

STATE OF ART NDE IN QUANTITATIVE INSPECTION

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INTRODUCTION

Before I get started into the main point of the discussion, the "State of the Art NDE in Quantitative Inspection," I would like to define what NDT, NDI, and NDE mean to me.

"NDT," nondestructive testing, is basically the use of various and sundry means for the detection of defects within structures or components without doing damage.

"NDI," nondestructive inspection, is the use of selected NDT techniques to inspect assembled aircraft in the field.

Several years ago we began to read in the ASNT magazine about "NDE," nondestructive evaluation. I had the feeling that a group of people were trying for more professionalism and looking for a better sounding name. I would like to define nondestructive evaluation in a way to make it more meaningful and a challenge to you; and that is "NDE" is the use of equipment that detects and quantifies defects within a part or structure and provides the acceptability evaluation.

In the B-1 (which is shown in Fig. 1) contract, we have a requirement for fracture mechanics which requires a new look at the ability of nondestructive testing and nondestructive evaluation. The Statement of Work states: "Without special NDT you must design the structure to withstand a .150-inch defect; in its most critical dimension and orientation, for the life of the air vehicle." In the case of a surface flaw, that means .150-inch deep. The engineers were very concerned with this requirement since it would make them have an airplane with a tremendous weight, and it would never be able to get off the ground. However, the Work Statement continues: "If you have some special

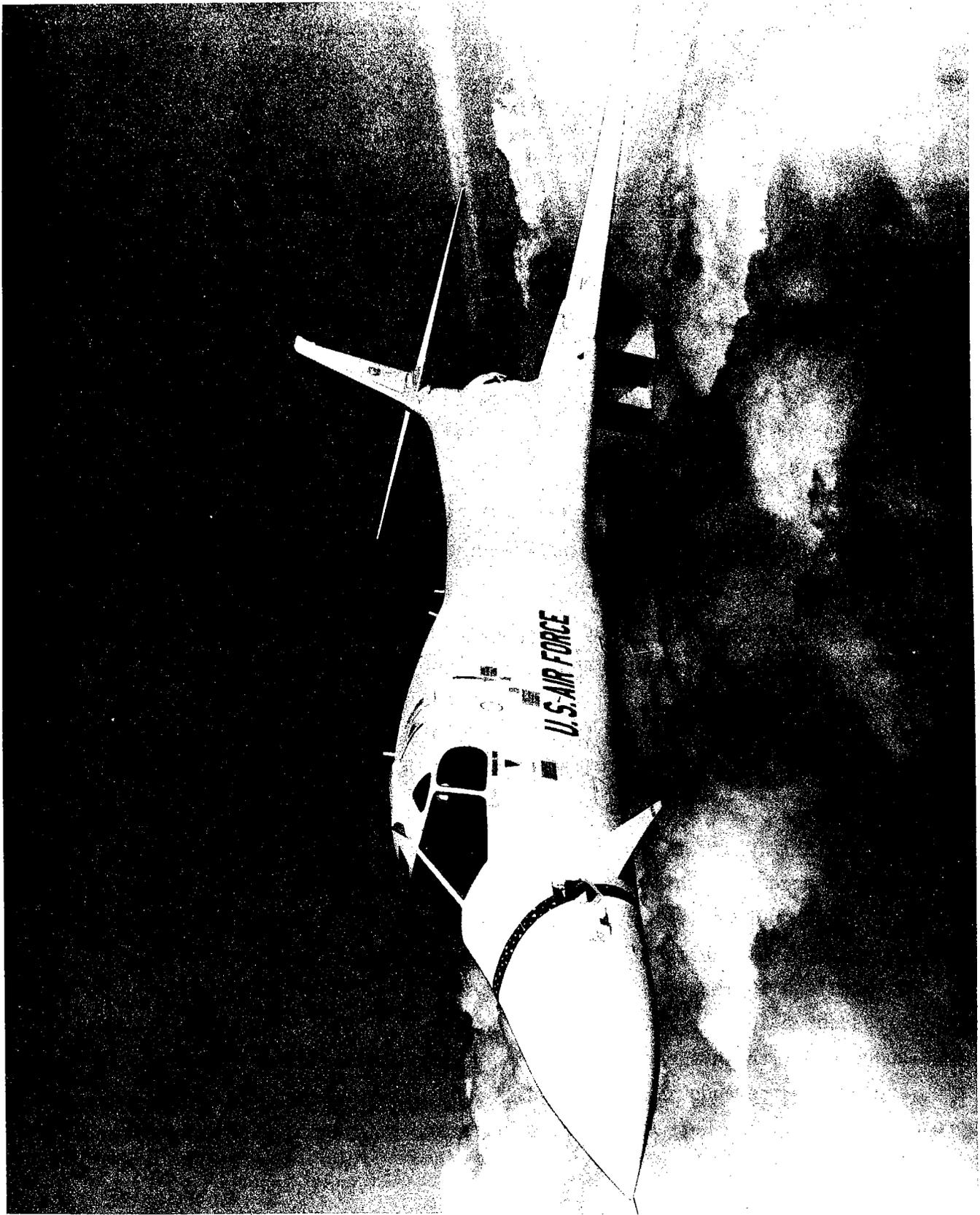


Fig. 1
"The B-1 Bomber"

