SUMMARY OF THE CONFERENCE

ACOUSTICAL FATIGUE - FOUNDATIONS AND FUTURE NEEDS

by

Alan Powell
University of California at Los Angeles

INTRODUCTION

The needs for further research pertaining to fundamental notions and to problems faced by the designer are discussed, with emphasis on their position in the acoustical fatigue problem as a whole. Fundamental aspects of particular importance concern unsteady and especially turbulent fluid motion at high speeds and the resultant induced motion of complicated structures under random excitation by the associated complex pressure fields. The ultimate consideration of fatigue or noise dictates the quantities of importance of the structural motion, and this in turn of the fluctuating pressure field of the fluid motion. The principal design needs concern methods of prediction, the establishment of adequate design rules, the general development of testing techniques, and the exploration of new materials and methods of construction; all of these should rest on the best foundations fundamental research can make available. Progress in both fundamental knowledge and in design rests upon a balance of theory and experiment in their proper context. A feature of vital importance in this problem of acoustical fatigue - but by no means restricted to it - is not only the necessity of bringing different fields of fundamental interest into close harmony, but also of endeavoring to establish a more intimate relationship between the various disciplines of widely differing outlook which play a role in the overall scene. Since much of this hinges on foundations which are of an educational nature, some part of the overall research effort devoted to this aspect may not be out of place.

THE BROAD AND VARIED FOUNDATIONS

In following the proceedings of the conference with an eye to my charge of summing it up and of discussing aspects to be emphasized in the future, some of my preconceived ideas received an initial stimulus from Dr. Glass' opening address when he spoke of the importance of interdisciplinary activities. As the conference proceeded, I found that its organizers had laid before us a most complete picture and, although its participants wove a pattern of great complexity, some very strong and really very simple themes emerged with great clarity.

One of the most distinctive features of the acoustic fatigue problem - and one laid out overtly to the participants of this conference - is that its study envelops many fields of endeavor, and not only involves suitable development of each of these but also means bridging them. The beginning of the problem lies in unsteady and usually turbulent fluid motions; the associated pressure fluctuations induce random motions of contiguous and usually complex structures, frequently by radiation; and the randomly fluctuating stresses cause fatigue failures of the material concerned, or other unwanted vibratory and acoustical effects. While an extensive literature exists on each of these aspects, a great number of relevant questions of ostensibly disarming simplicity can, as yet, be responded to only by rather speculative arguments, supported though they may be by lengthy and abstruse discourse. Nevertheless, there is a firm backbone of general understanding of the principles involved, with a continual enrichment as further research fits into the framework. There is an abundance, almost a glut, of fundamental theoretical and experimental research problems to tackle: it is more a question of which and when, and the choice should rest upon an appreciation of the problem as a whole.

But this fundamental research - broad and vital in an interest that it may be - is but one aspect of the problem. It is easy - and often tempting - to treat the problems as of purely scientific interest, instead of in their engineering context. For there can be no doubt that the prediction or prevention of acoustical fatigue is an <u>engineering</u> problem. As a consequence, the usually rather idealistic fundamental research must, in some way, be carried over to the situation faced by the designer, which often presents pretty intractable terrain to the researcher. As so often happens in engineering, the designer has got a long way ahead of the researcher and so cannot be provided with all of the fundamental tools he would like to have. Because of this, the designer has had no alternative but to develop his own techniques of getting at what he needs. All too often this results in ad hoc tests which, while perhaps resolving a specific problem, can cast but little and probably fading light on the scene as a whole; if carefully planned and executed, such tests can - and indeed have - been transformed into experiments of lasting value, providing guidance and strength for the development of fundamental ideas, which in turn consolidate the design techniques, perhaps as a base for further exploration.

The incomplete state of the art -- it is, I maintain, an <u>art</u> based upon a skeleton of scientific principles -- makes it impossible for the designer to always achieve his ambition, faced as he often is with an endless chain of compromises; consequently fatigue failures will arise. Hence, philosophies of inspection, maintenance and modification must also enter the picture. In the past this very important development and operational aspect has consumed a very considerable effort and while it is fortunate that failures of a very serious nature have been remarkably few, the enormous cost which is not only financial -- but witness Rogers' megabuck talk -- takes acoustical fatigue right out of the 'nuisance' category. No longer can considerations having acoustical connotations be relegated to the very end of the design process as has very often been the case in the past, but now they must enter into the preliminary design stages alongside the more traditional and firmly rooted aspects of design.

