FLOATING BRUSH SEALS

Jack Braun
B&C Engineering
Akron, Ohio

Our next presenter is Dr. Jack Braun from the University of Akron who is also a formed for a company called B & C Engineering Associates. He will be talking about an SBIR contract that he has with NASA Lewis Research Center working on a floating brush seal concept.

As Bruce introduced me, my main stay is with the University of Akron and we started some technical activity at a small company, an associate of mine Dr. Fred Choy and its a pleasure here before my previous presenters. Brush seals have indeed entered the main stream of jet engine technology. Rolls Royce, P&W, Allison, they are all using them. There are some huge problems with these brush seals. And one of them being the significant wear either of the shaft or the bristles at high speeds. We have an idea at that time to cut this wear in one shot. And that was what if we would make the brush rotate with the shaft? This way you'll have no wear at the interface; for if there is some relative motion between the brush and the shaft it's still not going to be at 40,000 rpm. So, with that concept in mind, we created a hybrid type device. One of which can be seen here, figure 1. And this hybrid type device is formed out of a spiral groove seal, which is in the class of the film riding face seal , the smooth face that rotates against the grooves of the stationary seal. Two things happen here. Number 1, we will maintain the integrity of the sealing. We will allow the shaft to move both axially and circumferentially and radially. And at the same time we considered it would probably be stable and we actually with a prototype we demonstrated that to ourselves, and look to obtain flows that are actually below the typical flows that are characteristic to the brush seals. But somewhat above the flows of the film riding face seal. Some curves presented by John Munson last year and it's shown here in figure 2. This is the flow if this represent the labyrinth seal and this represent the brush seal projected performance and this being the film riding face seal. The place where we will be will be somewhere in between, closer to film and riding face seal. This is not a wishful position there. The brush seal that you are using in this configuration that is being manufactured by Cross Mfg. Ltd. doesn't look exactly like the standard brush seal that people are using. It's wider and it has a different structure; I'm not going to go into it. It has a different structure, the back plate has a different structure, the front plate has a different structure. The point is that the brush is being used both to cut the flow that characteristically goes through the brush and to provide additional damping to the support mechanism. As a final thought, the central overall concept that we are presenting here is that the relative motion is now being shifted from the interface between the shaft and the bristles to the interface between the backing plate and the spiral groove seal , figure 3. As it ended up we have actually got ahead and built this brush seal. And what you can see in this figure 4 here, there are two alternatives for the spiral groove seal . This portion of the project we are working with Durametallic which is manufacturing and helping us to design the most efficient spiral groove seal. Film riding face seals is one of their specialties. And in terms of the brushes, we have used a classic brush seal that takes the design and built by Cross Manufacturing. This combination between this part of spiral groove seal and brush seal has proven to have very low leakage.

And the picture that you see here that you can't see very clearly, is taken after one of the tests, actually after a multitude of tests, figure 5. And there is actually no visible grooves either on the back plate of the brush seal or on the face of the spiral groove seal. The general way in which these things are assembled can be seen here, figure 6. I'd like you to see a frontal view of the rotor with a brush and the brush/seal in another picture. Here one can actually see the brush is taken off, the rotor and the spiral, the spiral groove seal at this juncture. What you see in these pictures here represents actually experiments that have been done during phase one of the SBIR and on a 5.1 inch diameter seal, figure 7. Here is a schematic of the test section fabricated just to prove this ability at that time. A shaft is a rotor and hybrid floating brush seal is mounted in this area. The results that we have obtained were very good at the time we got a Phase II. And during Phase II we are now in the process of starting a test facility that should be functioning in December where we can test up to 40,000 rpm on a specially designed spindle. And Durametallic is working with us on generating very efficient spiral groove seals that will ensure a very quick lift off. Cross Manufacturing has designed single and double brush seals for us to test and modified brush seals for us to test in this context. What I want to show here is the flow chart of how our interaction with NASA, which funded this project and various industrial entities as formed, figure 8. This is Phase I that I talked about. We have proven its ability. During Phase II we have the spiral groove seal that is being designed by Durametallic. The design of brush seal that we have actually done and have commissioned to Cross Manufacturing. Once these are fabricated we are going to test them on our test facility at room temperature. Once this thing is done and we are satisfied with it, we will go to NASA at the high temperature test rig that is run by Bruce Steinetz and Margaret Proctor, figure 9. We are going to test this configuration at temperatures up to about 900 degrees F. This you can see here is the general design of the high temperature test rig at NASA and the detail of the installing of the brush seal on the rotor can be seen in this picture. Once we are be satisfied with these results at this juncture, the next step will be to go to the Army Research Lab Vehicle Propulsion Division, Bob Bill and George Bobula, testing this seal on a T-700 engine. If this phase proceeds in a good way we have commitments from Allison, John Munson and Westinghouse (Ray Chupp) agreed to help us test these seals both on jet engines and power generating turbines. Of course the complications are quite different. The problems that are going to be involved are quite different since the device that would have to be built for this industrial turbine are a lot larger diameter than for a jet engine. So there will be other problems to handle over there. But we think that if we can prove that the prototype is working in these two stages, people will have practically no resistance in going forward from there. During all this period, Durametalllic which is our main collaborator in this project who has taken the time to remodel the face seal if there is a need for such a redesign. And further on we have projected interactions for the Phase III that I'm not going to actually bother you with. So pretty much at this point in time we are on schedule with generating our prototype and probably December starting to test this.

Will Shapiro showed some work he is doing with Stein Seal that prompted me to show some work with hydrostatic seals and you were talking about doing experiments to obtain the discharge coefficients we have from another effort that is sponsored by Pratt & Whitney. We have generated a computer code that can model flow in a variety of pockets, a variety of pockets with restrictors with a variety of restrictors figures 10 (a), (b), (c.). This is a 3-D Navier-Stokes based code. One of the main reasons we designed this was to actually do update the discharge coefficients. So if you have an interest in doing something analytically before you do something experimentally, probably this code will do it for you. One last thing that I will like to show is that some of the results obtained from modeling some of the flow with this pocket is 3-D, figure 11. A very interesting finding is the following. In fact in a pocket of a hydrostatic bearing, the flow that comes out, at least according to this 3-D computer program that we have, comes out through a cork screw effect axially. The flow screws itself out and very little flow actually does go out circumferentially. The thing that really surprised us was this corkscrew effect here. You can see the flow going through the restrictor and there is a corkscrew effect that lets it go out in axial directions. For a hydrostatic pocket, these six pockets, like you see here, figure 12, this is the type of 3-D pressure profile that we have obtained, figures 13 (a) for a dimensionless velocity (or Reynolds number) of 8 that shows the restrictor jet velocity recovery effect on pocket pressure; it spikes and Figure 13 (b) at U=12 the effect is mitigated. Now this is not for cryogenics, this is only for oil. The problems with the cryogenics is that they have such low viscosity, there is so little dampening in that system that the calculation just goes hay wire unless you manage to increase the number of grid points to a very high level. A good point, you are basically left with the conclusion to calculate and modify those hydrostatic bearings like this for cryogenics for instance you will actually need parallel computers to work the problem.

QUESTIONS

Q. Your brush seal with the spiral groove face seal is a very interesting concept. Two questions. Obviously your whole brush is going to be rotating at some velocity relative to the shaft to some point and how do you find that point?

A. It depends on which velocities it is going to rotate. What is happening is this: The brush rotates with the shaft and when you get to a certain speed the centripetal forces may make the bristles to lift off. As soon as the bristles lift off the brush will slow down as soon as the brush slows down the bristles fall back on. We actually did make the calculation.

Q. What happens on the deceleration when the rotor decelerates faster than the brush?

A. That's a very good question. In fact it is very interesting. There are two things that you can do all right. We found out that actually when you decelerate, it can also happen when you are accelerating, if you are concerned that brush stays there. You go against the grain okay. It's actually going against a grain, at least for the experiments have been done that we have tested. The prototype experiments were up to 10,000 rpm, that was a pretty different install we were working in. What happens there when you go against the grain actually the bristles do not get destroyed. In fact if any slipping occur before starting to go against the grain stops any slipping and the brush rubs into the shaft. In fact one of the titles of brushes that we worked with from Cross Manufacturing was a double brush where the bristles are like this. (Shows X) For our concept, going against the grain is an advantage. That sounds strange, but it's true.