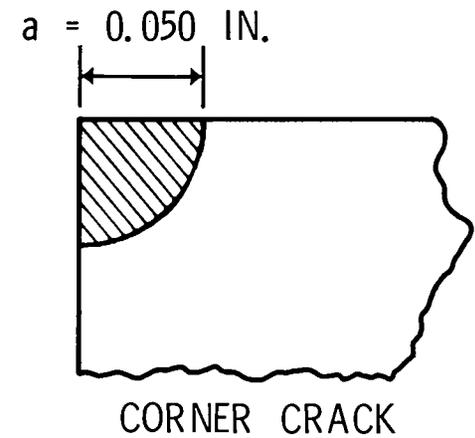
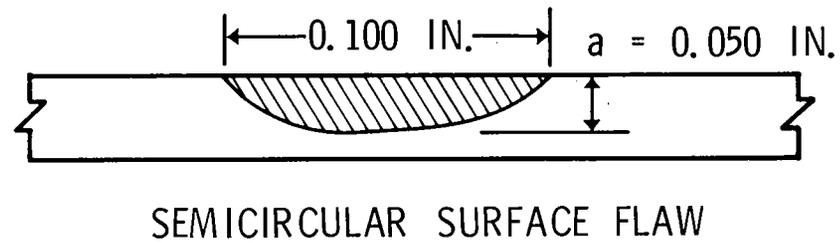
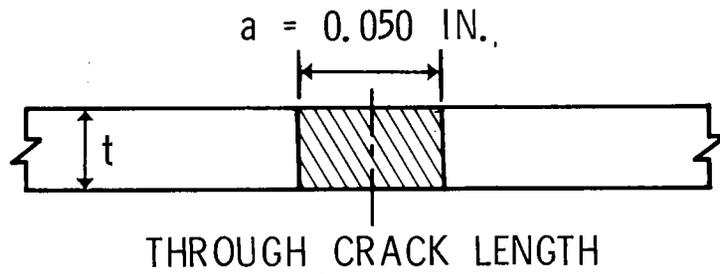
NDT, you may presume initial defects smaller than the .150, but you must demonstrate that you can find them with 90 percent detection and 95 percent confidence." That stated reliability is the same as that for the handbook properties data on materials used by design engineers. Of course, the engineers asked the usual question--"What can you find?" We can find all kinds of defects, but it depends on the kind of material, the structural shape, and such things as location of the defect.

We determined that our capability ranged from ten thousandths (.010") to fifty thousandths (.050"), depending on the type of inspection technique, penetrant, mag particle, radiography, ultrasonics, or eddy current. We estimated our capacity could demonstrate the .050" defect detection. Engineering immediately elected to design the B-1 to .050" and defined the critical cracks as shown in Fig. 2 for surface defects, and Fig. 3 for sub-surface defects. A depth of 3 inches was about the maximum we could reliably interrogate titanium.

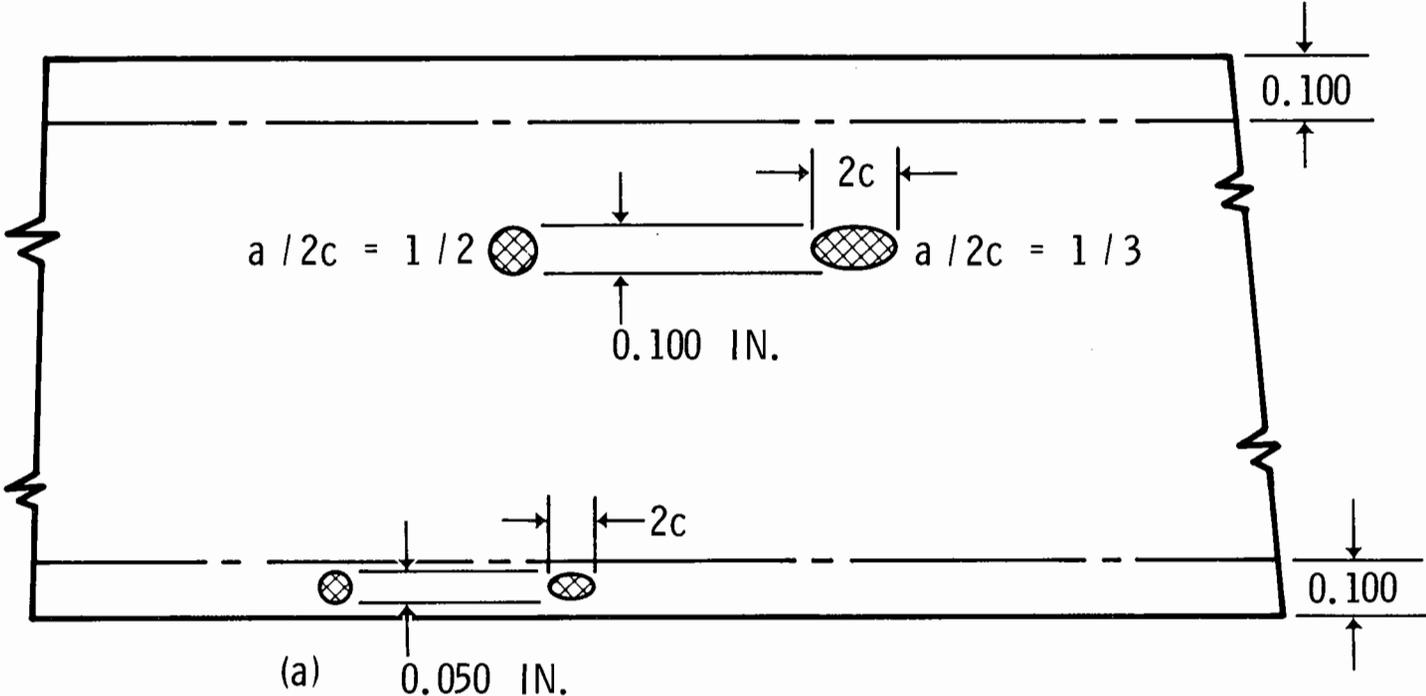
With the defect criteria established, two things happened: (1) the B-1 design was started, and (2) Quality Assurance started demonstrating their detection capability. This simultaneous effort made the need for success very apparent. Fortunately, we passed. Had we failed, it would have meant redesigning much of the B-1 airplane.