Thus the problem of acoustical fatigue rests on the one hand upon physical foundations stretching from an unstable gas flow through a series of connected events to the fracture of solids; and on the other hand from abstruse theoretical ideas and abstract models to the sometimes hard and always material aspects of the engineering world.

For convenience I have divided my analysis into several sections under certain headings which are supposed to give a clue about them; but these sections are most certainly not to be regarded as being anything like self-contained. Many aspects have a duality, others a continuity, and the impossibility of drawing hard and fast boundaries is readily apparent. Any attempt to interpret them so would be a direct antithesis of a major theme I wish to develop: that many of our difficulties are aggravated by, or even arise from, artificial barriers separating fields and disciplines.

THE ULTIMATE AIM

Progress in any field of endeavor has a large element of randomness, and the greater the diversity of disciplines involved, the more apparent is the randomness likely to be. For unconsciously each discipline tends to become self-centered, with progress and aim both being cast in the individual framework. Progress of the whole then hangs upon the fingers of knowledge extending from each discipline meeting up with each other: and those fingers have to be developed to form bridges, achieved best when the associated disciplines have reached about the same state of the art. But if there is a wide discrepancy in those states, then it is difficult to derive the full value from the more sophisticated so far as the broad picture is concerned.

This situation must be present to some extent in every field of engineering, but the nicely balanced nature of this conference has resulted in one of the clearest demonstrations to be found, many widely varying interests having the common bond of acoustical fatigue.

What, then, should our ultimate aim be? It should emphasize the essential nature of these interdisciplinary aspects, while not inviting stultification by unduly relegating any individual activity below its proper station. It is, I believe, not unique to acoustic fatigue but pertains more generally to engineering activity as a whole. I contend that it can be stated in essence in a single sentence:

> "The early establishment of adequate design rules expressed in their most simple form and whose nature is understood as fully as possible."

This dependence on many fields, and the differing approaches within each, inevitably raises special problems. These are common to many spheres of modern technology, but are very evident here where there are relatively few really radical concepts. One problem is to determine how the various workers -- theoreticians, experimenters, designers and the like -- can best acquire a perspective so that each may see how his effort fits into the general picture, and to have some means of pursuing certain aspects to the necessary extent.

Several means come to mind: conferences from time to time like this one are immensely valuable in sketching out the general picture, and spasmodic meetings of the engineering societies play their part; summer short courses are well adapted to provide a working knowledge of any field which is sufficiently established; and regular university courses can provide thorough study of those aspects which are adequately consolidated and are of lasting value.

Thus the educator should be added to the team, for it is his prime responsibility to ensure that as many of the available tools as possible get into use. He has a strong influence on the general outlook, and considerable mutual benefits ought to be gained from his frequent dual role of researcher or consultant. The pressure to pack more and more into regular university curricula is great and still growing; and of course, something has to go to make room. On the whole, things qualifying as "fundamentals", seem to command more attention than design and laboratory activities. While this conference may not truly represent the whole picture of engineering activity, I think it is not too far off: but it has reinforced my feeling that the pendulum should not be allowed to swing further in the direction of science at the expense of the more traditional aspects of engineering without justification based upon a most thorough study of the real needs of engineering. Perhaps it may not be unconnected to the rather ironic observation that while technology makes such startling progress, the methods of imparting the foundations to those who are to build on them are on the whole pretty unimaginative, the basic techniques remaining much the same as they were a quarter of a century ago. There is certainly a most urgent need for a better and possibly -- even probably -- radical means of doing this job: I feel sure that there is a way, and that it can be found if sufficient research be done in this direction.

The problem of acoustical fatigue is likely to be with us for a long time; the first step towards combating it on a long-term basis is to ensure that all those associated with it have the maximum awareness of all its aspects and of the knowledge available; and it is part of the central problem of engineering education to do this as efficiently as possible.

In harmony with the general theme I have adopted, each development of the so-called fundamental aspects of our subject should be looked at from the points of view both of furthering knowledge in the specific area and of enriching the picture as a whole. I shall, in general, pursue a path which follows the action, so to speak, commencing with fluid motion and ending on fatigue. Yet the informational needs of each part of the action play a large part in determining what is of vital interest in others: the bridges are crucial.