Q. It seems to me that the proper design is a very tricky operation. You really have to look at the stiffness of the bristles and design it around a certain speed. Have you considered what would happen if the bristles wear and the stiffness changes? And also the effect of pressure on that stiffness.

A. But that is exactly the whole point. The whole point of this device is that the bristles won't wear.

Q. What about the pressure effects on the stiffness? That is a factor.

A. When we designed the project, we have calculated the bristles against bending and against buckling and against lateral bending. What would happen with pressure I don't really know.

B. That would be very interesting to see that calculation.

A. We have a team workshop next year? (We're still planning that.) I will report next year. Hopefully I will have a prototype to show you. But one of the major benefits of this device is that you should never have to replace the brush. If you have to, then you can throw the whole concept away.

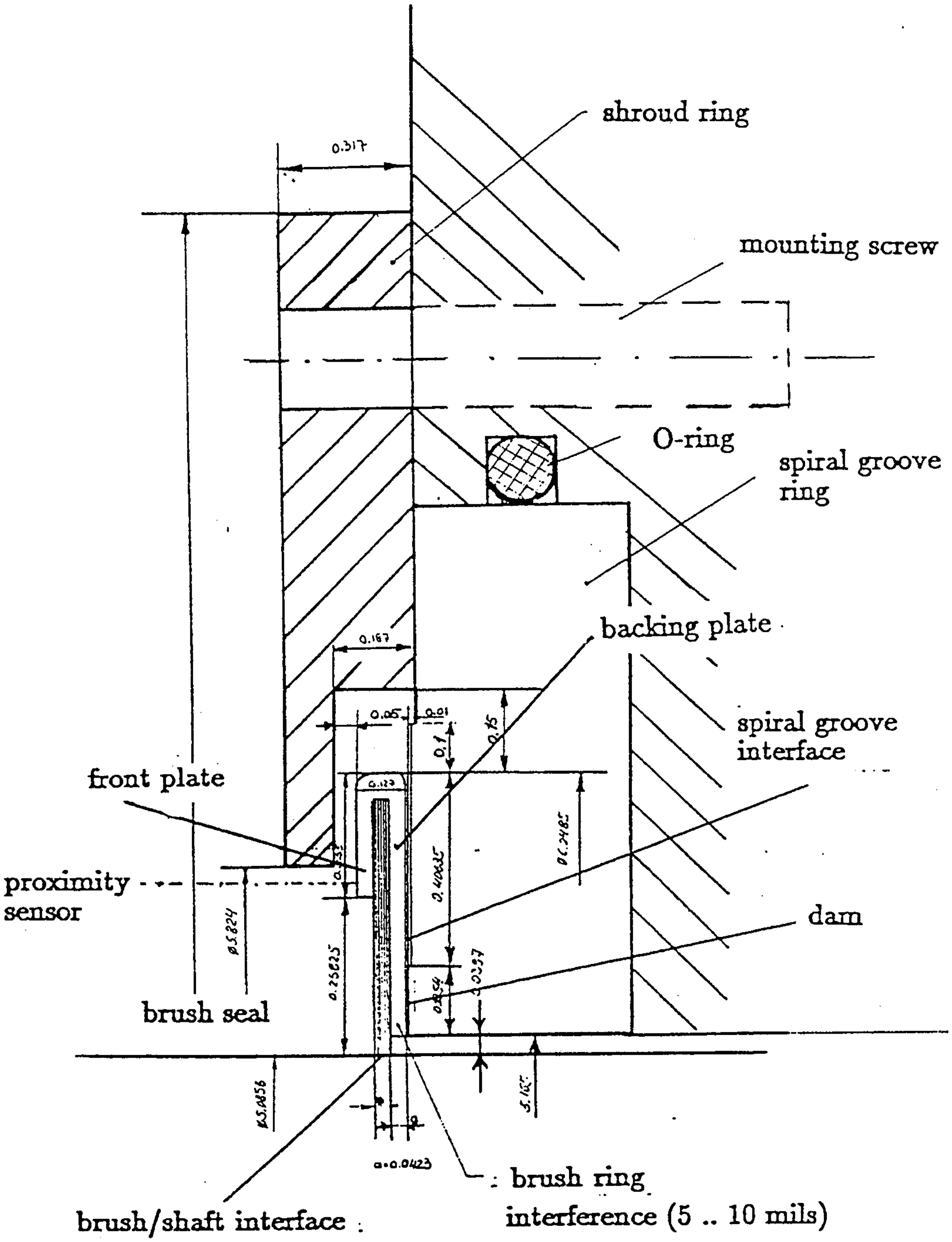


Figure 1. Schematics of the Floating Brush Seal

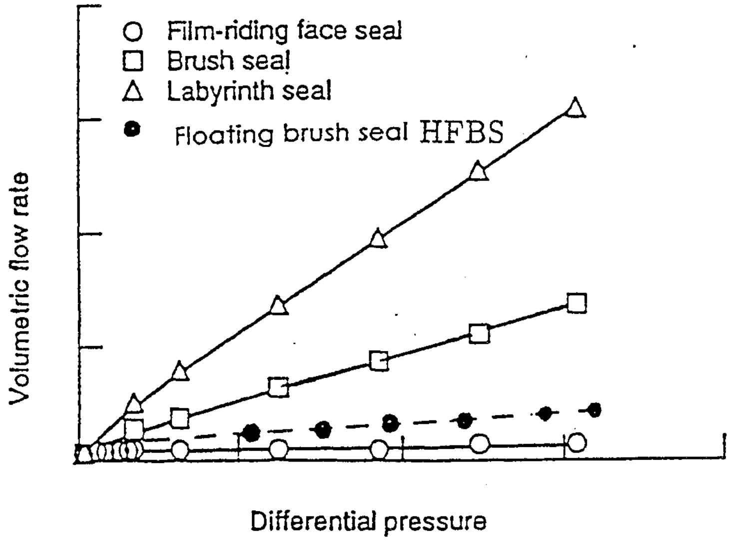


Figure2a. Floating Brush Seal Performance Expectations

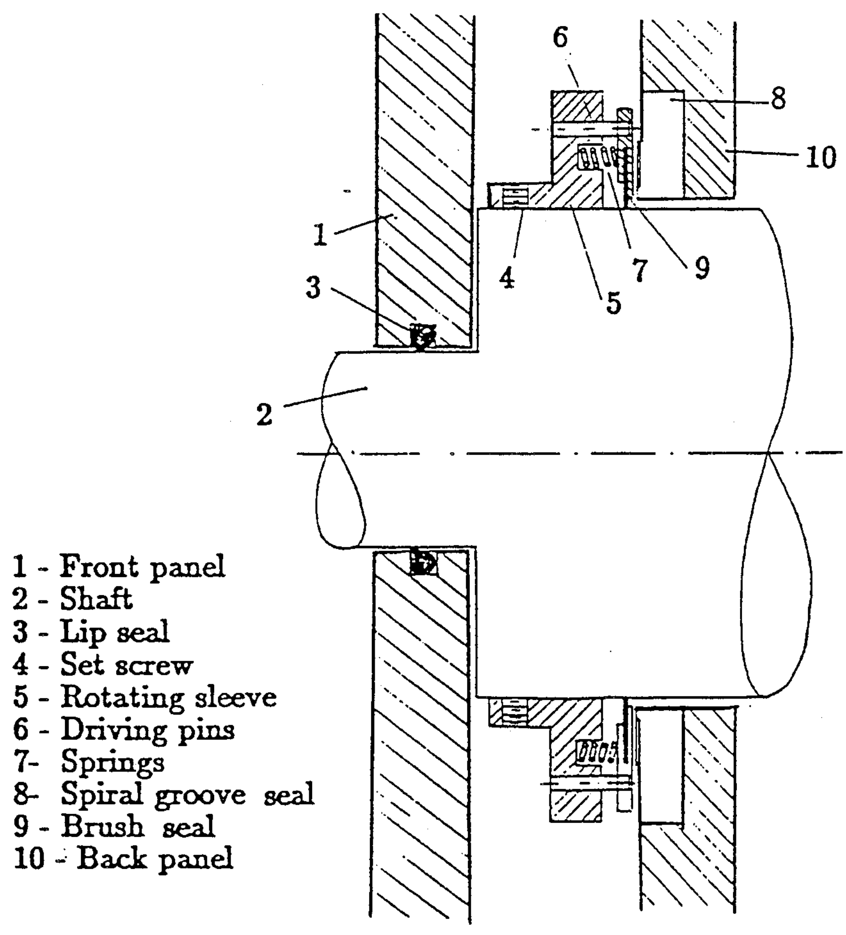
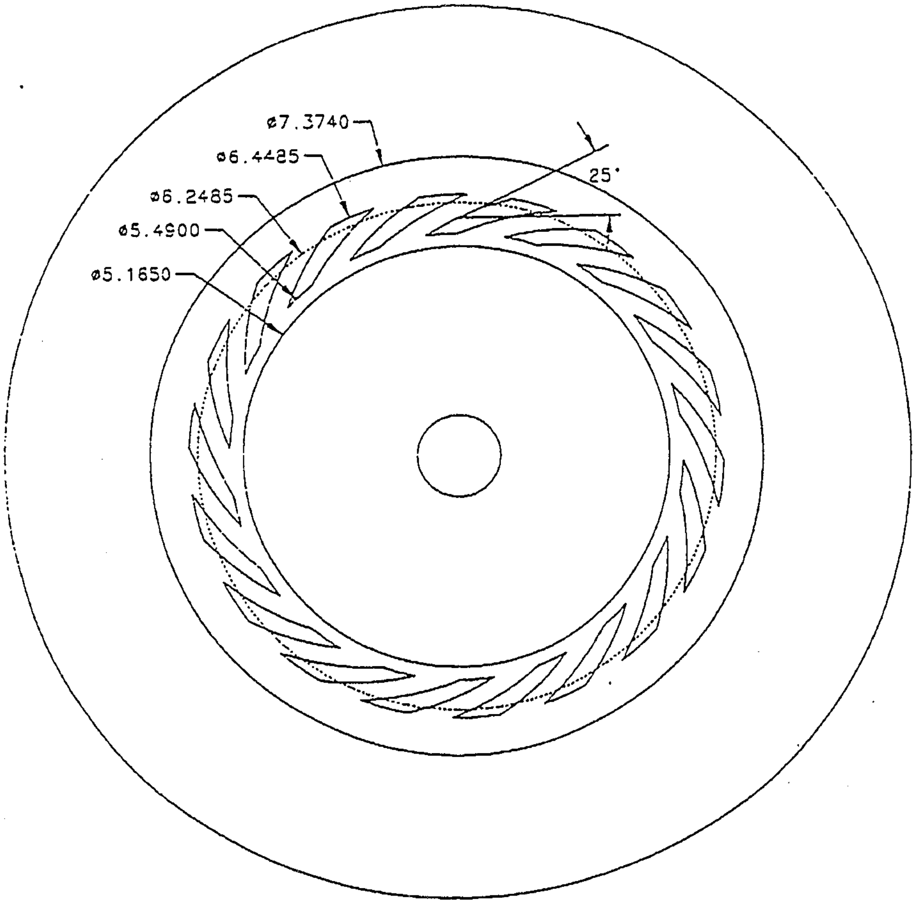
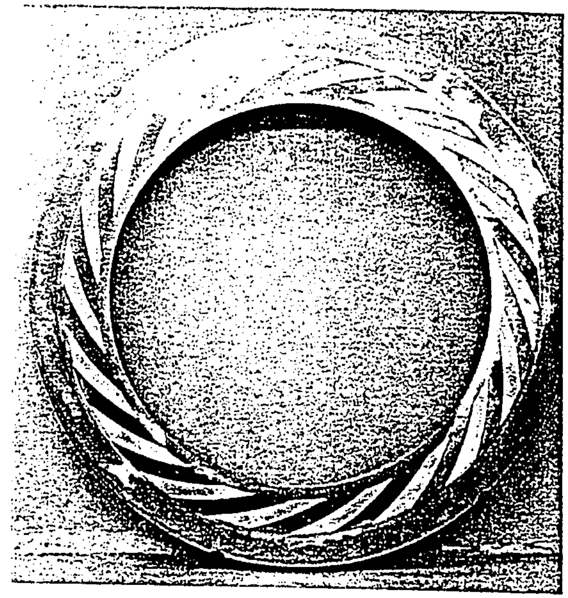


Figure2b Schematics of the Floating Brush/Mechanical Seal Assembly

CENTRAL to the overall concept is that the relative motion has now been shifted from the shaft/bristle interface to the interface between the brush backing plate and a spiral groove seal(SGS). The backing plate is in relative motion with respect to, and supported by the SGS. Thus the brush will start rotating in phase with the shaft, there may be some small slippage, but any high speed relative motion between the two will be practically eliminated.