There were some ground rules that were established to satisfy the demonstration program. (1) The specimens were to be furnished by the government, the B-1 Systems Project Office. (2) The defects were to be fabrication-type defects. In other words, the flaw should represent those that occur by fabrication techniques and not by fatigue or other field environments. (3) The fabrication methods had to be described to us so we could agree that the samples represented fabrication-type defects. (4) Rockwell was to receive a few standards to use to establish the inspection procedures. (5) Any go or no-go intermediate decisions during the demonstration had to be approved by the Air Force. (6) The procedures that were to be used on the B-1, had to be used. (7) Must use the inspection personnel that were certified to do the job and that were actually going to do it on the B-1. (8) The Air Force

SURFACE FLAW SIZE



SUBSURFACE FLAW SIZE



CIRCULAR & ELLIPTICAL EMBEDDED FLAW

(a) SUBSURFACE

(b) CENTRAL REGION

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Fig. 3

personnel on-site (AFPRO) were to continually monitor the program. (9) The data analysis was to be done on the basis of destructive testing and as a cooperative effort between the Air Force and ourselves. The test plan (Fig. 4) was established by Dr. Packman, a member of the Air Force team. He set up the four flaw-size groups that ranged in depth from .010 to .120.

There are some techniques that do very well at either end of the size spectrum. That is, they can detect the small defects but may miss the larger ones, and vice versa. For example, some penetrants are very good on small defects, but when the crack is larger, they are easily washed out, thus missing the larger cracks. We had to pass the complete family of crack sizes from .150 to a minimum size of .050. The sampling plan was set up on a statistical basis, and a given lot of specimens contained both flawed and unflawed specimens. The plan, with no misses for a given technique, would require 244 observations. If one miss occurred in any one size group, another 30 samples would be added with another 60 control specimens. When adding all the possible observations for the techniques we used, and all the materials involved, there could be a total of 6,172 individual observations to demonstrate for the B-1 program. Of course, the effort would be smaller if no misses occurred (2,200).

We decided that the B-1 fracture critical parts could be inspected with penetrant, magnetic particle, ultrasonics, and eddy current. We dropped X-ray as we didn't feel the required reliability detection of .050" defects for the material thickness involved was obtainable, and we didn't need it as a final inspection technique.

These pictures (Figs. 5 and 6) are of the various types of samples that were used. You can see bent titanium sheet (small cracks in the bends), titanium blocks (that were diffusion-bonded with internal defects at various depths), drilled specimens (with corner cracks), a series of specimens of titanium, aluminum, steel specimens (with surface cracks), and welded steel and welded titanium specimens in a variety of thicknesses (with cracks). The machining specifications that we use on the floor were employed on the specimens. This provided a machined surface, the same as we would experience with the B-1 parts during manufacture. The welded specimens were protected to allow access from only the far side of the defect. The Air Force were the

TEST PLAN

(90-95)