Thus, in considering the origin of pressure fluctuations, which cause all the trouble, one must first decide what are the characteristics of major importance.

The most important single feature of the pressure fluctuation is its order of magnitude; if it is low enough then there is little point in asking for more detailed information, because no fatigue can occur. If it is higher, then more information is required: how much energy is contained in those frequency bands at which the structure is most easily excited? Next, if there is enough to be concerned about, are the spatial characteristics of the pressure field going to match those of the structure or are they going to more or less cancel out? These last two questions involve resolution of the pressure field into frequency and wavenumber and their order could, from a fundamental point of view, be inverted; but from a practical point of view, the order given is much the best, since it is, in general, so much easier to find the frequency content than that of wavenumber. The complete answers to these questions would be pretty well adequate except for one thing. The whole theory of the random structural response is based upon the ideal of stationary stochastic processes following the normal (Gaussian) distribution; it is well, therefore, to see how well the fluctuating pressures follow this ideal. This really constitutes a measure of confidence in applying the available method of analysis, since if this ideal were far from met, there is not much that one could do about it at the present time.

The pressure fluctuations are associated with unsteady fluid motion, and in the unimportant cases of jets and boundary layers, it is a fully established turbulent motion so that quite a bit of information can be derived from consideration of similarity. The same is true of wakes, although the base pressure of blunt bodies may be random in a rather different sense. The foot of an oscillating shockwave may cause considerable pressure fluctuations on an adjacent body; in some cases the oscillation may be periodic or almost so, as in some choked jets or unstable duct flow, while interaction with turbulence will obviously have results as random as the turbulence itself.

The nature of the pressure fluctuation ranges between two extremes. One is when the flow itself sweeps over the surface - as in a boundary layer- and the other when the surface is far away from the flow itself and the pressure is transmitted to it by radiation, as in the far field of a jet. However, the latter situation is less common than the intermediate case, when the pressures are of the so-called near field, a mixture of pressures directly associated with the nearest eddies sweeping past and of the pressures radiated by the flow as a whole.

Common to the extremes just mentioned is the idea that to a first approximation the pressure field is a convected one, that is, the contours of equal pressure retain the same shape as they are swept along, at the velocity of the turbulent flow, an outlook adopted by Ribner in his boundary layer problem and which is proving of help in the very near field of a jet as Clarkson had indicated. In the far field the convection velocity is obviously to be associated with the velocity of sound. In the former case and in the awkward intermediate case this concept just cannot be altogether true, and so it becomes of importance to find how nearly the case it is, and to explore the situations when that assumption would lead to results of acceptable accuracy and to know when further modifications are necessary and what these should be.

Since the existing extensive knowledge of turbulent flow has been established with other objectives in view, it is clear that the information which is required now must be mainly derived from carefully designed experiments. The necessary experiments, involving spatial correlations in narrow frequency bands with variable time delays, are both difficult and lengthy to perform. With this I am sure Willmarth, Harrison and Laufer, working on boundary layers, and Clarkson on turbulent jets, would heartily concur. However, it is because of these very facts, together with the great hazards of extrapolation, that it is extremely important that such experiments be very thoroughly and fully executed and reported: all the available parameters should be explored to the greatest limits feasible. In view of the enormous effort involved, it would be prudent for such projects to be preceded by most careful analyses of what are the characteristics to be sought and the optimum means of expressing them. If this is done, the utilization of various concepts can be fully reaped without the fear of the late discovery of damaging lacunae. For example, it would be risky to generally assume that the convection speed is the same for all frequencies and wavenumbers as it is in the far field; in fact, perhaps it would be wise to think of each component having a band of convection velocities, or alternatively of each convection velocity being associated with a certain pressure field.

While the idea of a convected but "frozen" pressure field may be an extremely useful step so far as any induced structural motion is concerned, it doesn't help too much from the point of view of determining the sound radiation power from any element of the flow which is convected at a subsonic speed; for such radiation depends upon temporal fluctuations, that is, upon the amount of departure from that "frozen" state. Nevertheless, the awareness of such convection greatly simplifies the position, since means can then be sought for finding the temporal variations, per se, with the effects of convected spatial variations thrust into the background. This is a most promising development from Southampton and one which I hope will be exploited to the full.