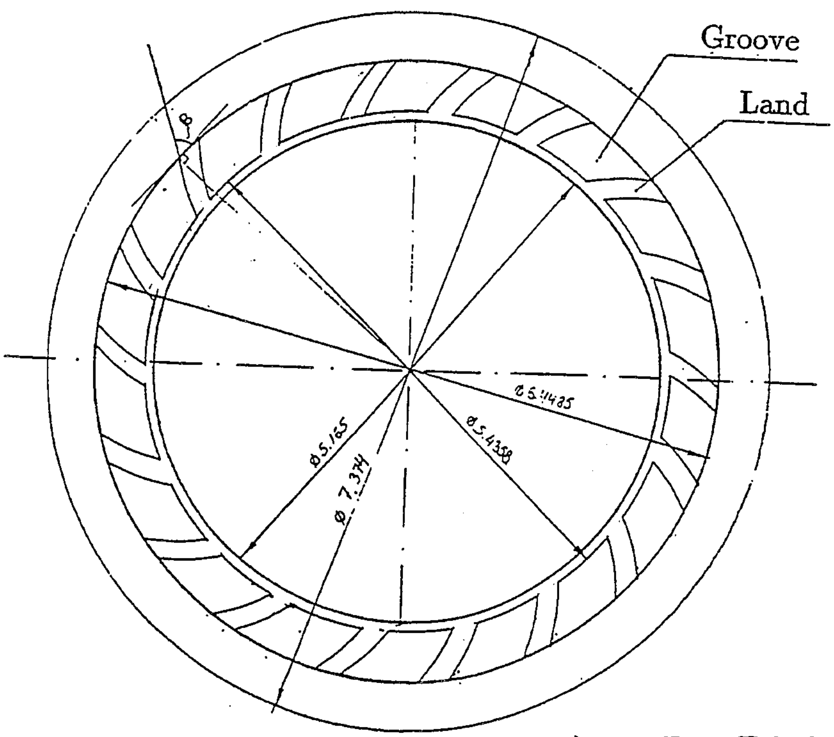
Figure 3

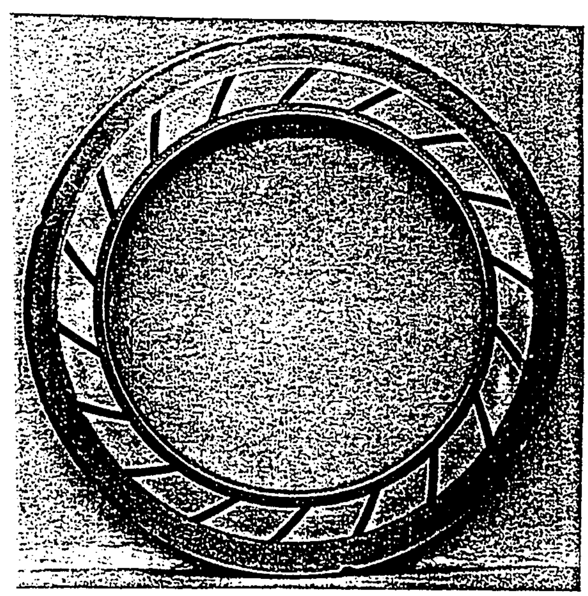




Standard Design

A)Standard Design Spiral Groove Seal

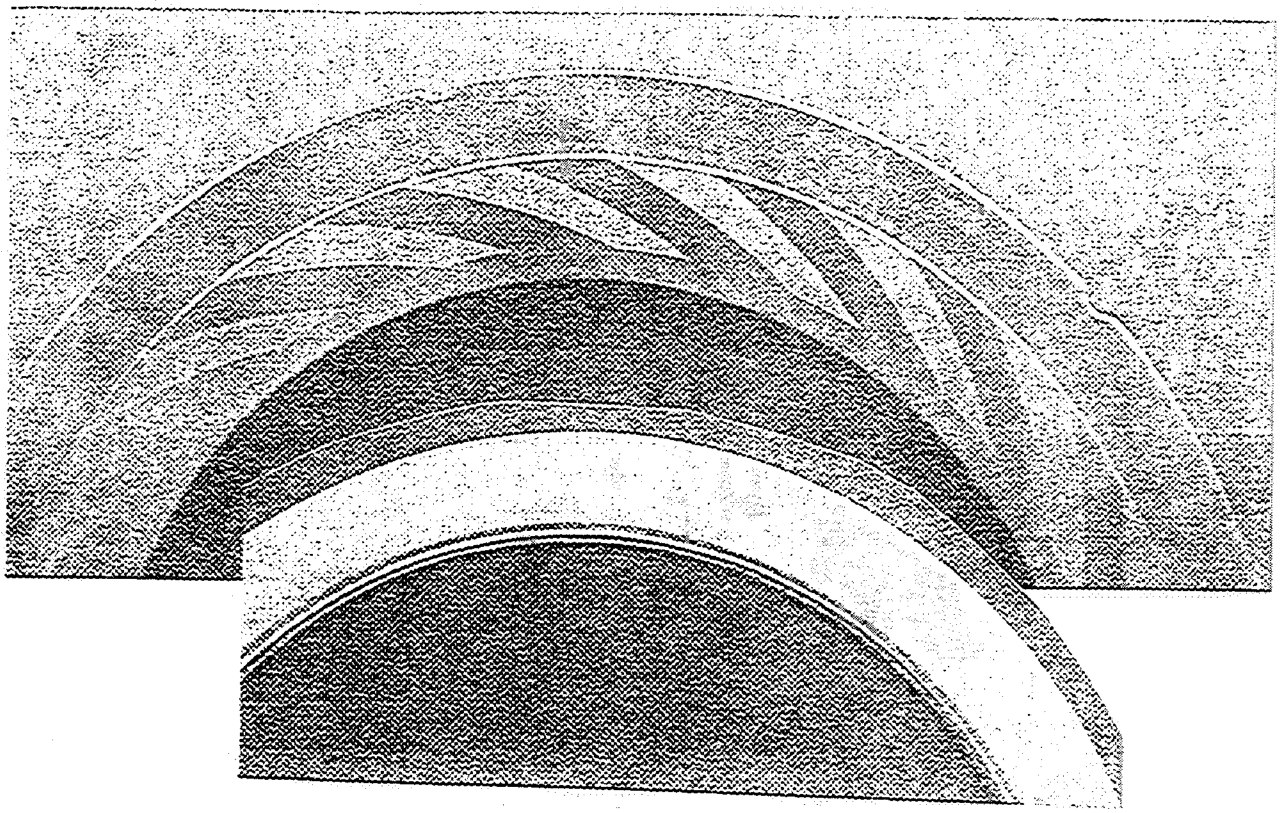




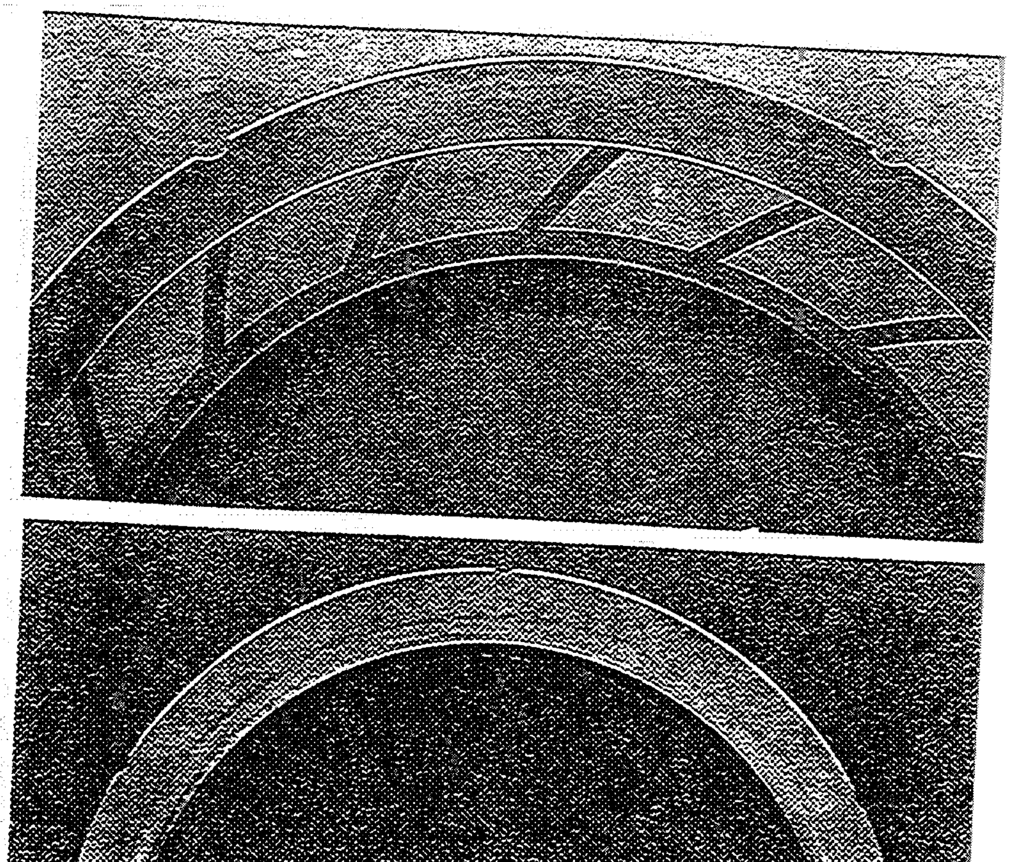
Optimized Design

B) Low Face Friction Spiral Groove Seal

Figure 4(A,B). Spiral Groove Seal



A) Second Version EFBS/V2



brush used with collar/springs assembly

B) First Version EFBS/V1

