LIGHTWEIGHT ENGINE CONTAINMENT

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SUMMARY

This presentation covers preliminary evaluation and development of Kevlar fabric as a lightweight containment material for use to contain blades released from gas turbine rotors. The evaluation and development included review and selection of fabric styles and weaves as well as methods of application for advanced gas turbine engines.

During this investigation effort, the Kevlar material was subjected to high speed impacts by simple projectiles fired from a rifle, as well as more complex shapes such as fan blades released from gas turbine rotors in a spin pit. Just contained data is developed for a variety of weave and/or application techniques and a comparative containment weight efficiency has been established for Kevlar containment applications. The data generated during these tests is being incorporated into an analytical design system that will allow a designer of future engines to make blade containment trade-off studies between Kevlar and metal case engine structures.

In addition to the evaluation of the containment efficiency of Kevlar, certain laboratory tests and engine environment tests were performed to determine the survivability of Kevlar in a gas tubine environment.

LIGHTWEIGHT CONTAINMENT

INTRODUCTION:

Current regulations require that blade containment be provided on all gas turbine engines certified for commercial flight. Since the structures that provide this are generally parasitic, engine technology dictates that they be as light as possible. In order to meet this requirement, new materials and new containment concepts are being explored. Initial data generated using fabrics as energy absorbing devices under high speed impact indicate that a significant weight improvement can be achieved. This presentation deals with the evaluation and development of fabric structures for blade containment applications for gas turbine engines.

DISCUSSION:

A cross section of a typical gas turbine engine is shown in Figure 1. The red outline represents a typical rotor stage for which a containment structure must be provided. The rotor is enclosed in a metal case which provides support for the engine weight, and imposed thrust loads. Additionally, the case must provide the necessary containment in the event of a blade failure. This containment is provided by the energy absorbing capability of the impacted case structure which normally bulges or deforms when struck by a released blade. Sufficient material thickness must be employed in the containment structure to prevent the blade from exiting the case.

In current gas turbine engines, the metal case structure is fabricated with adequate thickness to provide the necessary containment. In future gas turbine engines, fabric wrapped thin metal cases may be used to provide the necessary level of containment capability with a minimum weight. (See yellow outline in Figure 2.)

The thickness of the engine cases, in the plane of the blades, can then be reduced to a value limited by normal engine loads such as thrust and rotor support.

DEVELOPMENT PROGRAM:

The following development program was performed at P&WA East Hartford to provide a data base for future applications of fabric containment structures for gas turbine engines:

- Ballistic Impact Evaluations
- Laboratory Tests
- Spin Pit Tests
- Engine Tests

The ballistic impact tests consisted of subjecting various fabric structures to impacts by projectiles fired from a gun. "Just-contained" data were developed for a wide spectrum of fabric weight densities and projectile velocities. (See Figure 3).

In this testing we were able to determine the degree of participation of Kevlar^{R} DuPont versus the associated metal structure. The results of this testing showed:

1. Kevlar impact resistance by itself is 5 more weight efficient than AISI 410 hardened steel.

2. Kevlar structures lose efficiency if the fabric is not allowed to deflect.

3. Kevlar fabric can absorb multiple hits closely spaced without apparent loss of containment strength.

The laboratory investigation included wicking and flammability tests to assess fire risk associated with Kevlar fabric around the outside of an aircraft gas turbine. The results of this testing showed:

Wicking

Kevlar 29, style 71 fabric, wicked engine oil and hydraulic fluid in an applicable bench test.

Flammability

Kevlar 29 was non burning by itself.

The spin pit testing consisted of wrapping Kevlar cloth around a thin metal engine case and subjecting this containment structure to an impact by a released blade from a spinning rotor. (See Figures 4 and 5). A thin aluminum witness case was mounted outboard of the Kevlar wrapped blade containment structure to determine if blades/pieces exited the Kevlar. "Just-contained" data were obtained for typical gas turbine speeds and several configurations of Kevlar fabric.

The fabric configurations evaluated were:

Kevlar 29	1:1 plain weave
Kevlar "	3:1 weave
Kevlar "	6:1 weave
Kevlar "	3D weave

The results of this testing showed that the blades would penetrate the thin engine metal cases; however, the blades were contained by fabric wrap. The containment weight efficiencies for the above Kevlar weave configurations were determined to be basically identical.

