Prof. Paul Höller (University of Saarbrücken): Good morning, Gentlemen. I will try to use these ten minutes to make some more general comments on what we are doing in our country and mention the impressions that I received here.

The first point we should ask is why do we have reasonable support for NDE research in any country these days. I think it is worthwhile to make the point that the reason for that is that NDE already has a number of very important applications in many branches of industry. The other point is that we must all try to promote interactions with the people who represent the industrial applications of NDE. I got the impression during the meeting that this interaction between those who are applying NDE and those who are doing research is no stronger than in our country. Another point is that we regard NDE as a technology. It is not yet a science. We need science to improve NDE, but NDE itself is a technology to be applied in industry. That means the goals and the objectives of research primarily have to be determined by those who should later on apply what is the result of research. The main point the scientists have to contribute is to show and demonstrate the potential of scientific methods to contribute to solutions to very important problems.

In our country, the most important problem which people in applied NDE are discussing is the reliability. They fear they are not well enough informed about the capabilities of the present NDE art. They want to know what the capabilities are with regard to real materials defects. And we all, I suppose, as well as you in your country and we in ours during the last years, have been really shocked several times. I would like to ask the question as to whether or not we react properly to those shocks. That means, those who are developing new methods need to know of the true, very difficult problems which occur in practical work. This aspect means that the testing systems and the testing procedures must be appropriate to the environmental conditions encountered in practice.

Another point, which is not shocking but striking, is the experience that in different countries there are exactly the same problems. Physics and the techniques to approach these problems are the same. Nevertheless, the solutions which the experts reached in the past and the research and development programs they have at present are very different. In the sphere of my experience, the most pronounced case is that of pressure vessels. If you look at the recommendations and specifications, they are different in this country and in Europe. The in-service inspection systems used and the philosophy which is behind them is different here than in our country and other European countries. The projects going on to develop the future systems for that application are again different. There is an international exchange of results and ideas in the form of round robins, however. I think that is a very good thing to make the exchange of knowledge and results more substantial. I don't know whether similar things are going on in the aircraft industry.

With regard to basic research, I admire the efforts you are making here. I must say very frankly that we have nothing similar, not with regard to the developing theoretical basis for future NDE systems. On the other hand, perhaps we are doing more work in getting the basis for theoretical engineering. We are calculating and designing systems of probes for particular applications and we are doing much research to improve that. But with regard to the scattering theory and diffraction theory, much less is going on in our country than I have heard this time and upon other occasions here.

Another very particular point not understandable for me is the fact that all engineers and mainly American engineers say the most important area of any component is the surface. Because by stress distribution the surface cracks are very much more dangerous than the interior, and also the surface is rough. There is much more attack for instance by corrosion. There is a probability of starting
cracks at the surface for many reasons. It is much, much greater than the probability of initiating cracks inside the wall. But if you look into the literature and the research programs, I would say the ratio of money and time and brains spent for developing surface methods and quantified methods for surface inspection to the amount spent for interior inspection, it is exactly vice versa. The efforts expended don't seem according to the demands. Maybe this is not so important for thin section components, but for thicker components I think it is a very important fact.

The NDE effort in Germany is organized in three parts. The first one is the actual NDE research, both basic and applied. The second part is devoted to development and the third one to the application. In some cases we may be able to go immediately from research into the application. This is certainly not the normal path which would be to go from research through development to the application. As I understand the present ARPA project, it takes the normal path and is devoted to research and development. We in Germany concentrate more on the overlapping area between development and application. There is some research going on but it is more of an applied nature than in the U.S.

G. Quentin (University of Paris): The NDE effort in France is not as well supported as in the United States and Germany. Nevertheless, there is a lot of work being done in France and I shall give a short summary of this work.

One of the groups in France working in NDE is the Atomic Energy Commission. Much of their work is devoted to usage of focused transducers. They have implemented focused transducers for detecting badly oriented defects in nuclear reactors.