There is, of course, much interest in the pressure fluctuations in the neighborhood of rockets, and while many techniques pertaining to the acoustic field can be carried over from those developed for air jets and jet-engine effluxes, measurements in the rocket efflux itself promise to be particularly difficult and dependent upon novel techniques. It would be very nice tho, if theoretical developments could lead the way so as to indicate as clearly as possible what is to be looked for. Obviously, near-field studies may give some good clues, apart from their prime purpose of providing design data.

So far as the induced motion is concerned, it may be said that the essentials are well on the way to being understood, though much remains to be done, especially with regard to adapting the existing theories for design purposes. The most simple situation where a single mode of vibration dominates, as in Miles' analysis and is sometimes the case for certain simple structures excited by jet noise, has been tackled with considerable success and carried right into the design activity with the help of carefully designed experiments. Belcher and his colleagues have described such a development. Of help here is the idea of the exciting pressure fields having wavelengths that fall into "long" or "short" categories, in rough analogy to frequencies being below or above resonance.

Once again we find that in the other extreme the situation again assumes an air of apparent simplicity, at least in analytical principle, when that structure is representable by a thin plate. Then very many modes are excited, so many that the structure may be considered to be of infinite extent. This outlook, studied by Corcos and Leipmann, may be a fair picture for the boundary layer noise problem when the panels are large; and it reduces to Ribner's very simple form when the pressure patterns are "frozen" and convected. In fact, it is now known under what conditions this method may be used when the panels are not so very large in comparison to the spatial qualities of the pressure field. In the intermediate case, when the pertinent dimensions of the pressure field are not small compared to the structural size and many modes are present, the situation is more complex; it is beyond present methods when the structure is of a less elementary nature. Even so, progress is being made in that a theory of fairly general applicability is available when the motion is linear and of simple damping characteristics, but for such a general situation a great deal must be known about the pressure field and about the details of the possible motions of the structure before it can be used for design purposes. For the moment we must often be content with order of magnitude estimates: these may at least tell us whether the situation is one to worry about or not.

In short, if the structure is an extremely simple one, and if the pressure field can be represented in a very simple way, we can find what we want and the way for the designer is clear. But often these simple situations do not prevail: existing methods are then best used for sketching out the factors of importance to give the designer pointers in applying his own techniques.

Much remains to be done in laying bare the vibrational characteristics of complex structures. For the simple panel, the effective mass, damping and stiffness can be found experimentally without too much difficulty; even then as Lazan and Mead indicate it is only recently the mechanism of the damping is becoming clear and it is perhaps not heresy to suggest that some of the experiments performed ostensibly to test theories of simple random excitation have in fact been more of the nature of examinations of certain qualities of the apparatus. But when the structure is a complexity of thin panels and not-so-stiff stringers and flappy frames, perhaps with a frustrating lack of regularity and overall symmetry and a few inconsiderate but not inconsiderable holes, the situation is one absolutely defying present methods of analysis; they remain ill equipped despite the extremely powerful stimulus of the modern computer, which Plunkett has been excercising in a way beyond our dreams of not long ago. But even "simple" experiments on complex aircraft structures such as finding the damping of some fairly high mode or other, always seem to run headlong into difficulty. But it makes one wonder whether some of the basic concepts are in need of revision, or need special adaption to the circumstances.

The random character of the excitation poses additional problems. If the randomness can be assumed with acceptable tolerance to be normal, in the sense discussed by Rice for example, then we know how to handle the situation -- provided that the response of the structure is linear. But difficulties immediately arise if the excitation is markedly different from normal, or if the response is nonlinear: and the likelihood of both of these eventualities increases with the intensity of the excitation and that is precisely when the need for a reliable means of analysis is most acute. The absence of an invited paper on this sticky problem probably reflects pretty well the state of affairs: present, but largely an unknown and therefore unwelcome customer.