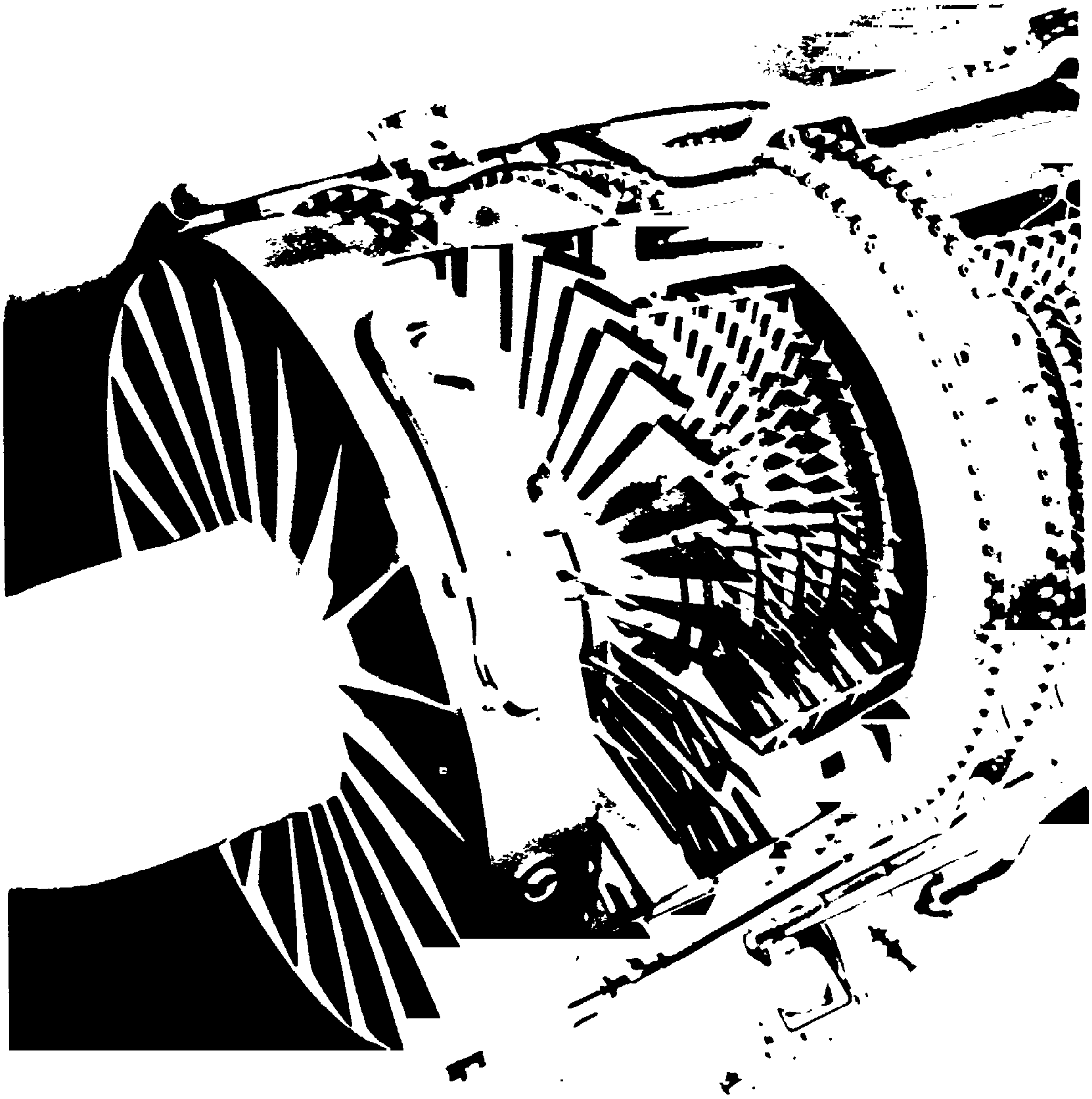

FIGURE 1
GAS TURBINE ENGINE SHOWING TYPICAL FAN STAGE (RED BLADE TYPE).