Another group of people is trying to produce artificial defects by diffusion bonding of steel (similar to the work going on at Rockwell). In steel they have produced some one hundred of different kinds of defects. This group uses these diffusion bonded specimens for the characterization of defect by multidirectional analysis under ultrasonic spectroscopy. They also work on the Barkhausen effect, which yields very good results about the state of the material just close to the surface. They have made studies on the decarburization of steel and also the influence of superficial stresses on Barkhausen noise.

In my laboratory the main objective is to determine the scattering of ultrasonic waves by rough surfaces. We determine the signature of the surface with randomly rough surfaces and natural non-random rough surfaces (some results of this work have been presented this morning).

The characterization of surface defects by Raleigh waves is an example of Franco-American collaboration. The work has been initiated with the assistance of Bernie Tittmann in our lab. Dr. Tittmann will present a paper on this subject. We have also used the Schlieren method to characterize the ultrasonic field generated by very short pulses which is a Franco-English collaboration with the City University of London. We have also studied detection of edge waves.

I am sure I have not given you a complete list of all the laboratories working in France. Let me just add that there is also some interesting work going on at one of the medical centers. They have obtained some good results with pseudo random binary coded, fast modulated ultrasonic, high resolution echograms.

Peter Doyle (Aeronautical Research Lab): First, I would like to say how much I have enjoyed coming to this conference. It is obviously something we lack in Australia, having a large number of people interested in this field. There is only a relatively small effort, not surprisingly, in NDE in Australia and for that reason I will probably speak rather more briefly than the other speakers. But some work I would like to mention: first of all, in acoustic emission, there is work going on at the Atomic Energy Commission and also at Aeronautical Research Labs (ARL) relating the acoustic emission signals to the microstructural properties of materials, particularly in zirconium. Also in acoustic emission there is some work beginning at ARL on the early detection of corrosion, and particularly paying attention to separating corrosion signals from noise coming from other sources. Actually it is a very important problem in aircraft in Australia because a lot of them are stationed in the tropics in the north and corrosion, and particularly stress corrosion cracking, is very important. Another aspect of acoustic emission work is monitoring the growth of actual fatigue cracks in trainer aircraft, jet aircraft, which are in service.

Next, in ultrasonics, there is some work concerned with the development of computer controlled testing of rails. On the theoretical side of ultrasonics, there is some work commencing at ARL which will deal with the geometrical theory of diffraction, and hopefully this will complement, rather than repeat, the work that is going on within the Rockwell program.

Next, there is some work on eddy currents which is concerned with coil design. This work is done at the University of New South Wales for the testing of wire rope. Again, at ARL they are concerned particularly with the effects of surface coatings on the reliability of the magnetic rubber replica technique. ARL is using this technique to monitor fatigue crack growth in aircraft which are in service.

Stewart McBride (Royal Military College of Canada): Well, again as in Australia, the problems that we face in Canada are a little bit different from the United States in that the country really doesn't have a substantial aircraft industry and so we are relying very heavily on having the vehicles and
the components, etc., supplied from outside. As a result of this, probably there is in the statistical sense, very little work being done. We just don't have any massive fleets of aircraft and therefore we cannot develop any statistics. Rather we would be hoping to use American statistics to do some evaluation on what is an extremely small fleet. With this in mind, it is most unlikely that there will be a massive effort going on in defect characterization as has been done here. However, at Drawn Military College in a way we are having a good look at the problem of transferability of the information from the laboratory to the field, and this includes aspects that haven't been discussed here at the conference. For instance, one of the aspects of the program that I am involved in is a post-graduate program in essentially nondestructive evaluation where we take in military officers subjecting them to a Master's Degree program which involves quantitative ultrasounds and acoustic emission, studies in holography, a modest background in microprocessing, stress waves in solids and so on. We are hoping that we will essentially be putting these people into positions as they apply to field units. We are hoping that these officers will be able to make some contribution to this transition from NDT in the laboratory to field applications. We take into consideration that in Canada we are really talking about the evaluation of American equipment rather than trying to really develop new things on our own.