Figure 5 (A,B) Face Seal Contact Surfaces after the Experiments

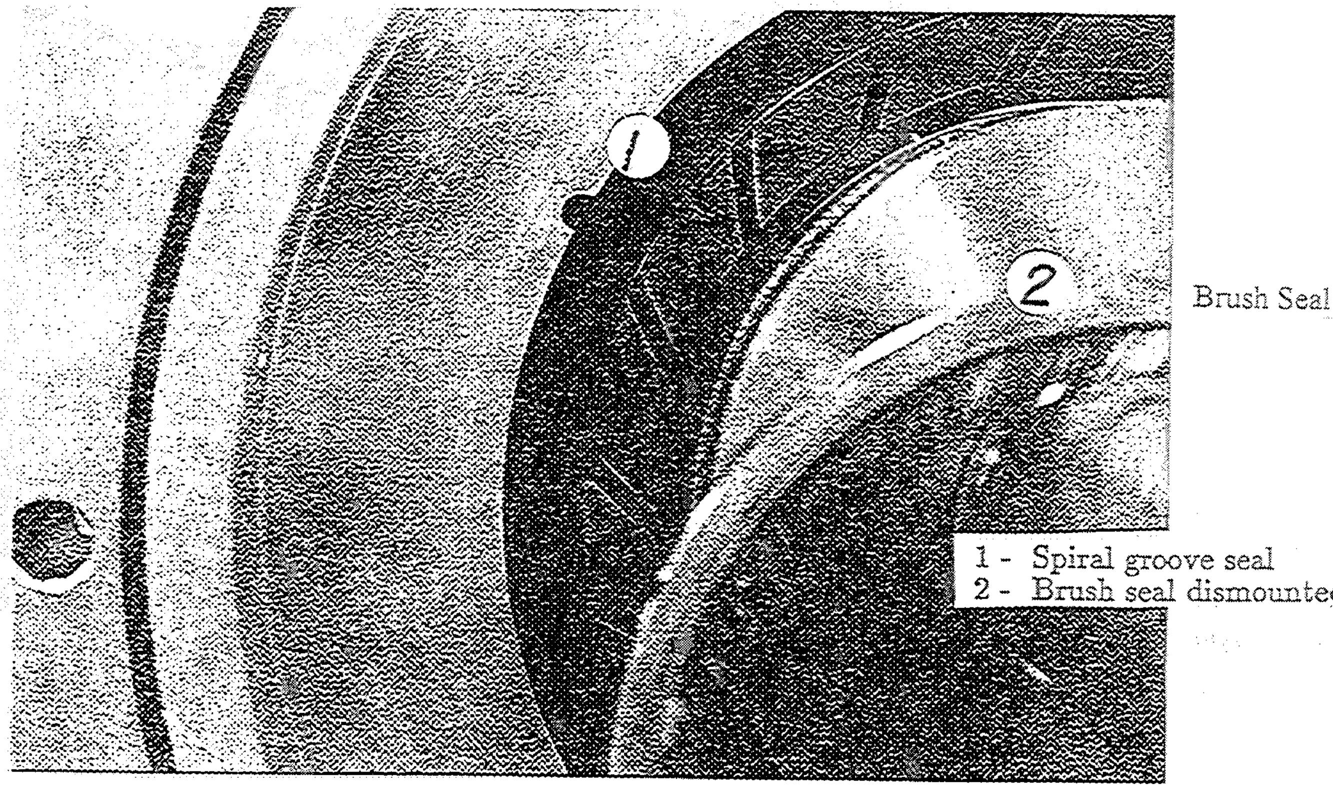


Figure 6 A Spiral Groove Seal Mounted in the Housing

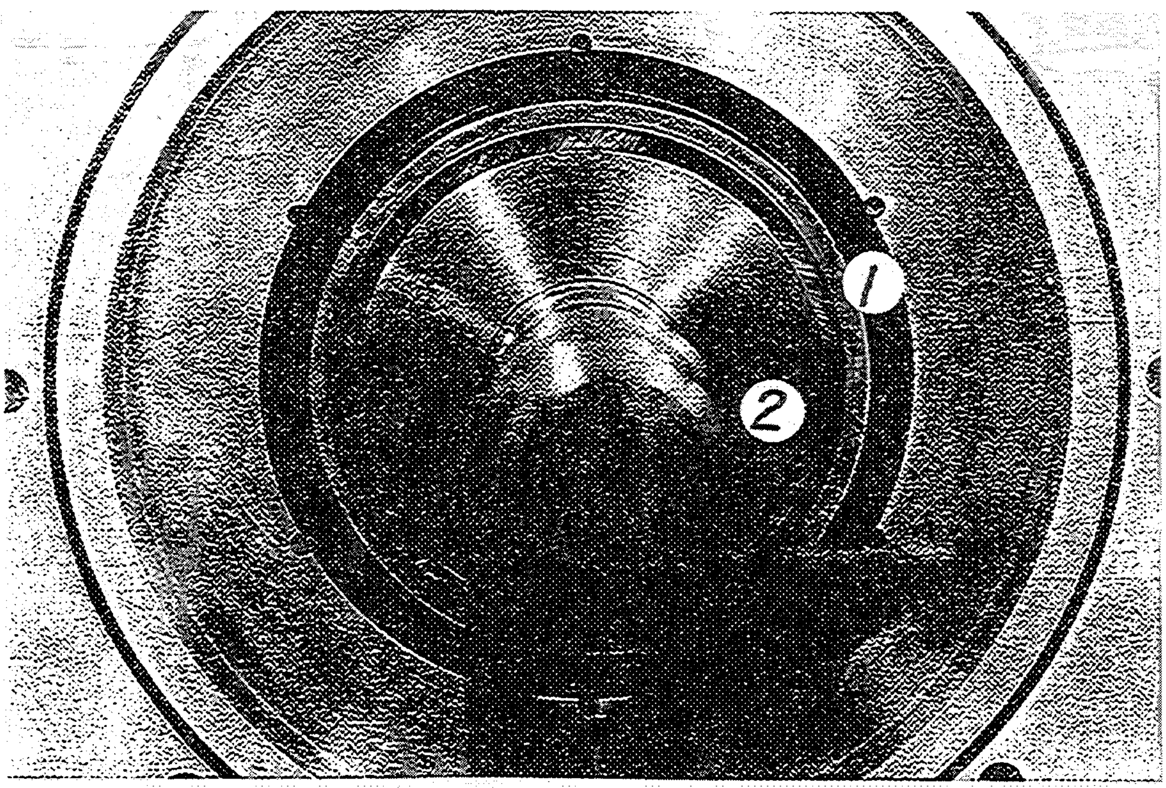
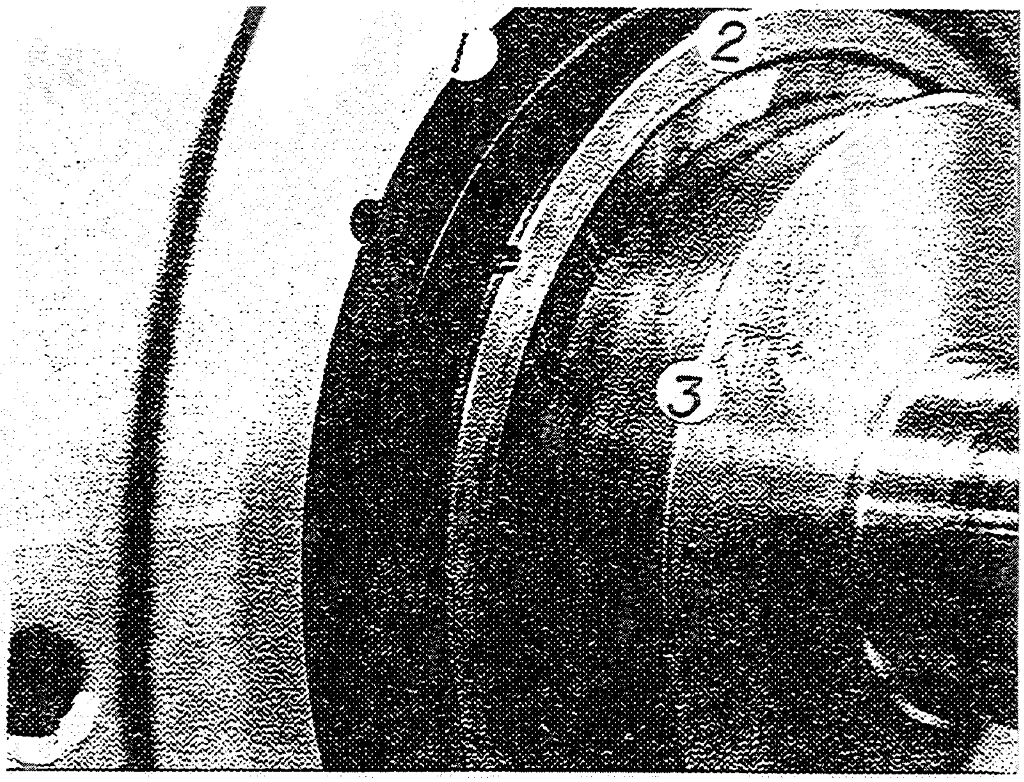


Figure 6 B Shaft/Brush/Spiral Groove Housing Assembly

1 - Brush seal against Face seal
2 - Rotor



1 - Spiral groove
2 - Brush Seal
3 - Rotor

Figure 7a Detail of the Hydrodynamic Seal Assembly
(Housing/Spiral Groove Thrust Bearing/Brush Seal)