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ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

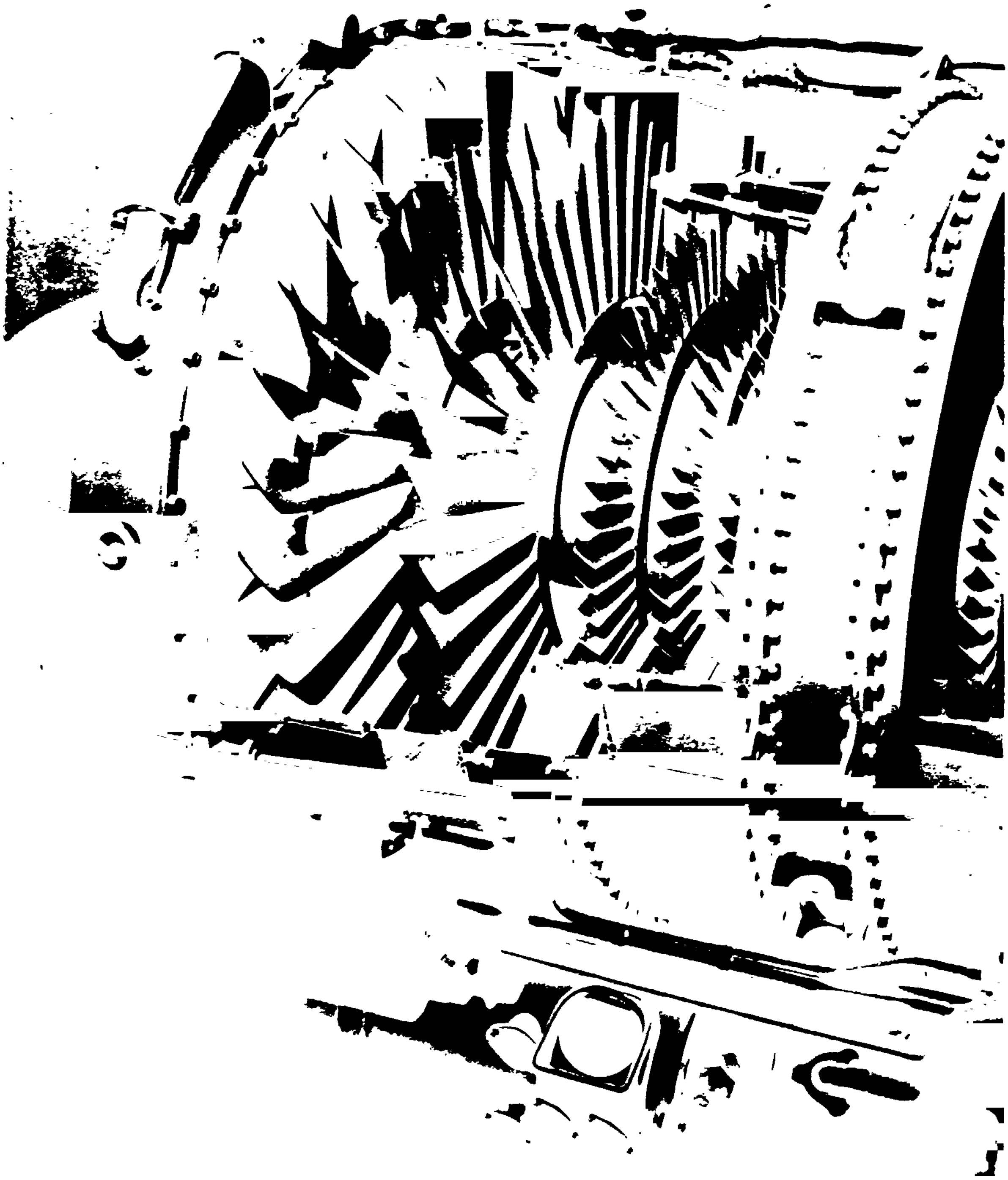

FIGURE 2
GAS TURBINE ENGINE SHOWING LOCATION OF FABRIC CONTAINMENT WRAP (YELLOW BAND).