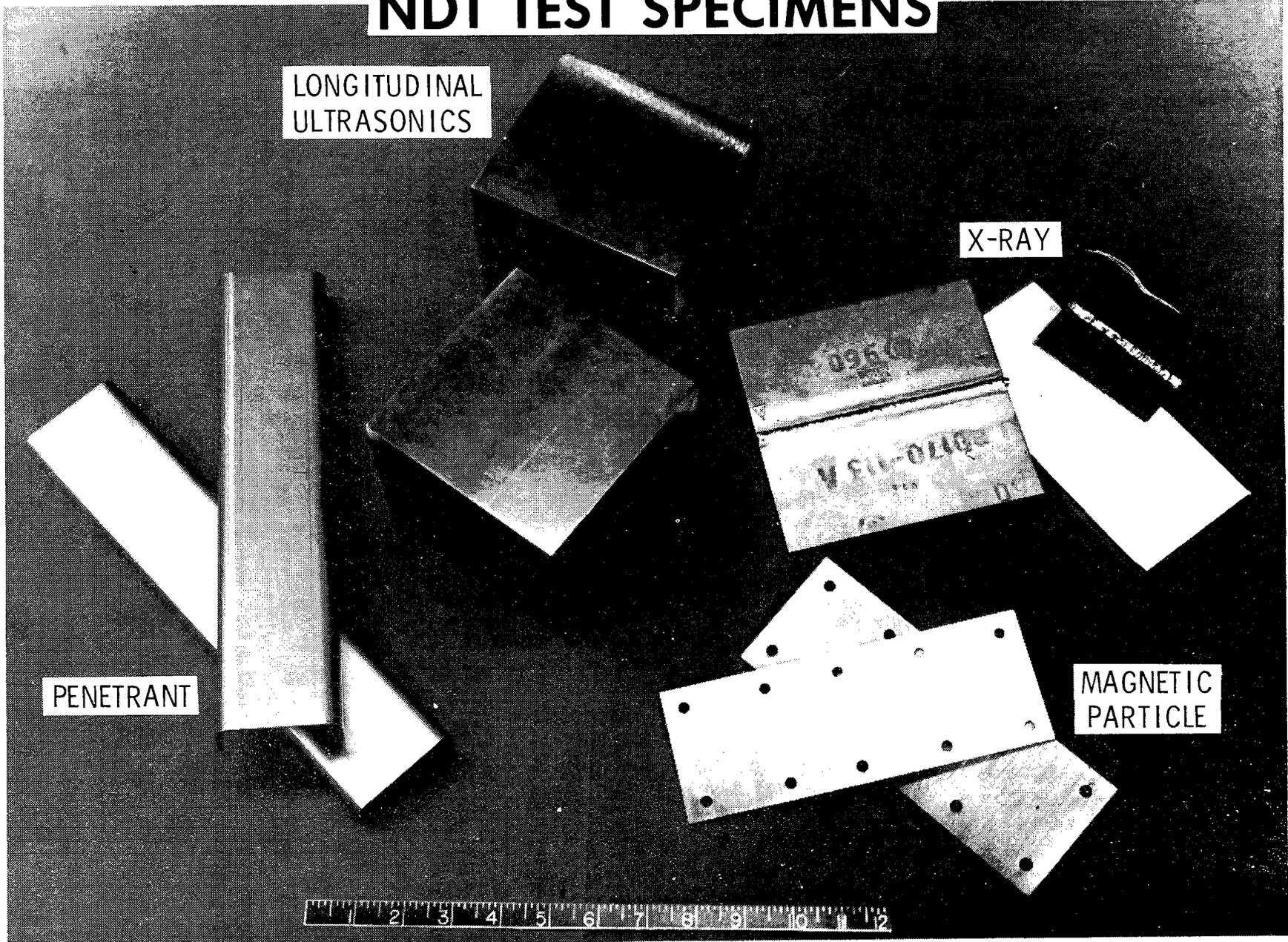
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GROUP NUMBER	FLAW SIZE RANGE		INSPECTION SEQUENCE			
	TARGET SURFACE LENGTH (2C) - INCH	CRACK DEPTH - INCH	A	B	C	D▲
1	0.030 - 0.075	0.010 - 0.035	8	8	15	30
2	0.076 - 0.100	0.020 - 0.050	8	8	15	30
3	0.101 - 0.150	0.020 - 0.070	8	8	15	30
4	0.151 - 0.250	0.020 - 0.120	8	8	15	30
TOTAL FLAWED			32	32	60	120
CONTROL			30	30	60	60
CUMULATIVE INSPECTIONS			62	124	244	424

▲2 MISSES ALLOWED
TSP72-3890

Fig. 4

NDT TEST SPECIMENS

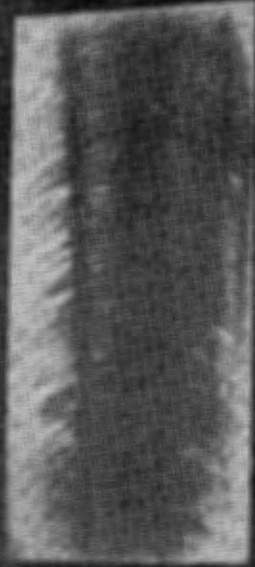


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TSP71 -10831

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Fig. 5



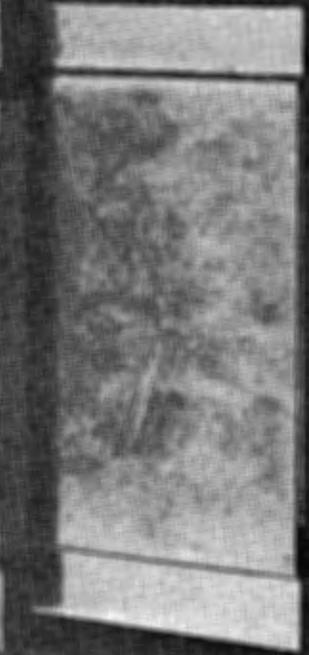
TITANIUM - PENETRANT

ALUMINUM - PENETRANT

STEEL - MAGNETIC PARTICLE



TITANIUM - ULTRASONIC (S-wave)
RADIOGRAPHY



STEEL - ULTRASONIC (S-wave)
RADIOGRAPHY

Fig. 6
Test Specimens

were the only ones who knew which of the samples contained the flaws, and in which size group they would be. The specimens were numbered and controlled by the Air Force.

To simulate the bolt holes in the wings of the airplane, we have samples of stacked up material of aluminum, titanium, and steel in various configurations, and here we were looking for cracks within the drilled holes (Fig. 7). Somewhere within the stack is a flaw. There are many more unflawed than flawed holes in this case.