From the technical point of view, the tendency in Canada is to say "Keep up with the state-of-the-art in NDE and the transition to wherever it will be in a couple of years in NDE." But at the same time, the trick has to be to be able to detect the defects in service. Furthermore, the more complex the methods become, the farther and farther we are almost bound to go away from a hundred percent inspection of the vehicle. That is why we are going toward continuous in-service monitoring and the particular technique we are using at the present time—and we seem to be using it successfully, at least in the cases we are working on—is acoustic emission. I would envisage that there will be a shift towards a fairly serious look at in-service engine health monitoring.

Now, in the acoustic emission effort, which is the one that I am most actively involved in, it has taken three directions. One is, by our standards, a fairly massive attempt in the laboratory. We've taken essentially the material that we have the biggest problems with, 7075 aluminum, spend a lot of time on fatigue crack propagation in this material, and try to essentially use acoustic emission in a way that it was really a criticality detector. In other words, not really thinking about actual flaw size, but trying to concentrate on the size of the next jump that the crack is going to make. With that in mind, the work has been directed toward trying to relate the acoustic emission signal to the amplitude of the acoustic emission signal, in particular to the new area of the fracture surface that was generated by the most recent crack advance. What this means is that we are really talking about looking at unstable crack propagation in vehicles, trying to wed together the continuously periodic maintenance procedure with the possibility that something unusual happens during the life of the component. So, obviously, laboratory work is much cheaper than doing it on the real thing. Having done that, we felt that there had to be an effort going simultaneously with this one where we would be looking at the problem of transferring the acoustic emission data from the laboratory into the field. Therefore, we are fairly successful now in that we can take the acoustic emission data and transfer it from one geometry to another.

The third effort with respect to the acoustic emissions program is to try to start putting together a library of in-flight noises in aircraft. In other words, rather than have the services faced with another feasibility study every time they ask us if we can tackle a problem, we are anticipating this request and putting together a book of in-flight noises in the acoustic emission range.

Finally, we have tackled the logistical problem, which is always the most difficult one, of course: the logistical problem of having data collected in-flight and transferred to a data analysis center which we have at the military college.

So far we have been successful in this effort. I understand that there have been some failures in use of acoustic emission in-flight. We, in Canada, have not run into any problems. We have got a good handle on the size of the acoustic emission signals, how they are related to fairly gross features on the fracture surface. We have demonstrated this and successfully done feasibility studies in one aircraft. A crack and the crack growth has been detected in flight. The data are in good agreement with expectations on newly cracked fracture surfaces and the acoustic emission data. Another airplane that I had a look at is the CF104 and, indeed, there is no reason to suspect that acoustic emission monitoring cannot take place on wing-fitting type components.

David Dean (P.E.R.M.E.): I propose to limit my contribution today to ultrasonic techniques. Looking at the U.S. effort here, I was amazed at the quantity and quality of it and it was very difficult, in fact, for me to find any area where we are doing something different. But, nevertheless, I hope today to try to concentrate on these areas where perhaps there is some difference between what we in England are doing and what is happening in the U.S.