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BALLISTIC IMPACT EVALUATION OF KEVLAR®

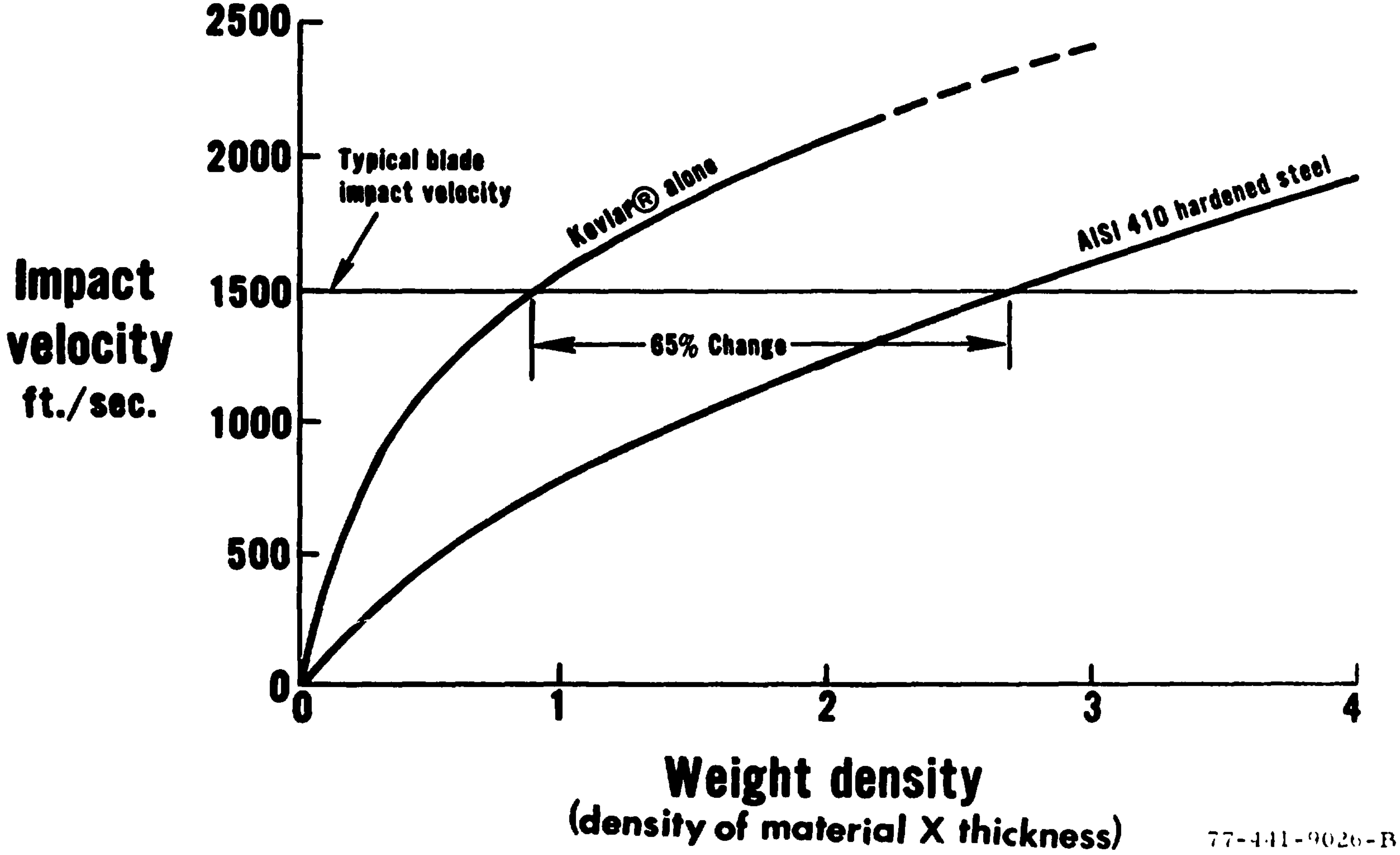

