, we must rely on presenting a series of alternative views hoping that the important and central concept of Resilience Components will emerge from or, perhaps better, survive the different perspectives.

We begin at the end, with a set of proposed definitions. These are followed by a trivial example contrived to introduce in an impressionistic way the three resilience components. This is provided for the sake of overview only and we would ask you to imagine while reading it that there may be more there than meets the eye ... Our second pass at the Components concept is adapted from a draft report of our ecological work on the subject. The presentation is highly abstract and tied to the technical ecological literature but represents the area of our most detailed and critical studies on the subject. To be fair, however, the reader might best consider that there is likely to be a bit less here than meets the eye. Finally, we discuss a few of the examples from outside the ecological literature which have thrown light upon the Components analysis.

A) Formal Definitions of the Resilience Components

We define three Components of Resilience. The Class I or Boundary Component includes mechanisms which give the part of the system which has been perturbed an ability to recover without any contribution from nonperturbed areas. These are generally state-dependent, negative feedback management rules or control mechanisms. The Class II or Restorative Component concerns (a) the existence of unperturbed parts of the system, and (b) the ability of those unperturbed parts to contribute to the recovery of perturbed parts. Relevant mechanisms enforce or induce heterogeneity of the system, establish reserves of uncommitted resources or insurance, and allow for the reallocation of resources among the heterogeneous units. The Class III or Contingency Component considers the degree of dependence of a system's resilient properties on aspects of the environment beyond its immediate influence. Mechanisms here deal with provision of diverse sources for necessary resources, and with reducing sensitivity to single factors or elements of the system.

B) Resilient Components in the Food Retail Business - A Contrived Example

Imagine yourself as the manager of a medium sized North American food store. Your short-term goal is to make a profit by keeping the amount of food in stock and the number of customers waiting for checkout within reasonable limits despite fluctuations in deliveries and buying behavior[1]. We will consider the effects of the following relationships (rules,

[1] It is assumed that too large an inventory results in spoilage and high storage costs; too low an inventory results in empty shelves and perhaps irreversible loss of customers; too slow a rate of check-out also results in customer dissatisfaction; and too high a rate of check-out implies uneconomic over investment in cashiers.

mechanisms) on your ability to achieve that goal:

(a) Your internal operating procedures,

(b) Your possible links with other food stores, and

(c) Your relationships with food supplies, labor markets and consumer demand.

Your first line of defense against an uncertain world is an effective inventory and personnel control system. You will set up standard operating procedures through which present shelf stocks trigger deliveries from 'the back room', and total inventory governs orders from your wholesaler.

Both sets of stock control rules will doubtlessly have factors built-in to account for known daily, weekly and seasonal buying patterns of consumers. Similarly, rules will be devised to switch a certain number of stock-boys into check-out bagging operations when lines begin to grow. Both inventory and personnel regulation procedures will incorporate sufficient slack to accommodate surprises: inflated inventories to buffer late deliveries, extra or multiply-trained employees to anticipate absence and illness. We define this class of management mechanisms (rules, relationships) as the Boundary (or Class I) Component of Resilience. Their key characteristic is that they include only those "in-house" procedures which are keyed to your local conditions (inventory and line sizes) and utilize authority, control, and resources which are normally available as part of your local (i.e. in-store) operations. Sales, early closing hours, orders to wholesalers[2] and job allocation to employees all come under this category.

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(2) Temporarily considered as a passive entity reacting to your purchase orders.