The demonstration consisted of these four methods: Penetrant, magnetic particle, ultrasonics and eddy current. The various materials--steel, aluminum, titanium, welded as well as diffusion-bonded--were employed. I would like to point out again that we had to use the inspection personnel that were certified to do the job and that were actually going to do it on the B-1. The NDT engineer or technician from the laboratory could not be used. Further, the shop inspectors were not told that they were being tested in any way. At that period of time, on the B-1, there were a lot of similar specimens going through the shop, such as tensile bars and coupons with which the engineering materials laboratory was evaluating materials; therefore, we made up regular manufacturing orders that were just like those of similar parts going through the shop. The tickets were dummied up to show operations performed and accepted by inspection, down to the NDT "Inspect" line, which was left open. This line told the inspector what criteria and what procedure to use.

I am happy to report that all the various techniques we used with the combination materials were all passed, and the limits ranged from .030" to .050", as shown in Fig. 8. This demonstrated detection capability proves that the detection capability of NDT today is very adequate. We had predicted that it would probably take about 4,000 observations to do the job, expecting some misses. Actually, it only took approximately 2,500 observations to demonstrate the 90-95 percent capability. This kind of success tells us not only that our capability of detection is adequate, but that it is much better than what we demonstrated.

Let's take a look at some results. In Fig. 9, it can be seen that a few specimens were at the .050" end of the spectrum. Had more samples been

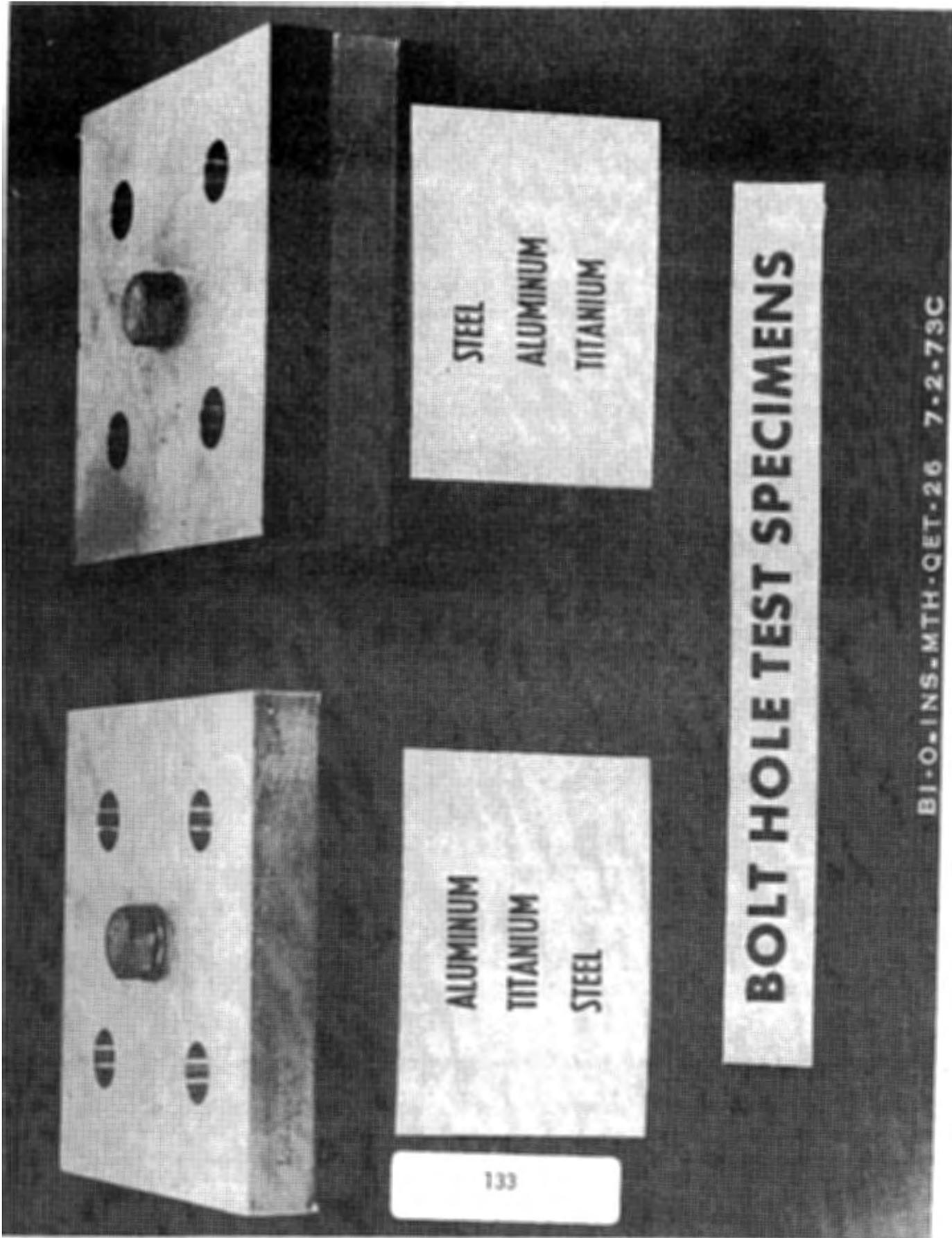


Fig. 7

NDT CAPABILITIES DEMONSTRATION SUMMARY

		<u>DEPTH</u>
● ALUMINUM PENETRANT	PASSED	0.035
● TITANIUM PENETRANT	PASSED	0.035
● MAGNETIC PARTICLE (STEEL)	PASSED	0.050
● LONGITUDINAL ULTRASONIC	PASSED	0.046
● EDDY CURRENT IN BOLTHOLES	PASSED	0.030
● ULTRASONIC STEEL (SHEAR)	PASSED	0.050
● ULTRASONIC TITANIUM (SHEAR)	PASSED	0.035
● STEEL PENETRANT	PASSED	0.040