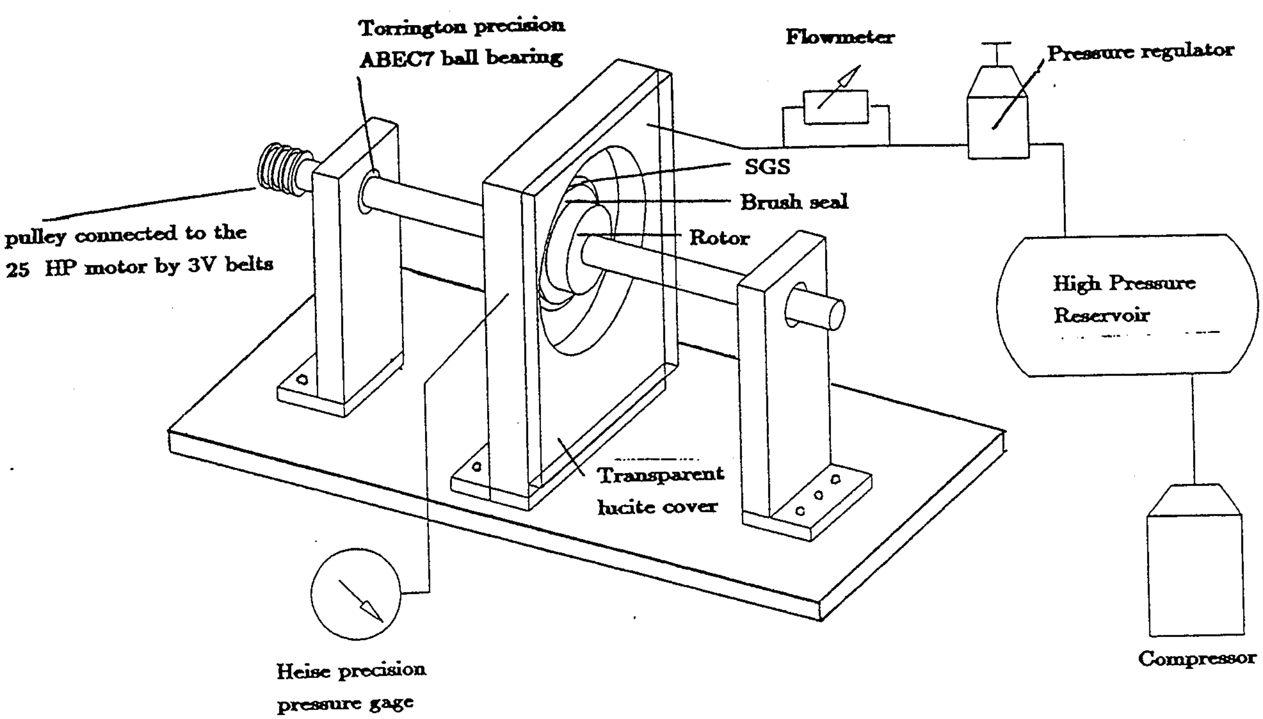
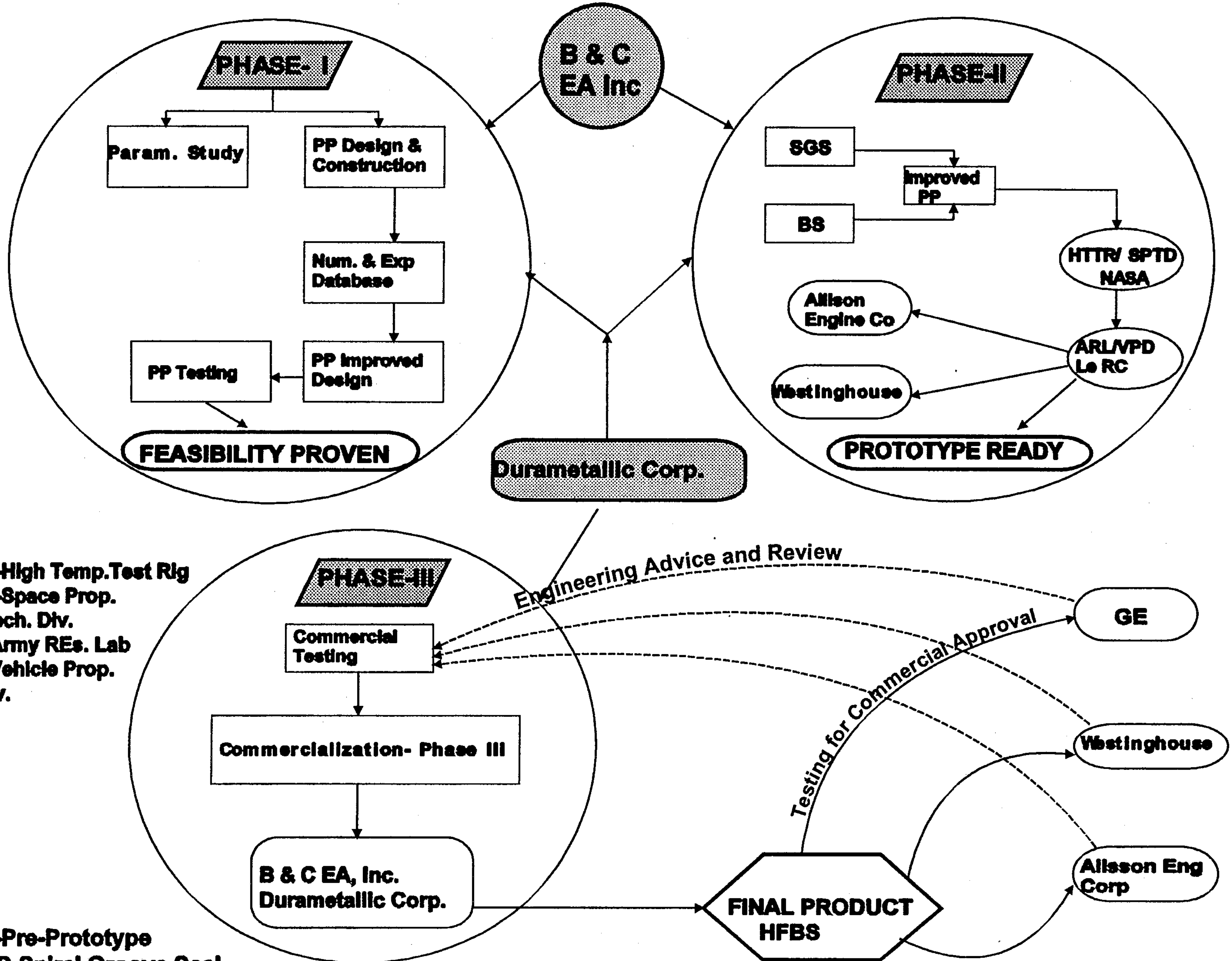
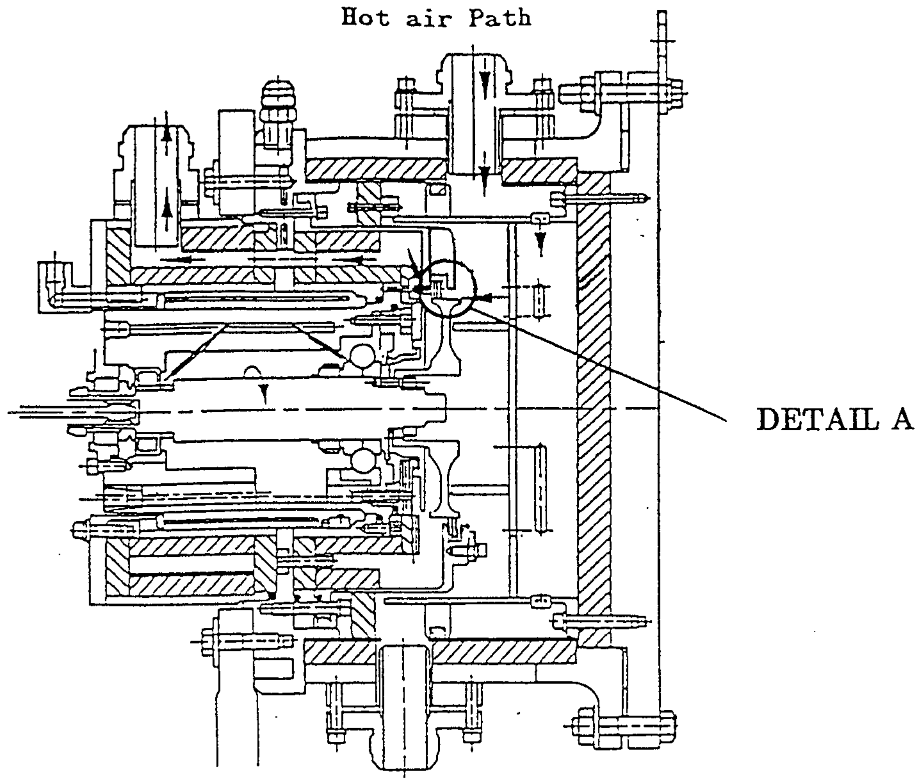


Figure 7b Test Rig Schematics



HTTR-High Temp.Test Rig
SPTD-Space Prop. Tech. Div.
ARL-Army REs. Lab
VPD-Vehicle Prop. Div.