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FIGURE 3

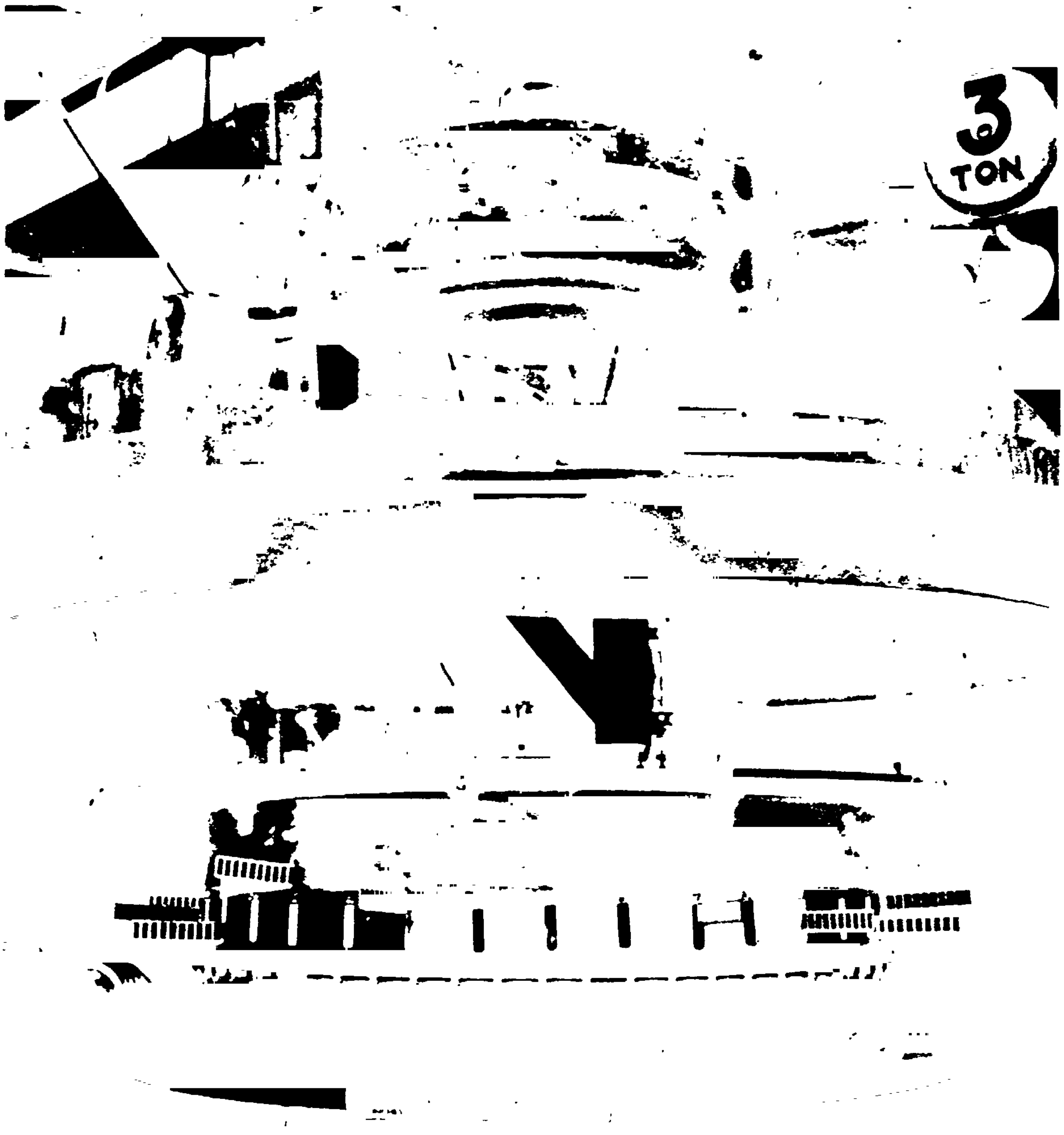

FIGURE 4
SPIN PIT CONTAINMENT TEST RIG SHOWING KEVLAR WRAPPED CASE.