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Fig. 8

RESULTS

PENETRANT

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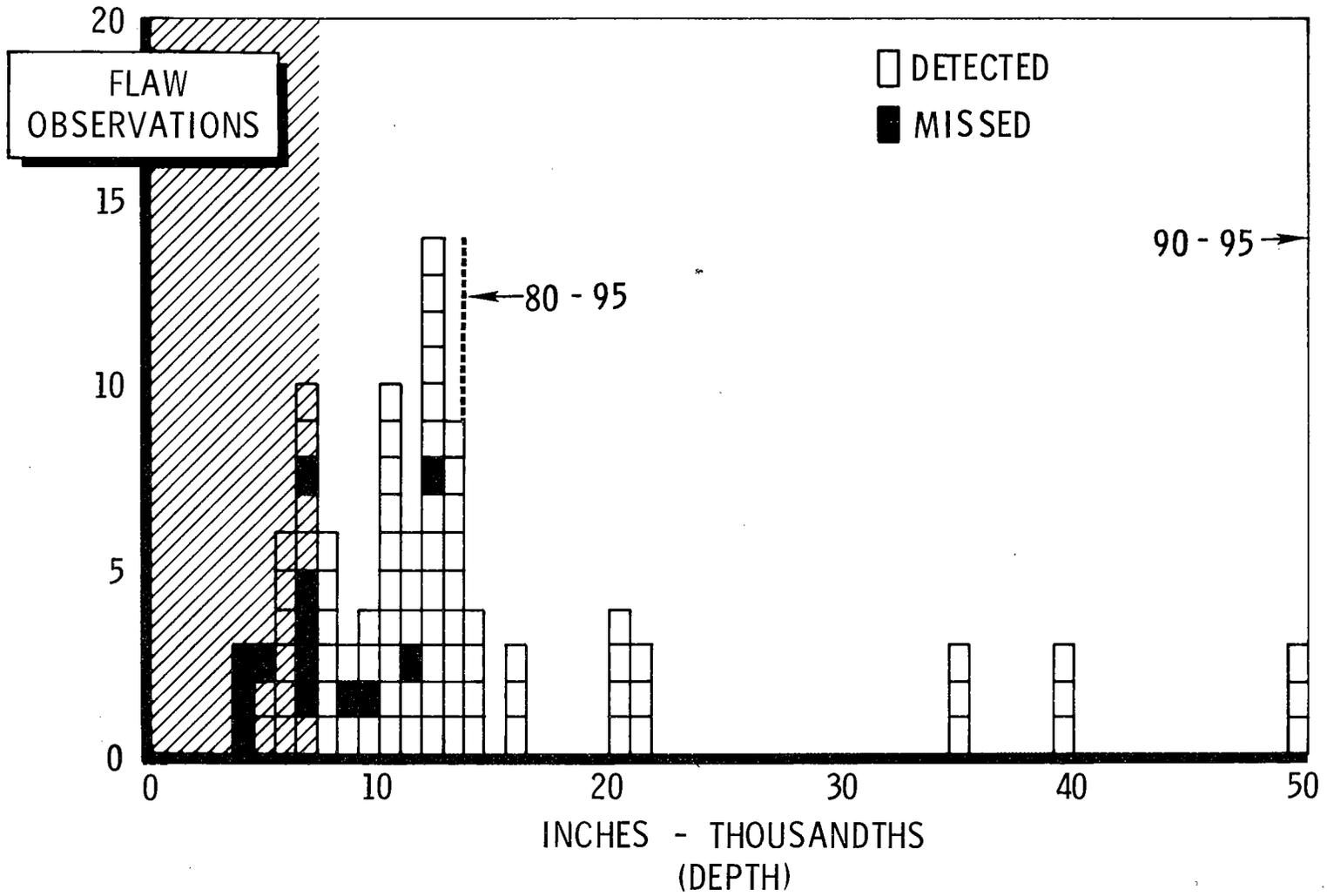


Fig. 9

selected of the smaller size, we would have easily demonstrated 90-95 per cent at a level of .020". The only misses occurred at ten-to-eleven thousandths. As it turned out, one particular inspector, out of about six involved, missed four observations in the same size range. A review revealed a very interesting fact about certification of people. Once certified, some become "inventors" by altering the processes so they are comfortable in doing the work. That's what happened here. The inspector found a simpler way, he thought a better way, of doing the job, but it made him ineffective in detecting the smaller defects. Discipline to the NDT procedures is very important for success.

Now that we can detect a defect and know in what size range it is, there is still the question remaining as to whether or not the part is good, and can it be used?

Today, our nondestructive evaluation and quantitative values are obtained using a standard which is run with the part, Fig. 10. NDE then is really one of comparison to some known standard. This is a time-consuming approach because once you find a defect, one must manually go back over the defect and characterize it. For example, what kind of losses are involved? What kind of wave shape is produced on the scope? etc? This method relies considerably on the technician's experience. It is considered slow and not too cost-effective. Those standards are very costly. For the B-1, it takes quite a few standards to do the job. Someone mentioned earlier today that they are going to have a shelf on which to put their standards. I say your shelf isn't going to be big enough. Figure 11 shows a few of the standards we are using on the B-1.