The fatigue characteristics of materials have traditionally been found for sinusoidal stress variations, imposed upon some mean value (which may of course be zero); this is not only because that was and still is the easiest thing to do, but because in most situations that was what was wanted or was quite adequate. The cumulative damage concept is simply a means of carrying over results from one situation and applying them in another; the basis of the most simple form is somewhat naïve, taking no particular account of the mechanism of fatigue. All the same, this "Miner's rule" is admirably suited to the situation in question, being the most simple one-parameter rule suggested so far, and it leads to a result of useful accuracy. A modification of this, introducing a second parameter whose value can be fixed by experiment, is probably the most fancy technique that could be reasonably handled. One such modification that has been suggested by Shanley is open to some criticism, for as Freudenthal has pointed out, it is based upon certain concepts of fatigue that are not universally valid. Nevertheless, it would seem to provide a good starting point for a semi-empirical, two-parameter method if greater accuracy were found to be desirable. These methods are likely to be quite adequate for our needs until the random fatigue testing of materials has been carried far enough. They may have to suffice for some time as Head's start does not seem to have been followed with the greatest of vigour. But it is to be hoped that such testing will provide a means of turning the semi-empirical cumulative damage rules into more fundamental channels and so remove the necessity of extremely large fatigue testing programs. Of course, any new information that is found may throw some useful light on the conundrum of the mechanism of fatigue and that would be all to the good. But it must be admitted that, so far as the overall acoustical fatigue picture is concerned, the lack of a real understanding of the details of fatigue is a good deal less serious than the fragmentary state of knowledge of several other aspects.

Two other consequences of random excitation are the noise radiated by the structure and the effects of the general excitation of the structure on equipment.

So far as noise is concerned, it is most important to notice that this depends upon movement of the structure, while fatigue is more to be associated with displacement. Hence, a cure for one does not necessarily take care of the other; but there is clearly a need for research so that both these aspects may be properly considered in the early stages of the design of the primary structure.

Equipment may be susceptible to both noise and transmitted vibration; consideration of this lies in the sphere of reliability engineering, which is a natural embellishment of our general subject. Fatigue of parts is one aspect, the effect of induced vibration causing unwanted relative movement of component parts is another. Maybe there are some ideas that could be usefully exchanged with the reliability engineers - for the empirical methods of other but associated fields sometimes can be most useful.

From the point of view of establishing a sound theory of good utility in complex situations for the designer, the present approach suffers from the excessive attention that must perforce be paid to detail. It is based upon a grand embellishment of theories so as to incorporate the randomness and structural complexity. There is a definite need for an altogether new theoretical outlook, such that the essentially random character of the whole process can be seized upon with great advantage, instead of it being a burden. Some preliminary sketches indicate that such a thing is probably feasible and I am sure Getline would give a warm welcome to any such theory. After all, the excitation is random in time and space, many structures have an irregularity embarrassing from the conventional point of view, there is scatter in the constructional standards and material, and the material itself has an inherent uncertainty of fatigue life, while the final answer to any overall calculation must be of the nature of an expectation, and this should most certainly be accompanied by confidence limits.

DESIGN ASPECTS

The designer takes a central role, and while it is his activity that has developed in such a way as to produce the whole problem of acoustical fatigue for us, it is with some poetic justice that it is he who is charged with the task of overcoming it as economically as possible. He has the challenging task of deriving what value he can from sometimes rather abstruse theoretical and experimental research, almost always too idealized as it stands and over which he frequently has little or no control; of designing tests to guide him where no other means is available, a situation almost normal; and to blend these together so that he can produce a design which is adequate but not unduly conservative.

His activity falls more or less into two main categories, namely preliminary, or overall, design and detail design. While the former has some element of glamour, it would be a sad mistake to underestimate the importance of the latter; they are complementary and interdependent to a high degree. Frequently residing in the no-man's-lands between them is the specification writer, concerned with contiguously located equipment. He has the delicate task of laying down criteria bounded on the one hand by extrapolations of environment, so dependent upon the actions of the designers just mentioned, and on the other by progress in the equipment design.

The developments of the last few years have seen the acoustical problems enter considerations of general layout and design as never before; this raises severe problems of extrapolation of existing knowledge and techniques. If anybody be rash enough to think that our basic understanding of these aero-acoustic problems is adequate, he would soon come down to earth if faced with some of the straightforward and pointed questions such designers have the habit of posing. Much progress in reducing the debilitating effects of jet effluxes, of jet engines more than of rockets, by the development of fancy nozzles has been achieved by step-by-step test programs. It is a challenge to find soundly based arguments which can predict the effect of such devices: elementary thoughts at present hinge mainly on Corcos' idea of the ameliorating effects of induced flow, or the idea of reduction of the radial diffusion of axial momentum; the fundamentals are as yet still far from clear. These devices seem to have reached a plateau of success, and further benefits are most likely to accrue from the combination of these features with others of a more far-reaching nature in the overall design, and so must lie more and more in the province of the preliminary designer.