Whatever internal inventory and personnel controls you adopt, however, they cannot protect you from all of the nasty tricks which fate may hold in store. Consider the impact of a case of scarlet fever in a clerk which quarantines a third of your staff. Or an ordering error which results in the delivery of 100 instead of 1 case of ripe avocadoes. Or a major break-down of your "back-room" cold storage facilities. No internal adaptations will help you stay within your limits here. The only real hope is that there is some accessible external source of trained personnel, of avocado outlet, of cold-storage space which is sufficiently independent of your own operation that it is unaffected by your scarlet fever, bookkeeper and mechanics. Such exogenous, (your) state-independent mechanisms for coping with stress and disaster are characteristic of what we have called the Restorative (or Class II) Component of Resilience

Several specific mechanisms are imaginable in the present context, but the most likely is a net of similar food retail stores, each committed to helping the other in times of stress. To the extent that they are decentralized with respect to location and administration it is highly unlikely that disasters of the sort we have been discussing will affect more than one or a few members of the net at once, leaving the others undisturbed and able to spare resources to effect their brother's recovery. Various sorts of insurance are another example(3).

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(3) There are, of course, disasters which will affect all of the units simultaneously and render many of the Restorative Resilience aspects of their relationship a moot point. Consider large union strikes or national crop shortages in this context. Certain types of insurance schemes would remain meaningful here precisely to the extent that the food store business representsd a small segment of their total clientèle. Disasters in their food store accounts could then be absorbed via Class III (below).

Finally, we come to a consideration of the linkages and dependencies of your store on various aspects of its external environment. We have touched on this in a passive way in considering the impact of, for example, delivery failures. But let us now take a more active stance: How, as a conscientious manager, should I structure my relationships with those aspects of the external environment on which I depend but which I cannot control? This is the problem to be dealt with by the Contingency (or Class III) Component of Resilience. An obvious concern in this respect is my relationship with my supplies of food. If I deal with a single wholesaler and am only one of his clients, I am relatively helpless before his changes of prices, supply schedules and so forth. I can clearly make my situation less tenuous by diversifying my sources of supply so that no one supplier's behavior can strongly effect my ability to achieve my management goals[(4)].

A similar situation is faced with regard to labor supply. Again my worst case is encountered when I must buy all my labor from a single monopolist (union) whose behavior I cannot influence. An extreme response analogous to the purchase of suppliers noted above consists of buying ownership of all labor -- the company town solution[(5)]. The intermediate and

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(4) Alternatively, I can change the rules of the game by buying control of all my suppliers so that they become part of my locally determined operations and subject to Class I Component adaptations.

(5) This may be nonresilient for other reasons, the most obvious being its negation of Class II concepts.

probably most generally "resilient" response from the manager's perspective in the case of supplies is an essentially "free market" one in which there are multiple independent sources of the desired good[6]. A final example of a Class III Resilience Component would be represented by a decision to reduce dependence on the public power grid by installation of generators in the store for emergency usage.

C) Components of Resilience in Ecosystems

Ecological studies have emphasized the idea of resilience as a key to the conceptual organization and synthesis of perturbed ecosystem studies. This viewpoint has beem more fully articulated in Holling (1973). It had been clear since the beginning of our work, however, that these initial concepts would have to be further developed if they were to provide a solid, unambiguous framework for the study and analysis of disturbed ecosystem behavior. In particular, at the stage of our research summarized in Holling (1973), we felt that we had good quantitative handles on resilience only for the simple case of a closed, homogenous, deterministic system. The importance of "open" system effects, of spatial and temporal heterogeneity, and of random or irregular events was recognized, but understood only hazily and at a most uncomfortably qualitative level. Yet our review of the literature on "stability" properties of disturbed ecosystems made it clear that these latter factors

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(6) This is not to suggest that equilibrium free-market systems are bound to be resilent. As pointed out by Cyert and Marsh (1963) (see below), the equilibrium solution is generally characterized by zero "slack" and is thus highly unresilient.

would have to be dealt with explicitly in any really satisfactory conceptual framework. A significant part of our work over the past year has consequently addressed the problem of refining the basic resilience concept. Drawing on the existing stability literature, relevant theory, and our own simulation models, we have made some progress in articulating three qualitatively distinct but inclusive Components of Resilience. We believe that, when fully developed, these will be sufficient to encompass and relate all presently known factors affecting the response of ecosystems to stress. The components are summarily described below, with a more formal and rigorous treatment to be provided in a manuscript now in preparation (Clark, Holling & Jones in prep.). We emphasize that these results are tentative and anticipate many refinements to emerge from interactions with other Project Groups in the coming year. The following treatment is designed to indicate the directions of our work, not its conclusions.