In the B-1 Program we have tried to minimize separate standards. For example, in diffusion-bonding, the standards are built into the part itself. Within a portion of a diffusion-bonded part, there is a section that is removed for process control purposes, so we bond known defects into these bond lines. This provided standards with the same material and processing history as the part. It is an excellent inspection aid. The nondestructive evaluation technique employing the "inspection aids" (referred to as "standards" in industry today) is a relatively slow process. There are parts that can almost be built faster than they can be evaluated. From a cost/schedule standpoint, this puts NDE in a bad light. We need NDT equipment that can be

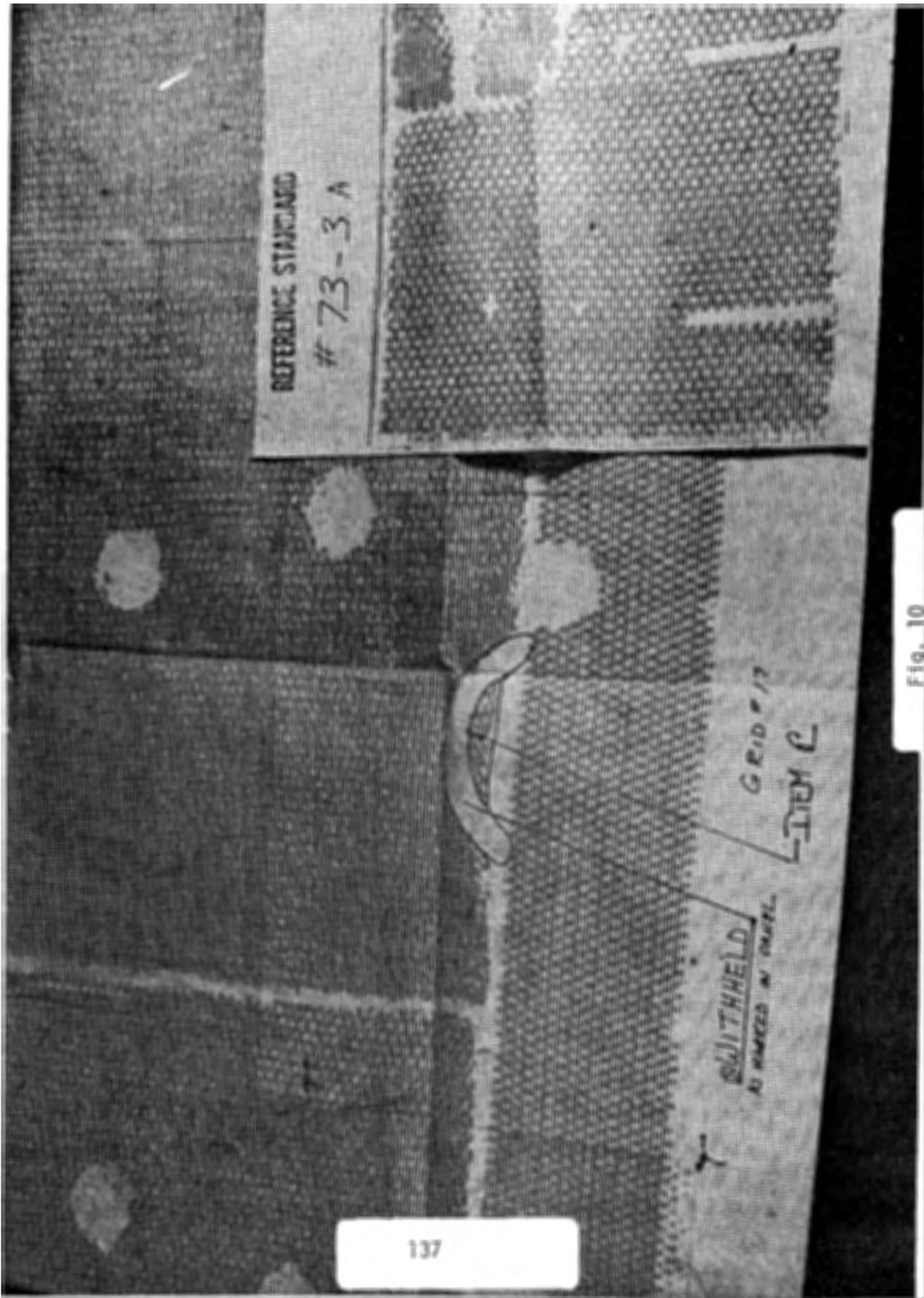
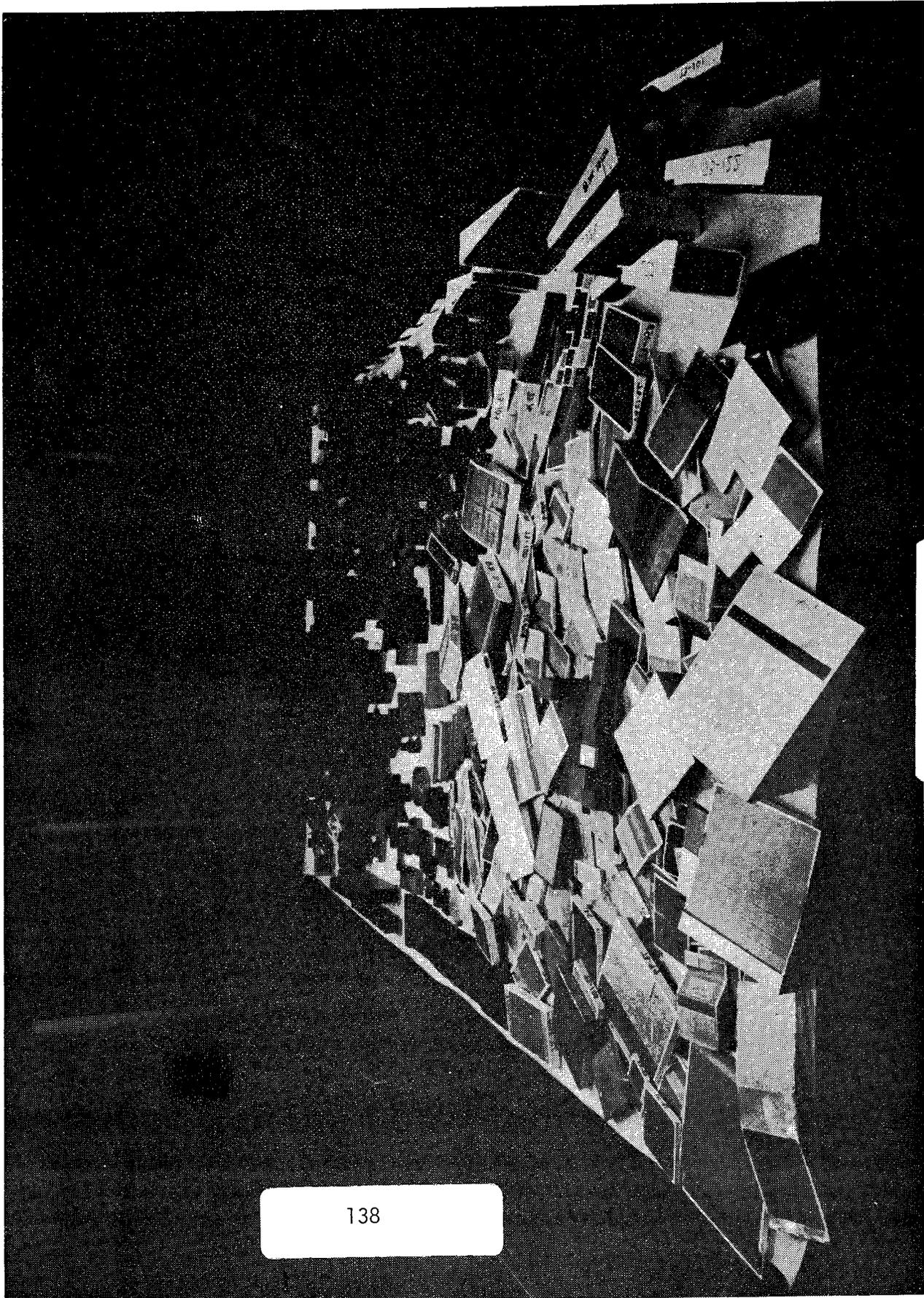