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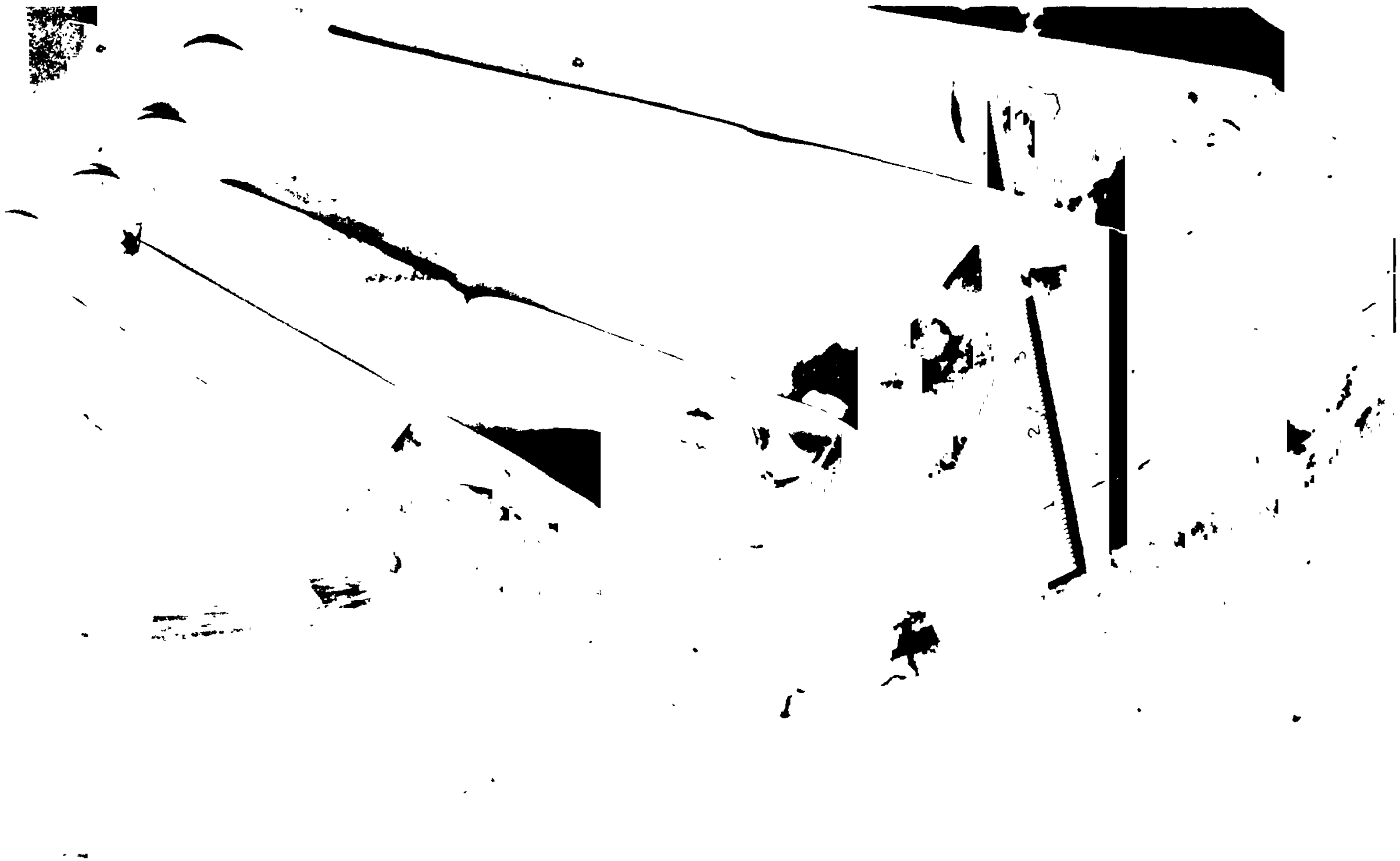

FIGURE 5
SPIN PIT KEVLAR WRAPPED CONTAINMENT METAL CASE
AFTER TEST.

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DISCUSSION

J.C. Wallin, BAC

Al, as one who spends much time worrying about fires, I think you tossed off the absorbability of Kevlar pretty lightly. If the casing were wrapped around with asbestos, I'd be pretty unhappy. But as you described the wicking, I would not be any happier with Kevlar. I think that before you can have a practical system on the engine you've got to have some way of avoiding that soak-up (fire hazard) problem. Is there a suitable coating that can be used to prevent its soaking up fluids?

A. Weaver, P&W

I share your concern about the fires; an engine can experience some leakage of oil or fuel at some time. This leakage could be characterized as so many gallons of this flammable fluid; all the Kevlar played a part in was simply in wicking it. I'm not too certain if that's any more of a threat than allowing the fluid to collect in the bottom of the nacelle, although this can be drained off or trapped.

However, this is not going to take care of all of the leakage. Some of the engine parts are going to be covered with this liquid because of its natural adherence.

I'm not yet convinced about the Kevlar increasing the fire hazard. We do agree that it wicks, and probably is going to hold more of the fluid than a metal part would hold just because it sticks to it. But it still may be a small quantity and not an increased threat.

J.H. Gerstle, Boeing

Al, wouldn't it be possible to put a very lightweight nonabsorbent sheet around the Kevlar?

A. Weaver, P&W

That is a possibility that is being considered. One could also put in a certain amount of impregnation. This might result in some loss in containability, but with a 65% weight saving as it is, I can afford to give up some of that and still have it very attractive.

Some of these questions are long-range considerations that we'd like to pursue and get answers on. That's why we're quite a ways away from putting this out in the field.