Boundary Resilience

"Resilience" may be seen as a behavioral property of an ecosystem: its ability to absorb or "bounce back" from perturbations. The property of resilience derives from structural characteristics or adaptations of the ecosystem. It is these structural characteristics -- the "sources" of resilience -- that we have classified into Resilience Components. We distinguish three such Components -- Boundary Resilience, Restorative Resilience, and Contingency Resilience -- which may be most succinctly characterized in simple abstract terms.

Figure 1 shows our initial concept of resilience, interpreted in terms of state space behavior of two interacting populations. The subsequent behavior of the two populations

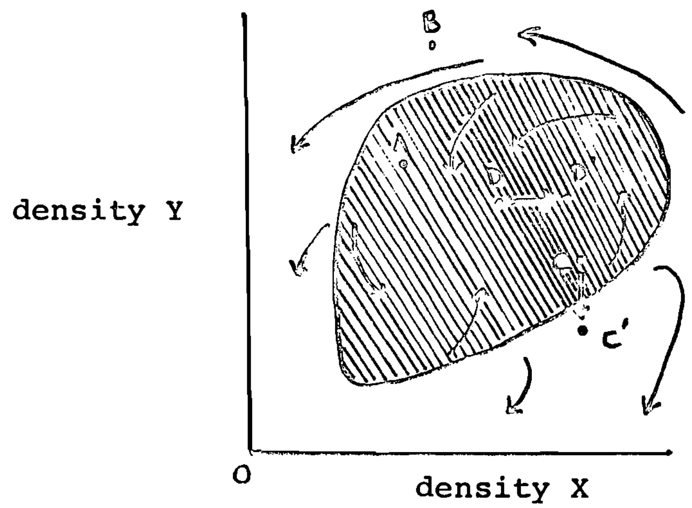

Figure 1

(arrows) is defined by their present state, or location, in the space. Boundary conditions arise in natural systems such that populations (A) presently within those boundaries (shaded area) tend to remain within them ("stability") while populations (B) outside the boundaries (unshaded) do not, in this case going to zero density and extinction. External perturbations which move the populations from inside the shaded region to outside (C⇒C'), can change future behavior, making a previously "stable" system go extinct. Perturbations which do not result in boundaries being crossed (D⇒D'), do not result in such changes in persistence. All of this is detailed in Holling (1973).

We now know from our own theoretical work and analysis of data-rich simulation models that the location and configuration of the boundary in Figure 1 -- and thus certain aspects of the resilience properties and perturbation response of the system -- are altered in definite and predictable ways by changes in the population parameters (growth rates, reproductive rates, predation rates, etc.) and structure (genetic diversity, phenotypic polymorphism, age class composition) of X and Y (Jones, 1974 a,b; Walters 1974). Most classical stability theory (e.g. May 1973), predation efficiency arguments (e.g. Rosenzweig and MacArthur 1963), studies of refuges and minimum grazing densities (Parsons 1974), work on high-density emigration and notions of the adaptive function of polymorphisms and genetic variability in fluctuating environments are most readily interpreted as dealing with the same issue: How do state (density) dependent relationships within and between the populations determine their resilience/stability behavior in the face of perturbations?

This question -- or class of questions -- was the focal point of our initial resilience concept and is now being further developed as the important "Boundary" Component of overall resilience.

Restorative Resilience

Refer again now to Figure 1. However strong the boundary forces in a system, external perturbations (violent weather effects, physical trauma, management) will occasionally move the system outside of its stable (shaded) region, as in $C \Rightarrow C'$. If this were really a one-way, irreversible sort of event, very soon no system would be left inside its stable region. State dependent phenomena cannot, by definition, ever move the system from $C' \Rightarrow C$. But state-independent phenomena can and do, and it is these which we have termed the Restorative Component of overall resilience.