PP-Pre-Prototype
SGS-Spiral Groove Seal
BS-Brush Seal



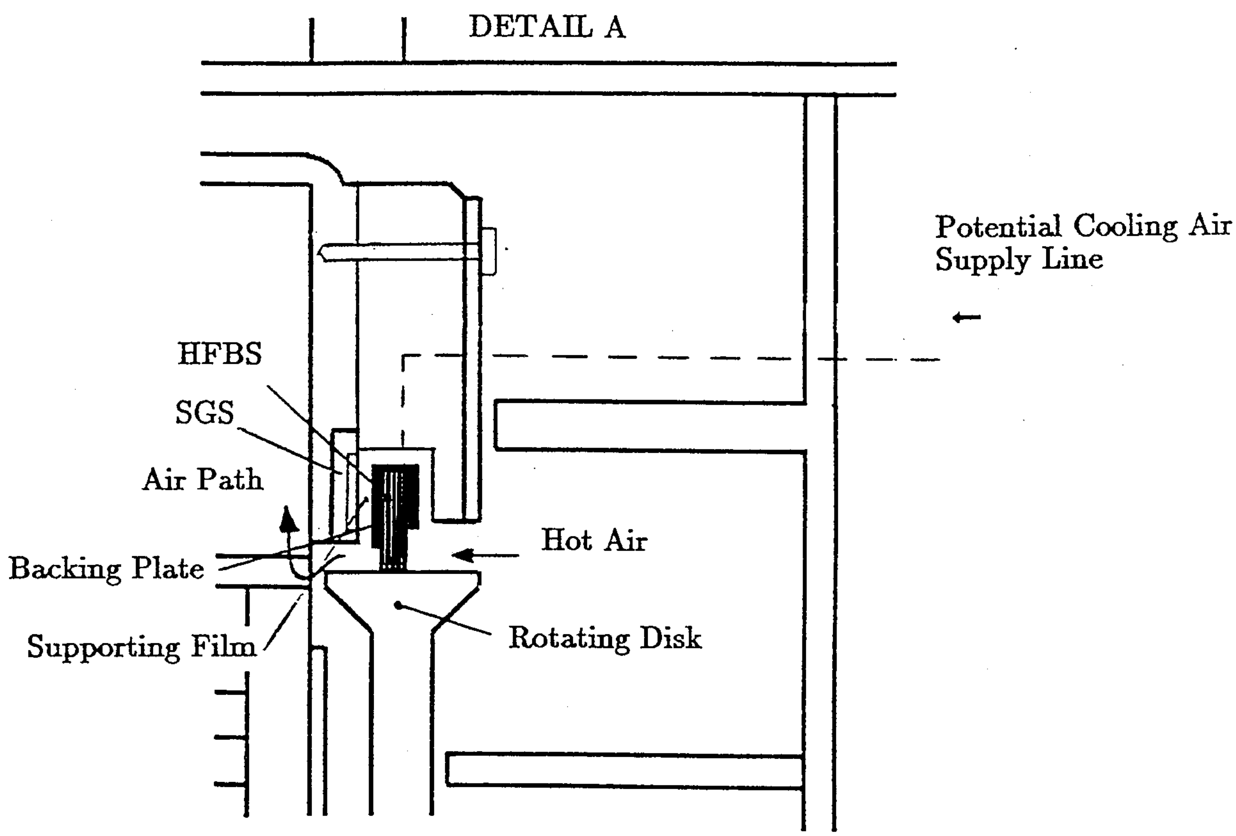


Figure 9 NASA HOT GAS TEST RIG

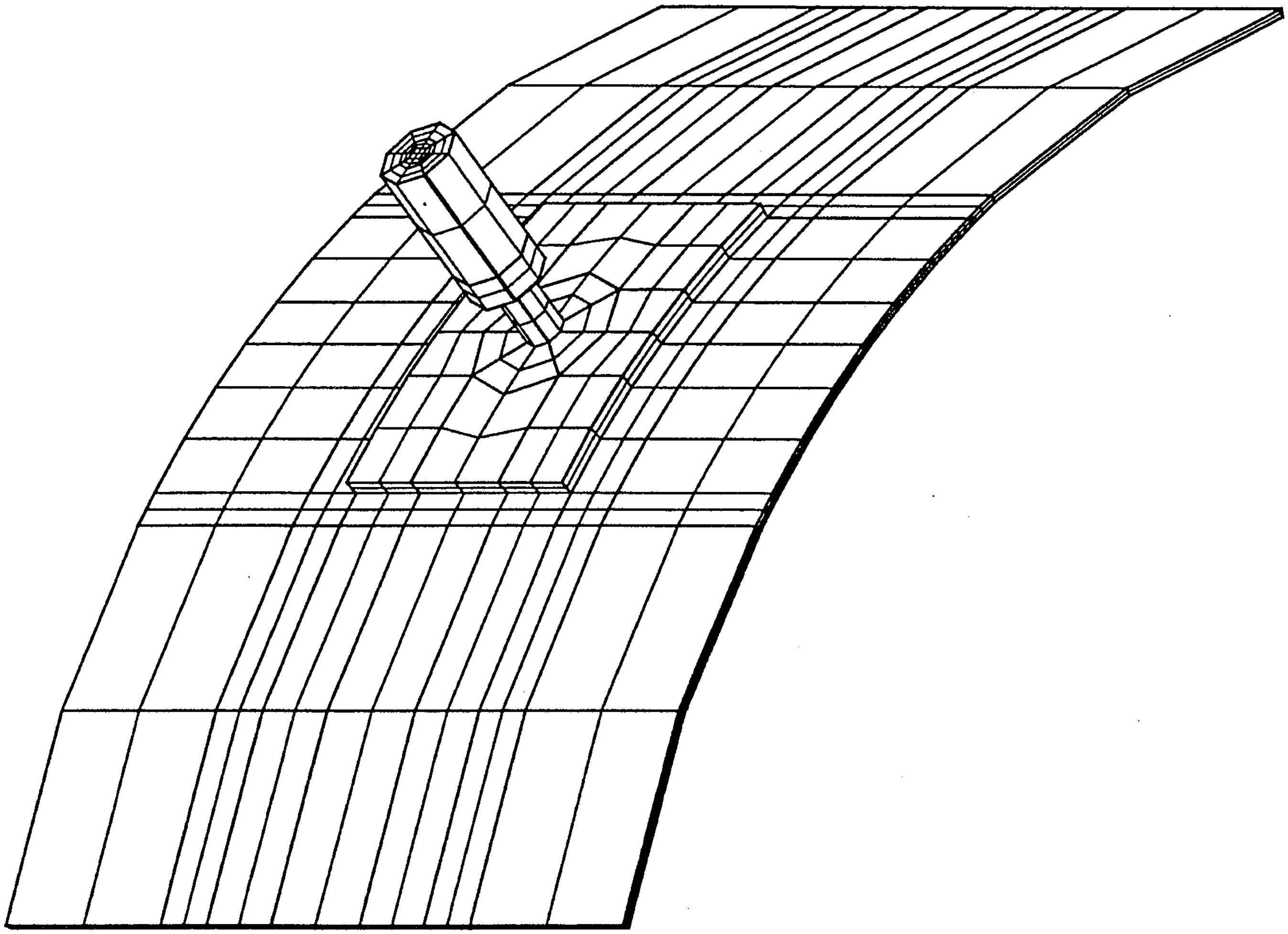


FIGURE 10(a)