Again, the boundary layer noise problem should be recognized in the preliminary design stages of, say, the passenger compartments of future supersonic airliners; to the maximum extent possible the anti-noise measures should contribute to the basic structural integrity, even apart from any possible fatigue considerations. The same philosophy is likely to find its proper place in the design of many of the other new vehicles.

If the preliminary designer has done his job well, the detail designer has enough scope to be able to tackle the threatened areas in a fundamentally sound manner. Of course, the early crop of fatigue failures arose because the problem had not been anticipated, and the structural parts concerned had been designed to be adequate for the conventional more or less steady loads. It is not surprising, in retrospect anyway, that the shaking about of these structures would result in numerous failures, nearly all of these in parts that otherwise would have been quite satisfactory, many in minor parts that were hardly designed, their function being to simply hold things in place against purely nominal loads. Now the designer has to recognize the deformations that structure will undergo, even be it in rather general terms, so that he can bring in his basic principles - fundamentals? - of design technique to good effect.

Even so, he must rely to a great extent upon testing. Unless fundamental research comes quickly to the rescue, the controversy on the efficacy of artificial damping methods must be resolved in this way: the question is an important one and the designer wants to know the answer soon. Even if the dynamics of his subject were adequately known, a rare fortune indeed, the fatigue failure has little consideration for the limits of human knowledge, and frequently turns up in awkward places where stress measurement is impossible, and where the state of the material is not at all a well established thing. Success for the designer, as well as for the researcher, clearly hangs upon a careful balance of theoretical work and experiment, cast in their respective frames of reference.

One of the snags of conducting long-life fatigue tests that is particularly trying to the designer is the obvious fact that they take so long to accomplish; in the acoustical fatigue problem this is further aggravated by the fact that the frequencies involved are already high and there is no scope for any large raising of them. As a consequence, the designer has been forced to adopt other means of getting his failures to appear in a reasonable length of time: increase the intensity of the excitation. This type of accelerated testing calls for skill in the design of the test and in the interpretation of the results; and so far, the designer's faith in such methods has been borne out, even when some non-linearity cannot be avoided, as in van Dyke's case. Certainly, great care has to be taken when non-linearities appear, as is liable to happen in design situations of high intensities with consequent enhancement in such accelerated tests; not only are the details as yet defying a really sound analysis, but in several instances it is hard to say whether the appearance of non-linear effects is helpful or damaging.

It is most important to recognize that the occurrence of fatigue in the situations of interest to this conference is a most sensitive indicator; it is, in fact, of embarrassing sensitivity. For when the fatigue life is long, as it must be for aircraft, a change of stress level by ten per cent, which is small compared to the tolerances one must expect to encounter, may easily alter the fatigue life by a factor of ten or even of a hundred. The obvious cause of this is the flatness of the fatigue curve, as may be easily seen from one of Forney's plots, which, incidentally, deals with test laboratory conditions; the situation is much more amenable for low life.

This means that it would be wise to adopt somewhat different philosophies for long and short lives. For the long life, the aim should be to <u>prevent</u> fatigue occurring altogether; for the very short life, it would be more reasonable to try and <u>predict</u> the life. In practice, the structural engineer's traditional approach of allowing a safety factor in the stress levels is one that seems best fitted for the situation: his basic need is for a random fatigue curve of tolerable accuracy, defined in association with the problem in hand. It is just an unfortunate fact of life that it is not possible to conduct any fatigue test so as to find the stress level to be associated with a predetermined life.

The siren obviously provides a relatively inexpensive means of finding the weak spots of structural components and, if properly used, is a very valuable tool. The papers given by Hubbard and by Forney give some idea of the tremendous scope of siren techniques; they are at their best for ranking tests on fairly simple elements when the rather inflexible composition of the pressure field can be used to advantage. If only proper means could be devised for supporting the specimen as they would be in practice, much data could be obtained that could be applied directly to the design proper. Otherwise, just as Forney indicated, interpretation in terms of the ultimate application can be difficult.

It is to be anticipated that the future will see the development of many new methods of construction and of materials; the heating problems of hypersonic vehicles alone assure that. The early investigation of vibrational properties - especially damping - and of fatigue characteristics is a job for which the siren is well adapted, provided that the recognition of the special nature of its pressure field is not felt to render a disqualification, as well it might for the class of situations typified by the boundary layer problem. Perhaps some other simulator could be devised for such cases.