Fig. 10
NDE by Comparison

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Fig. 11
B-1 Standards

standardized and has the evaluation capability built in. For example, ultrasonics is potentially capable of actually measuring and characterizing a defect. If the NDT data were recorded by a computer and interfaced with a memory bank, containing the characterizations of the defects to be evaluated, an automatic comparison and evaluation could be obtained. A more universal standard could then be used to periodically calibrate the basic equipment, and not used as an inspection aid. This is the kind of NDE equipment that is needed.

To summarize, there are four points I would like to emphasize:

(1) nondestructive testing detection capability is adequate; (2) you must have discipline in the NDT procedures; (3) the NDT processes must be made to be faster to become more cost-effective; and (4) please accept the challenge to design the NDE capability into the NDT equipment. If money and effort is to be spent, this task should get a major share.

DISCUSSION

LIEUTENANT MICHAEL BUCKLEY (Air Force Materials, WPAFB): Ed, if they decide to build the wing of the B-1 out of a composite, are you all set to inspect it?

MR. CAUSTIN: Of course, it depends on the design, but I believe this: for composites, the detection capability is adequate and is just as good as with any other material. A recent workshop, held by the National Research Council, on NDE of composites, reported that the NDT capability of detection was adequate. The big problem was--what is the critical flaw size?

LIEUTENANT BUCKLEY: Put it this way: Would you fly on it?

MR. CAUSTIN: Today, I am flying in airplanes I know a lot less about than I will with composites. I see FAA reports with sizeable cracks in spars and in longerons on the airplanes we are flying in today. Yes, I'd fly in it.

PROFESSOR GORDON KINO (Stanford University): I am kind of interested in the fact that you say you have to use standards all the time. Surely a hole has a certain size. You are using a particular piece of equipment that either is using time or space or something as its own internal standard. Is it a matter of not having a gray scale so that the amplitude is all over the place, or what makes you have to keep on using standards that you are recalibrating?

MR. CAUSTIN: I think it is more a lack of confidence in the techniques as far as the capability of telling the exact defect size. Hence, a standard that closely represents the structure is used. Standards do help to sort out stray observations, or characteristics that the operators are not sure of. I expect the computerized techniques, and other methods of processing data, will help eliminate many needs for such standards.