H. Garten, GE-Lynn

How much weight saving do you think that you get as compared with a titanium shield?

A. Weaver, P&W

The data indicated a 65% weight saving compared with using 410 steel.

So, I think, the proper question would be: how does titanium compare with 410 steel? Then, obviously, how does it compare to Kevlar?

H. Garten, GE-Lynn

I thought you said that the actual engine test (the spinpit test) was surprisingly good. I thought that it inferred that it was better than the initial assessment of your ballistic test.

A. Weaver, P&W

Yes, there was some inference of that. We don't completely understand it whether it's because the ballistic test does not completely model what happens in the spinpit or not.

We have not pinned down in the spinpit the exact weight savings with the Kevlar. On the surface, it appears to me that the spinpit test results were going to be better than ballistic-test results. This may be due to the way we bookkeep the results. We have not completely understood the bookkeeping of the Kevlar versus the inner steel wrap that we have.

D. McCarthy, Rolls-Royce

We tested some Kevlar and found that when it was wetted with oil, its containment capability was seriously diminished; you suggested that the effect of oil wetting depended upon the shape of the missile. Have you done tests, firing blades at the Kevlar shield while it is oil-impregnated?

A. Weaver, P&W

No, we haven't; we certainly intend to do that. We would have done it some time ago had we not received the advice we did from Watertown saying, "you really don't have to worry about it -- your initial ballistic tests kidded you". We put that down to the lower part of our priority list, but it still remains to be done. We will not consider Kevlar to be fully developed unless we run tests in a spinpit with the blades impacting into the oil-soaked Kevlar.

R. Bristow, Boeing

I think you may very well find out that when you soak the Kevlar shield in oil that you're getting a similar effect to having a matrix, that is, the mass of the oil and the mass of the matrix is causing the problem.

E.A. Witmer, MIT-ASRL

Could you clarify the nature of the discussed test in the spin chamber: the way the failure was initiated and the sequence of events?

A. Weaver, P&W

We take a fully-bladed rotor, and purposely weaken a blade in the rotor so that when you operate it at red-line speed, that blade is running very near its ultimate tensile strength. The chamber is evacuated so the blade doesn't have a significant vibration imposed on its P/A stress, and it continues to remain intact. We then impose on the whole rotor a vibratory stress which forces the one weakened blade to failure, usually in a second. That's the simple way we conduct most of those tests. We normally fail the blade in a root attachment or in the root airfoil. This would be a significant mass of blade.

I think in the particular photograph you looked at on the viewgraph, there was probably a root airfoil. Though, on the same rotor we've also run with the full root attachments released into the case.

J. Meaney, Rohr

I have two questions. First, had you spliced the Kevlar and in what direction? Second, you say that the Kevlar must deflect to work, but in the pictures of the engine you show a lot of pneumatic lines that run very close to the shield. Do the deflections exceed that distance?

A. Weaver, P&W

Concerning the first question, the Kevlar application that you were looking at is a very simplified application that I would think of as analogous to an ace bandage. When you put an ace bandage on your wrist, you take the one piece and you hold it and you wrap the other piece around, and you depend on the friction of the layers to keep it there; the last little end of the ace bandage you take a couple little hooks and you hook. That's all we've really done here. I propose to let the designer make it very simple; don't require him to add weight.

As to your second question, the particular engine case you saw was simply a vehicle for subjecting the Kevlar to the environment of an engine. This was not designed to be a mock-up of a final design. One must provide for adequate clearance because Kevlar must deflect appreciably to do its work.

We had put some structure outboard of the Kevlar (not against the Kevlar) and the Kevlar has deflected into these structures. At the present time in the number of tests we've run, we've seen no effect on the containability of the Kevlar if it was deflected into a structure. If you back the Kevlar up in intimate contact with the structure, yes, you would probably lose containability. But, if you don't back it up and you give the Kevlar a gap and allow it to deflect through that gap, then if you hit the structure it didn't really appear to affect the Kevlar. The Kevlar still did its job.

J. Salvino, NAPTC

In your spin pit containment test on Kevlar, where did you find the blade fragment? Was it between the Kevlar and the outer case?

A. Weaver, P&W

Typically, the Kevlar is ripped and torn, and many layers of it are penetrated; the blade is trapped in the layers. The blade is generally in one piece not including the root; it does not always break up.