A great deal of developmental testing by siren or otherwise has already been accomplished, and even though interpretation may not be exactly straightforward in many cases, it does, nevertheless, provide the elements of a valuable accumulation of knowledge. In contrast to some other disciplines, there is a relative paucity of freely available and fully detailed documentation; perhaps sometimes its dissemination is cramped somewhat by the atmosphere of competition coupled with the uncertainties of the future.

There must be a great deal of information - and guidance for further meditation - to be gleaned from a careful and thorough analysis of <u>all</u> the failures that have occurred in service, or other fully representative situations. To be of real use, their documentation should avoid superficiality, but provide all the information that might be relevant. In particular, the prescriptions for cure and their efficacy would add greatly to the advancement of the art.

SUMMING UP

There is a need for more research in almost every aspect of the problem and the most prominent of these have been briefly touched upon. To the designer the most important research aspects concern the prospects of extrapolation into the future to guide his general deliberations on what environments to expect, how to get the best layout and to select the optimum structural type and material. The fundamental research is valuable in its own right and most of it will, in one way or another, help the designer. It seems to me that this conference has rather clearly emphasized the need for a different type of research, that might be called 'design research'. There is no implication of a lack of fundamental principles, but rather the need arises because in design a surfeit of them prevails and it is the act of seizing the dominant ones, and knowing how far the ideal can be pushed, which make design the art that it is. There is certainly an urgent need for the strengthening of the bridge between these vital areas, nor is it limited to the subject of our conference. In a rather analogous fashion, the subject areas themselves tend to have assumed an air of independence, which should give way to a deeper understanding as their intangible boundaries are recognized and become more evanescent; an obvious example is how acoustics and aerodynamics are becoming one again after an almost complete separation since Sir Horace Lamb's time. In this respect there is an enhancement of the value of simple concepts which portray the dominant features of a complex action and of any overall guiding philosophy. I have been bold enough to suggest one that may satisfy the needs, namely the early establishment of simple design rules resting upon sound fundamental foundations. But perhaps it is possible to mitigate many of the problems in the future by tackling them in a rather direct manner, taking full advantage of the educational foundations.

The conference has been a great service in bringing together so many of those active in one phase or another of this acoustic fatigue problem, there being plenty of elucidation of successes and difficulties to the rest of us, and providing a perspective of unusual depth and richness. If others have found the conference as rewarding as I have, then those who have worked so hard to bring it to fruition can rightly claim that it was a good job well done. Thank you.

WADC- University of Minnesota Conference on
Acoustical Fatigue

List of Attendees

Name	Affiliation
Ballentine, J. R.	Convair - Fort Worth
Barber, Walter J., Jr.	Chance Vought Aircraft
Baskin, J.	North American Aviation-Col.
Bates, George P.	NASA
Beeuwkes, R., Jr.	Watertown Arsenal
Belcher, P. M.	North American Aviation - L.A.
Berman, J. H.	Republic Aviation Corp.
Bingman, R. N.	WADC
Bishop, Dwight E.	Convair - San Diego
Blake, Bernard S.	Army Ballistic Missile Agency
Bleich, H.	Columbia University
Brodrick, Ronald F.	Lessells and Associates, Inc.
Buntin, W. D.	Convair - Fort Worth
Burgess, John C.	Stanford Research Institute
Callahan, J. A.	McDonnell Aircraft Corp.
Campbell, Bruce W.	Lord Manufacturing Co.
Chernoff, A.	Republic Aviation Corp.
Chang, C. C.	University of Minnesota
Clarkson, B. L.	Univ. of Southampton-England
Coale, C. W.	Lockheed Missile and Space Div.
Cornillon, Jacques	Sud Aviation - France
Corten, H. T.	University of Illinois
Craig, L. E.	Boeing Transport Division
Crandall, Stephen	Massachusetts Inst. of Tech.
Dahlquist, C. A.	Minnesota Mining and Mfg.
Doelling, Norman	Bolt Beranek and Newman, Inc.
Dunn, Wm. G.	North American Aviation
Dyer, Ira	Bolt Beranek and Newman, Inc.
Ezell, Wm. A.	General Dynamics Corporation
Farrow, James H.	Army Ballistic Missile Agency
Felgar, Robert P.	General Electric Company
Forney, D. M., Jr.	WADC
Franken, Peter A.	Bolt Beranek and Newman, Inc.
Freudenthal, A. M.	Columbia University
Fricke, Werner	Bell Aircraft
Fuller, James R.	Boeing Transport Division
Garrick, I. E.	NASA
Getline, Gordon L.	Convair - San Diego
Glass, Edward M.	WADC