The crucial thing to recognize at this point is that the phenomena depicted in Figure 1 and addressed in all the previously cited literature are in both a formal and intuitive sense essentially "local" and "continuous" in character. They are appropriate for situations in which everyone we are concerned with in the various populations is bumping into everyone else according to some well-specified set of rules; in which our state tomorrow is always a function of our state today. Our system must not be so big that what is happening between X and Y on one side of the field is different from, or not closely related to, what is happening on the other. Similarly, we must not get into situations where today's state has less to do with yesterday's than with some other factor which determines our present condition largely independent of what it has been in the recent past. Viewed in another way, these early descriptions apply rigorously only where the entire "system" under consideration is perturbed homogeneously and simultaneously.

Yet it is very clear that the perturbation behavior and resilience properties of most natural systems are critically dependent on just the sorts of temporal and spatial discontinuities ignored in Boundary Component considerations. The classic "density-independent factors"line of argument and evidence applies here, particularly as it pertains to weather as an influence which temporarily overrides the temporal state dependence of system behavior. This material is well enough established that we shall not comment further on it in this interim review.

We feel we have made some useful and original progress beyond providing a home for density-independent arguments, however. In our present working hypothesis, we view the growing evidence on "stability" effects of spatial heterogeneity and dispersal as part of the same largely state-independent, Restorative Resilience parcel. Briefly, the argument is as follows. The fact that the world is not spatially homogeneous means that although a perturbation may have pushed one local group of X and Y out of its stable region from $C \Rightarrow C'$, other local groups of the same species may still be happily functioning within their stable regions. The perturbation may have missed them altogether, or have been less strong, or affected them differently. Now, if there is no exchange between these heterogeneous groups, the one perturbed to C' will, in our present example, proceed on to extinction. (What happens then we will discuss under Contingency Resilience). But if there is exchange -- for instance, if the unperturbed groups are occasionally sending out emigrants in line with previous Boundary Resilience arguments -- then there is some chance that the perturbed system will be "reperturbed" from C' (or wherever it has gotten to) back into the stable region by receiving a suitable dose of immigrants from the outside world. Note that the dose of immigrants received can be viewed as essentially independent of the state or densities of the originally perturbed site. (The number of immigrants who "take" on the new site is doubtless <u>not</u>

independent of local conditions. This matter is being addressed in the context of our present research and we shall contend with it in the forthcoming detailed version of our Resilience framework).

If we are concerned with the perturbation response and resilience properties of the entire system, rather than particular local subunits, then our conceptual overview clearly must cope with dispersal and spatial heterogeneity as they function to provide an internal Restorative Resilience to the system. This Restorative Resilience provides a mechanism which "allows" the overall system to correct or compensate for local errors, mistakes, or perturbations, rather than "letting" such events accumulate or spread and cripple the entire system. Such a mechanism would seem, a priori, a necessary attribute of any persistent system functioning in an uncertain environment.

We have yet to work out the formal niceties of Restorative Resilience to the extent we have done for Boundary Resilience. This is one major project for the coming year (see Jones,1974b). Preliminary analyses of existing studies on the relationships between heterogeneity, dispersal and persistance (cf. work of Huffaker, Paine, Kennedy and Southwood and our own budworm studies) seem to fit with our presnet concept, however. In addition, we are exploring the potential conceptual foundation proposed by MacArthur (1972) in his "island view of competition".

Contingency Resilience

In our discussion of Boundary Resilience, we were concerned with perturbation behavior of the system inside and up to its stability boundaries. Restorative Resilience dealt with local possibilities of getting back into the stable region once perturbed out of it. For Contingency Resilience, we must take this progression one step further and contend with the matter of local extinction.

Consider a several (e.g. "k") species equivalent of the system represented in Figure 1 and assume that a local perturbation has pushed one of the component species (i) not just out of its stability region but, in this particular locality, completely to extinction. Once again, if this is a one-way phenomenon, every species will sooner or later become extinct at all localities. Now, if local extinction of species (i) results in no other substantial changes to the local system, we can view the extinction-recolonization problem as a Restorative Resilience one. For the local system to be restored to its full "k" species complement after the perturbation it is merely necessary to borrow some emigrant species (i) from adjoining local areas where their extinction has not occurred and disperse them into our perturbed site.