We, also, have a number of people who are using mini and microcomputers. These are used for acquisition and processing of data, control of scanners, plotters, etc. In fact, I can list the NDT Center at Harwell, the Royal Aircraft Establishment at Farnborough, and my own group at Perme Westcote who are all building and using equipment based on these devices. And, of course, with modern high speed digitizers it is possible to store complete information about wave forms up to tens of megahertz these days.
To turn to imaging systems, here we began work ourselves on trying to image defects in rocket motors and rocket motor propellants. This is an area which I don't think has been attacked very much, if at all, in the U.S. We began using techniques which are being pursued still by Allbridge at Harwell for the examination of metals, and I think his work is also used for human NDT, working at fairly high frequencies. On the other hand, we have been working with ultrasonic frequencies of about a hundred kilohertz to one megahertz. You cannot go any higher, unfortunately, because the attenuation is so high in rocket propellant. Over the last few years we have developed an acoustic holographic technique working at 500 kilohertz. We can image defects in 15-inch cubes of dummy propellant and obtain a resolution of about two wave lengths. Now, we want to develop a system to work in real time. At the moment, it is a fairly straightforward scanning system with a single transducer. We have also developed, in conjunction with another UK firm, a 124 element matrix of three millimeter square transducers. These are switched by a light beam that enables us to select any element of the matrix. This matrix, we hope, should be able to sense holograms. Plessey in the U.K. has developed for us a rapid hologram recorder. Using photochromic film, it can produce typically a 200 by 200 raster in less than a second and, as far as resolution goes, one can get down to about a thousand by thousand raster in an 8 mm square. Naturally, scanning in the field is often not at all easy to accomplish. We will now try to use a manually operated device which senses the position of the transducer with sufficiently high resolution to form polygrams from the hand scan data. And again, of course, one can put this on the photogramic film for later projection.

Ashby and Turner at Bristol University are imaging in glass rather similar to the technique we saw in the poster session. They are using glass which is acoustically matched to steel and produces images in the glass of defects in the steel.

We are just starting work with Lethbridge University to look at the ultrasonic equivalent of the X-ray tomographic technique whereby one scans the specimen in a number of directions and from, say, the attenuation or the phase change, time delay through the material, etc., any changes in the material.

Now, moving away from imaging devices to the area where defects are comparable to the wave length. We had a particular problem with trying to find very small defects in fairly large areas of material. We set up a water bath system in which we used a lens and put a detector at the focal point of the lens. We look at the defects using the diffracted energy from the defect. Of course, the lens will carry out the Fourier transform provided one puts the detector at the focal point in the Fourier plane. We used a piezoelectric detector with annular rings and detected the energy falling on the annular rings away from the center of the beam.

Now, there is a variety of techniques available in the U.K. for assessing the depth of surface breaking cracks. One of them, due to Hunt, relies on reflection from the crack tip. Silk and Liddington, for example, at the NDT Center, produced a variety of techniques which rely upon travel times of ultrasonic waves around surface cracks. One needs a very good understanding, of course, of the travel paths and the possible mode conversions in order to make these techniques work, but I have no doubt that these will be developed further in the coming years.

This practical work is backed by theoretical work at City University. Bond uses a Ricker pulse to evaluate the effect of surface cracks on Rayleigh waves. He uses a finite difference technique in order to calculate deflections in the material and displays this on a grid which is disturbed by the pulse. Of course, you have a series of these grids at different time scans. It is extremely easy to understand these phenomena and one can see progress. This work is going to be extended to other types of models. There is similar work going on by Temple at the NDT Center, Harwell.
DISCUSSION

M. J. Buckley, Moderator (ARPA): Well, we have some time now for questions. First, I would like to make one comment. I think people get somewhat of a misconception, perhaps, of what the NDE activity in this country consists of by this one meeting. I don't know what percentage of research in NDE is represented by this meeting, but it is probably about 5 percent and certainly it is the most basic part of any of the research which I am aware of, at least as a large entity. Most of the resources that are spent by the government are in far more applied areas of solving specific problems and I think you see that sort of a trend is coming about here. But this program was trying to create a different level of technology and so we are slowly trying to move that towards a reduction to practice and that's the reason for the test beds. But just basically, most of the work is much more applied in this country and we have never quite figured out how to put the researchers and the applied research side and everything else together and keep any large percentage of the audience in the room at the same time.

Ellis L. Foster (Battelle Columbus Lab): I would like to ask the speakers to maybe comment on any directions in the evaluation of composites that might be going on in their country.