List of Attendees - continued

Name	Affiliation
Goodman, L. E.	University of Minnesota
Gould, L. H.	Republic Aviation Corp.
Greenwood, W. B.	North American Aviation-L.A.
Hankey, Robert K.	WADC
Hardrath, Herbert F.	NASA
Harrison, Mark	David Taylor Model Basin
Hayes, James E.	Oklahoma City Air Materiel Area
Hieken, Milton H.	McDonnell Aircraft Corp.
Hubbard, Harvey H.	NASA
Junger, Miquel C.	Cambridge Acoustical Associates
Kamperman, George W.	Bolt Beranek and Newman, Inc.
Karnesky, A. L.	Aerojet General Corporation
Kelsey, Alton S.	Grumman Aircraft Corporation
Kerwin, Edward M.	Bolt Beranek and Newman, Inc.
Kite, Mark H.	Convair - Fort Worth
Klumpp, J. H.	Lockheed Space and Missile Div.
Kordes, Eldon E.	NASA
Lambert, Robert F.	University of Minnesota
Lassiter, L. W.	Lockheed Aircraft Corporation
Lazan, B. J.	University of Minnesota
Levy, S. L.	Midwest Research Institute
Luhrs, Henry N.	Space Technology Laboratories
McClymonds, J. C.	Douglas Aircraft Co., Inc.
McDaniel, O.	Grumman Aircraft Corporation
Magrath, H. A.	WADC
Mayerjak, R. J.	WADC
Mead, D. M.	Univ. of Southampton - England
Mentel, T. J.	University of Minnesota
Morrow, Charles T.	Space Technology Laboratories
Nash, William A.	University of Florida
Neilson, J. A.	Fairchild Aircraft
Neubert, V. H.	General Dynamics Corporation
Noiseux, Denis	Bolt Beranek and Newman, Inc.
Oberst, Hermann	Farbwerke Hoechst AG.-W.Germany
Oestreicher, H. L.	WADC
Overton, Jerry B.	Pacific Missile Range
Parry, David G.	United Aircraft Corporation
Plunkett, Robert	General Electric Company
Poppleton, E. D.	University of Toronto
Powell, Alan	University of California
Putnam, Abbot	Battelle Memorial Institute
Rebman, Jack	Lockheed Aircraft Corporation
Regier, Arthur A.	NASA

List of Attendees - continued

Names	Affiliation
Richards, E. J.	Univ. of Southampton- England
Rogers, O. R.	WADC
Ruzicka, Jerome H.	Barry Controls
Schell, Edward H.	WADC
Schjelderup, H. C.	National Engineering Science Co.
Schloss, Fred	David Taylor Model Basin
Schultz, T. J.	Douglas Aircraft Company, Inc.
Sevy, Robert W.	WADC
Smith, Preston W.	Bolt Beranek and Newman, Inc.
Spicer, Herbert C.	Federal Aviation Agency
Stapp, J. P. Colonel	WADC
Stone, Paul R.	Bureau of Aeronautics
Stulen, F. B.	Curtiss Wright Propeller Div.
Sutherland, Louis C.	Boeing Airplane Company
Thomas, David R.	The Martin Company
Trapp, W. J.	WADC
Trotter, William D.	Boeing Airplane Company
Trubert, Marc	University of Florida
Tyler, John M.	Pratt and Whitney Aircraft
Ungar, Eric E.	Bolt Beranek and Newman, Inc.
Vernier, Bruce R.	Northrup Corporation
Vigness, Irwin	U.S. Naval Research Laboratory
Von Gierke, H.	WADC
Wagner, J.	Sud Aviation - France
Weibull, Waloddi	Bochampöllan - Sweden
Wignot, Jackson E.	Lockheed Aircraft Corporation
Williams, T. R. G.	Univ. of Southampton- England
Wilmarth, W. W.	University of Michigan
Yen, C. S.	Douglas Aircraft Company, Inc.
Zeijdel, Edmond F. E.	Midwest Research Institute