But,as we know, the local extinction of species (i) will often result in quite substantial changes in the remaining "i"-less community. Paine's "keystone species" perturbations provide an obvious if extreme example. Obligate predators of (i) will follow it to extinction, competitive exclusion initially blocked through (i's) feeding behavior may occur, habitat alteration may follow, and so on. In cases such as this, the potential emigrant (i's) from adjoining unperturbed areas may well find it impossible to recolonize the perturbed site, at least until and unless simultaneous arrival of the other "lost" species occurs as well. The local extinction may therefore be essentially permanent or of a sufficiently long duration to permit various natural succession activities to "prepare" the perturbed site for eventual successful recolonization. Clearly, the longer this lag or recovery period, the better the chance that all local populations will go extinct through perturbations before any of the sites can be recolonized. This case is presented formally in Figure 2.

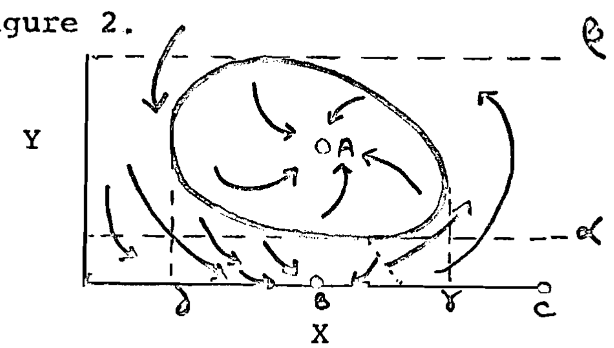

Figure 2

(A) is a standard X-Y bounded equilibrium. But there exists an equilibrium (B) in which X is positive and Y is zero (say X is a grazer at carrying capacity); (C) is a similar point, for a higher equilibrium X. Now assume the X-Y system has been perturbed out of its region (A) and settled to (B) with Y locally extinct. Class II can replenish Y, <u>but only in the strictly vertical dimension</u>. Y's Class II cannot bring about any X dimension change. From the equilibrium (B) it is clear that a Class II $\alpha \leq \Delta Y \leq \beta$ will put the system back in region (A). But from an equilibrium (C), no Class II ΔY can move the system into (A). Only a coordinated Class II ΔX and Class II ΔY of appropriate magnitudes will result in reinstating the system in region (A). If the points (B), (C) are viewed as probability distributions rather than constants the argument fits well with the generation of resilience number values for various configurations of the XY state space. Class III resilience for Y here seems not only conditional on the existence of X but on the particular relations between X, Y shown by the state space.

What we are talking about here, in a formal sense, is the similarity of adjacent stable regions in the multi-species state space. If we remove species (i) from a previously persistent community of (k) species, will the next stable configuration to which this community decays consist of "k"-1 species (i.e. only "i" is lost)? "k"-5 ("i" plus 4 others lost)? "k"-10? In general, the greater the difference in these adjacent stable configurations, the less likely it is that Restorative Resilience adaptations of the system as a whole will be able to reestablish species lost to local extinctions in a reasonably short time. The similarity of adjacent stable configurations in state space is one view of what we have called Contingency Resilience.

Note that although the development above is cast in terms of species removals, the concept holds as well for species introductions such as those being carried out by Group I and dealt with in the "invasions" literature. In both cases, the ultimate point of interest is the similarity of adjacent stable regions in the overall (here "k" + introduced species) state space. We shall develop this point in more detail in our final report.

Contingency Resilience, viewed in the manner described above, is what the sensible fraction of the eternal diversity-stability arguments are about. Both Elton (1966) in his empirical studies and MacArthur (1955) in his theoretical work saw diversity as essentially permissive, e.g. more species could allow more alternative food sources and thus less sensitivity of the community as a whole to changes in, or removal of, one of its members. Whether and to what extent this potential (contingency) resilience inherent in high species diversity is in fact realized is a matter to be determined in each particular instance.