David S. Dean (P.E.R.M.E.): We do have problems, trying to examine carbon fiber optics. We have used a variety of techniques. As I said before, ultrasonics, X-ray, acoustic emission. In short, you can see areas where the winding is not exactly how you would like it to be and so on. But it is extremely difficult to know what these are going to do in practice and I just cannot find anybody yet who can tell me. About the only technique we have found which looks like it may be helpful is acoustic emission. You get a massive acoustic emission signal in mutilated materials.

Philip Hodgetts (Rockwell, LAD): I would like to ask Mr. McBride if he has had any problems with type 2 errors (erroneous signals) with your in-flight monitoring? It is our goal to put expensive equipment on airplanes to keep them flying and sometimes we worry about grounding an airplane because we have got a false indication.

Stewart McBride (Royal Military College of Canada): Our emphasis has been trying to make the matter as quantitative as we possibly can and we have only done it in one material. But at this point we are saying we have indeed made it quantitative in that material in terms of the change in size of the crack. We are not really using it as a method of just finding the noises. In fact, at the present time the effort has been fairly primitive. We have just started using microprocessor methods to look at the data. But we have literally set a threshold, collected a lot of structural noises plus a very small number of acoustic emission signals. Six, I think it is today, in 6 months out of thousands of noise signals. We have literally scanned all the spectra of all the signals. We have the characteristic difference between the spectra of the acoustic emission and the noises and we know what the size of a particular signal means in terms of the change in the fracture area. We are not at the present time really concerned or worried about type 2 errors. We think we have solved it in the one case we have tackled.

The other thing I should point out on the in-flight monitor is that we got one side pay-off, which might be a very important one. We were able to pin down exactly where in the flight pattern unstable crack growth is taking place in a particular component. And this has turned out to be of great interest to the people who are doing the laboratory testing of the simulated structures.

Unidentified Speaker: The question is what type of an area of in-flight monitoring did you monitor? Was it a localized area or was it a fairly large area?

Stewart McBride: The entire effort at the present time is directed toward a single wing fitting. In other words, we are specifically picking components that are not really fail-safe components. If they go, the aircraft goes, essentially. It is an isolated wing fitting that we are looking at.

W. Sachse (Cornell University): I wonder if I could hear some comments about approaches that have been taken on calibration blocks, development of test blocks, and things like that which can be used to calibrate and standardize ultrasonic measurements.

Paul Höller (Saarbrücken): With regard to just physically calibrating instrumentation, I think there is nothing extraordinary to say besides perhaps a point that we are relying more in the ultrasonic field on flat reflectors instead of globulars.

With regard to simulating defects, we try to make artificial defects which are similar to real defects. Eddy current work is done with very narrow actual cracks. We are also trying to make corrosion defects and other types of real defects and trying to maintain a collection of specimens which have failed, in the sense of NDE.

Tom Cooper (AFML): I would like to direct a question to Doctor McBride. Several years ago under the auspices of T.T.C.P., which is the U.S.-Canada-England-Australia-New Zealand cooperative effort, we were trying to develop a noise source, a standard for use of acoustic emission. I think based on the helium jet test that you worked on. Can you tell us what the status of that is? Has that been accepted now as a calibration standard for acoustic emission?
Stewart McBride: I suppose I have accepted it. The general status of it is that there has been an internal test within T.T.C.P. program. I don't think, really, the test has been sufficiently wide enough however. We seem to have at least convinced ourselves that we are able to use a helium gas jet to get some indication of the acoustic response.

In terms of acceptance, I suppose the answer would be a guarded yes. It seems to be becoming a little bit more accepted. It has a serious disadvantage, however, in that it only gives you amplitude versus spectrum and no phase and no rise time information. But from the particular approach that I have been using it is giving me the information that I feel I need at this time.

Peter Doyle (Aeronautical Research Lab): I would like just to add, too, the acoustic emission people from Alpha prefer the helium jet to any other technique they use.