The theoretical literature in the diversity/complexity/stability area is generally quite useless for our purposes, as it tends to deal on the one hand with randomly connected webs of species (which real communities most emphatically are not)and on the other hand with a "stability" criterion which does not distinguish between two and twenty additional species going extinct as the reuult of a perturbation. Since this difference is precisely what is important in terms of resilience, persistence, and overall perturbation response, we are beginning from square one in our efforts to quantify and formalize the Contingency Component of resilience.

Summary

We are by no means convinced that the present Components of Resilience scheme will lead to a satisfactory framework for the analysis of disturbed ecosystem behavior. A good deal more theoretical work must be done, of course, but the meaningful test can only come as we try to relate the Components ideas to the emerging results of the field studies. Only to the extent that the overview aids in our interpretation and interrelation of these results will it have served a useful purpose. We remain convinced, however, of the need for some sort of framework which allows us explicitly to distinguish and relate the various aspects of disturbed ecosystem behavior alluded to above and in the contemporary stability/diversity/ resilience literature. Such a framework has not, in our view, been available and this is sufficient justification for the preliminary work reported here.

D) A Sampler of Examples.

We present below, in no particular order, a varied sample of design and management problems which have served to illuminate the Components ideas.

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* Internal Organization of the Firm

Cyert & March (1963) provide a particularly illuminating example of restorative resilience in their classic Theory of the Firm. They speak at length of the concept of organizational slack; "the difference between total resources and total necessary payments", i.e. uncommitted capital. They continue, "many interesting phenomena within the firm occur because slack is typically not zero .... (Slack) seems to be useful in dealing with the adjustment of firms to gross shifts in the external environment .... When the environment becomes less favorable, organizational slack represents a cushion..... (permitting) firms to survive in the face of adversity ..... (It) absorbs a substantial share of the potential variability in the firm's environment ..... (playing) both a stabilizing and adaptive role" (pp 36 - 38). And they conclude on a note which should be comforting to those nervous, about an incipient teleology in our resilience notions: "This is not to argue that slack is deliberately created for such a stabilizing purpose; in fact, it is not. Slack arises from the bargaining and decision process we have described, without conscious intent on the part of the coalition members to provide stability to the organization. In a sense, the process is reinforced because it "works" and it "works" partly because it generates slack, but we have seen no significant evidence for the conscious rationalization of slack in business firms" (pg. 38).

* The DC-10 Aircraft Disaster

This example is drawn from a recent article in the Wall Street Journal (3 March, 1975; pg.1,9). The DC-10 disasters occurred when the main lower hold cargo door blew open at altitude. The lower hold depressurized very rapidly but probably without immediate disasterous consequences. The crash seems to have occurred because, following decompression of the hold, the passenger cabin floor immediately assumed the function of a pressure bulkhead, separating the pressurized cabin from the depressurized hold. A decision had been made not to reinforce the floor to enable it to withstand such stress, and as a result the floor collapsed pulling several seats from the aircraft and

and leading to decompression of the passenger cabin. This would have been bad enough, but all of the control cables for the aircraft had been laid along the floor and were consequently severed or fouled when the floor buckled. As a result, the plane crashed. The telling part of the WSJ article was that the disaster scenario had been predicted during design phase and confirmed in early experience with the DC-10, but the recommended "safe-failure" solutions were ignored in favour of an ad hoc fail-safe one which did, ultimately, fail.

Early studies showed that if the cargo hold were suddenly depressurized at altitude, and the floor forced to serve as a bulkhead, the latter would buckle. Possible safe-fail solutions were to strengthen the floor to a stage where it could serve as a bulkhead, and/or to vent the floor sufficiently so that the passenger cabin could depressurize relatively harmlessly through the vents into the hold. Some vents were in fact installed in the DC-10 but these were known to be insufficient for coping with rapid and total decompression of the hold at flight altitudes. (It is interesting to note in passing that the recent crash of a C5A ferrying children out of Vietnam also involved a cargo door blow-out and rapid depressurization of the hold. The passenger cabin floor did not collapse however, and news reports made specific mention of the fact that sufficient venting had been built into the floor to allow pressures to be equalized without breaking the floor. This connects back to a reference in the WSJ article in which an engineer urged civil aircraft designers to adopt the military's design system of presumed failure rather than their present one of meeting standards). Instead of adopting either of the available safe-failure solutions, Douglas chose to install a fail-safe device on the cargo door which would guarantee its proper latching, thus "eliminating" the possibility of blow out. The fail-safe device was crude to begin with and, predictably, failed.

The lesson here is clearly one of designing to live with failure by having alternatives - i.e. a traditional Class III or Contingent adaptation. We were worried at first by the obvious parallels here to a Tocs-sort of Class I (see below) where we were changing boundaries by installing vents. The resolution of that ambiguity turned out to be straightforward however, and related to what level of "system" we are considering for the aircraft as a whole. We might manage to think of (say) the venting solution as one which expanded the boundaries - i.e. increased the field of conditions in which the system "aircraft" would survive, by including the condition (state-space description) of hold decompression within those boundaries. But we can also look at the problem as one composed of "cabin integrity","hold integrity", and so on which have simply been uncoupled from each other by the venting. That is, the floor is still incapable of with-standing the forces which would impringe on it as a pressure bulkhead. But the venting provides that it will never be called upon to serve as a pressure bulkhead, at least in the event of hold depressurization. My guess is that we will encounter many potentially confusing situations of this sort, all of which will depend for resolution on a clear and precise definition of just what the "system" is we are considering in our state space.

* Flooding and Hurricane Agnes

This example is due to Fiering (personal communication) as a result of Hurrican Agnes, the Susquahana River overflowed, causing substantial damage. This was of two sorts; the down-stream delta and valley inundations, and the upstream/tributary flash floods. Because of the area involved, the downstream inundations were responsible for the largest dollar damage by far. But the upstream flash floods were responsible for the greatest loss of life. It is clear that there are two different "surprise" situations to adapt to here. In the downstream areas, a graded hierarchy of adaptations can be observed. Levees have been built to reduce possibility of failure. Sandbag and other facilities are available for adaptive, real-time response to rising waters (all Class I). Many of the permanent structures such as roads and power transmission facilities have been "flood-proofed" to a certain degree so that they will be functional when the waters recede.This would seem a Class I adaptation, extending boundaries so thatt your system "transportation x water level" can tolerate high water levels without flipping into a state of permanent "no transportation" But it is also a Class III, where you have disconnected transport and water level so that the performance of the former is essentially independent of failure to control the latter. Again note here the ClassI/Class III confusion, resolved by carefully defining <u>which</u> system you are talking about. There are no <u>a priori</u> reasons for choosing either - i.e. the transport/water, or transport alone - and our guess is that the criteria in any given instance will be ones of convenience and engineering relevance. An additional adaptation is flood insurance and disaster reliefs both clearly Class II adaptations.

Finally, there is the Civil Defence warning and evacuation program which gets people out of the area when a flood is imminent. We are confused here, but think Class II is appropriate. We usually think of II as having several sets of resources, some of which the disaster does not strike. Here we are invoking the "external" character of Class II adaptations to get people where the disaster is not). Note that this last set of evacuation adaptations works only because the onset of the surprise is slow enough to allow the warning and evacuation to be carried out. Also,many of the great valley floods are of such a low "local intensity" that people can survive on rooftops for quite a while to allow the evacuation to catch up to them. This is precisely not the case in upper reaches of river and tributaries where flash floods occur. These cannot be prevented as the milage of levee would be absurbly prohibitive. They cannot be reacted to with sandbagging because of the many areas over which tremendous changes in water height occur almost instantly. The problem of high intensity impact means that anyoody still around where a flash flood occurs is likely to be dead. Because of the speed and intensity of onset, the only viable adaptation seem to be a risk warning when there is a possibility of heavy rains (this, historically, will be ignored), and a Class II program of insurance. A final alt rnative would be to eliminate any settlement in the flash flood-prone areas.

*The Tocs Island Hydro Project

This again, is due to Fiering (personal communication). The Tocs Island proposal concerns dam and reservoir project, which is being justified as a drought protection measure. The drought in question is the one in the early 1960's which seriously affected supplies throughout the north eastern United States. In this case, New York City (NYC) drew water from its upstream impoundments and would not release water to supplement the low flow of the Delaware. The estuary salt wedge began to creep upstream at a slow but distinct pace,approaching the freshwater intakes for the city of Philadelphia.

Actual response was a graded series of measures to force NYC to supplement Delaware flow. They finally agreed to do so but only on an experimental basis to see if a low release would stabilize the salt wedge a "safe" distance below the intakes. In this case the release accomplished its goal.

Proponants of Tocs argue that we need to assure that such a situation will never again arise, since "next time" the wedge might not be stopped so easily.Those opposed counter with a pair of observations. First of all, droughts of the magnitude necessary to create the wedge problem would seem to be extremely rare. Secondly, even in the previous case, a graded series of responses were available which could have salvaged the situation even had it grown worse. The National Guard could have forced NYC to honour their commitment to supplement low flows. New York could have switched its water intake completely to the Hudson using desalinization techniques, releasing all impoundments for wedge control. The Corps of Engineers was prepared to extend the Philadelphia intakes upstream as far as necessary to keep ahead of the wedge. And so on... The point here is not whether Tocs should or should not be built; it might be quite justifiable on, say, recreational grounds. Rather,the important realization is that there are two extreme ways of coping with the drought threat. One is to redesign the entire system so as to guarantee (ahem...) sufficient flow via the Tocs impoundment. The other is to design for a flexible response to the rare drought/low flow threat by providing for (e.g.) the rapid erection of desalination and intake extension capabilities.

This example illustrates a neglected aspect of Class I res lience. In exchanging control over a known problem for flexibility of response we are shifting from an equilibrium to a boundary view. Again we have an instance of dynamic boundaries and an ability to shift them at will, if temporarily. This approach we compare to one in which we are saddled with a massive, permanent, static "solution" to a problem which in fact may never occur. Note however that the flexibility option arises only because of the relatively slow rate at which the wedge moved upstream and our accurate ability to monitor its position. Given a faster potential onset or a more ambiguous monitoring capability, we would have to consider only very fast sorts of flexibilities, or provide for surviving during a period of time when the wedge did in fact override the intakes via Class II adaptations.

? Additional Material

A growing body of "Disaster" studies is available, documenting the ways in which various societies organize to cope with stress (see R. Kates, 1973. Science 182: 981 - 990 and G. White (ed.), The environment as hazard) Velimirovic's study (IIASA WP - 74 -36) of primitive cultures should be consulted for a number of ingenious Class I and Class II resilience examples.

Even a cursory look at the reactions of large business concerns to the recession of the late 1960's is sufficient to illustrate the existence and effect of Class II and Class III adaptations. The almost universal response of the hard hit aerospace industry, for example, has been to diversify its product lines, control practices and markers. In a parallel move, former "aerospace" cities like Seattle have gone to great lengths to diversify the assemblage of businesses which form their tax and employment bases (Classic Class III). Raiffa (personal communication) tells us that each of our Resilience Components has parallels in business management theory.

Finally, no review of applied resilient design would be complete without at least passing reference to the literature of military history and strategy. Whether comparing the Army of the Potomac with that of the Confederated States, or Nelson's navy with that of Bonaparte, the clear superiority of adaptive

(Class I), semi-autonomous (Class II), diversely supplied (Class III) organization is obvious for circumstances where uncertainty and surprise are the order of the day.

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