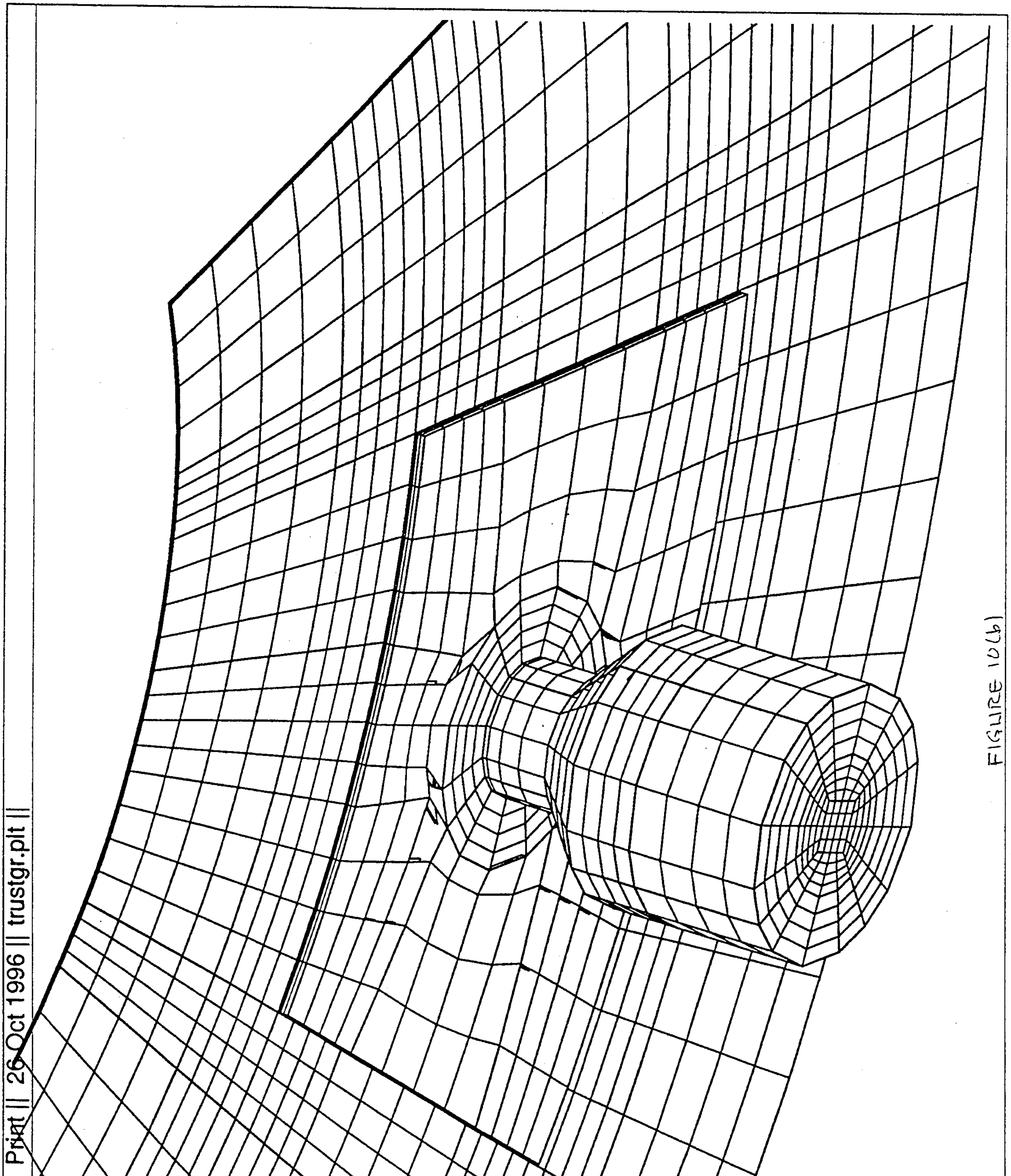


FIGURE 10(b)

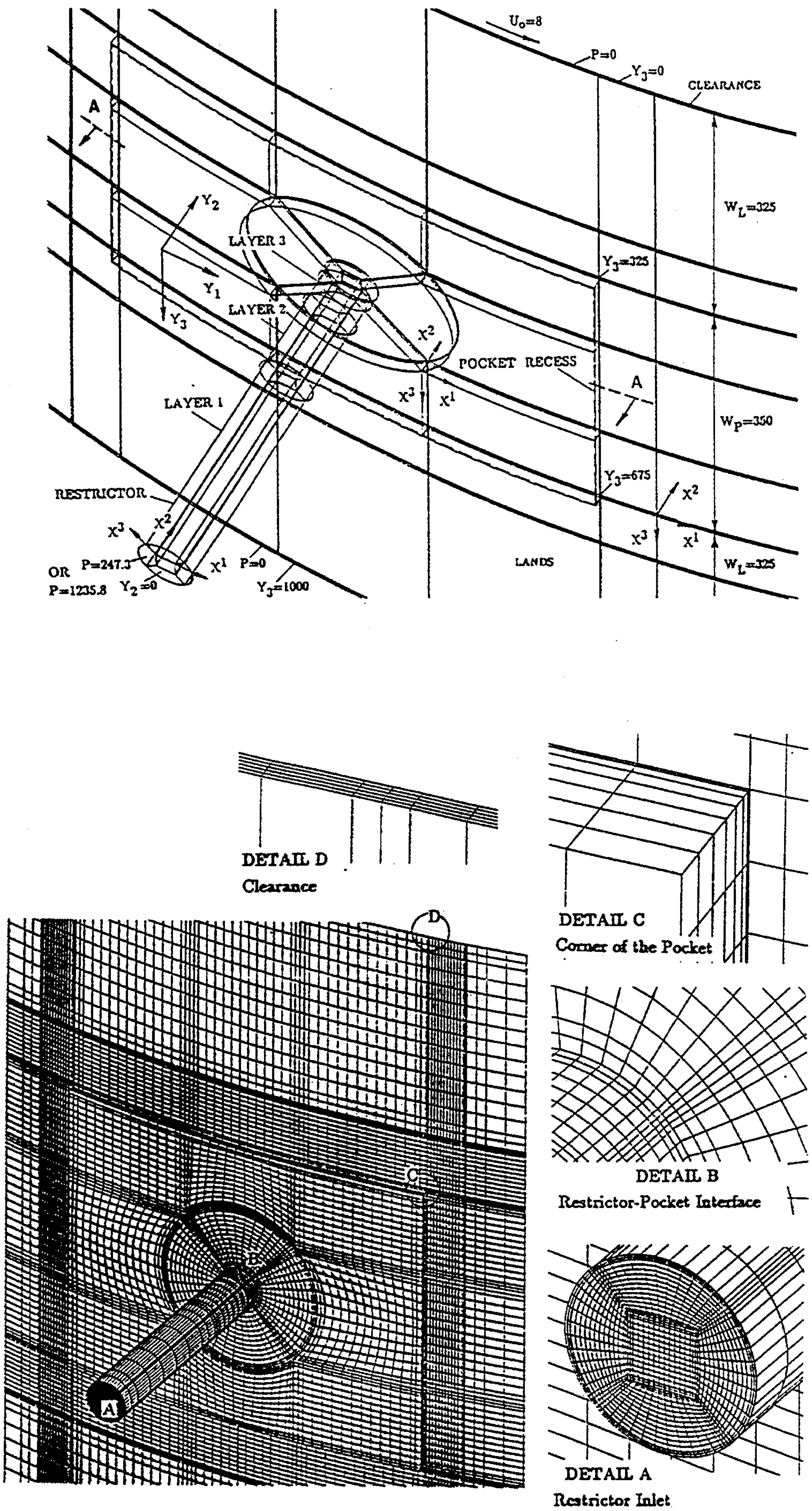
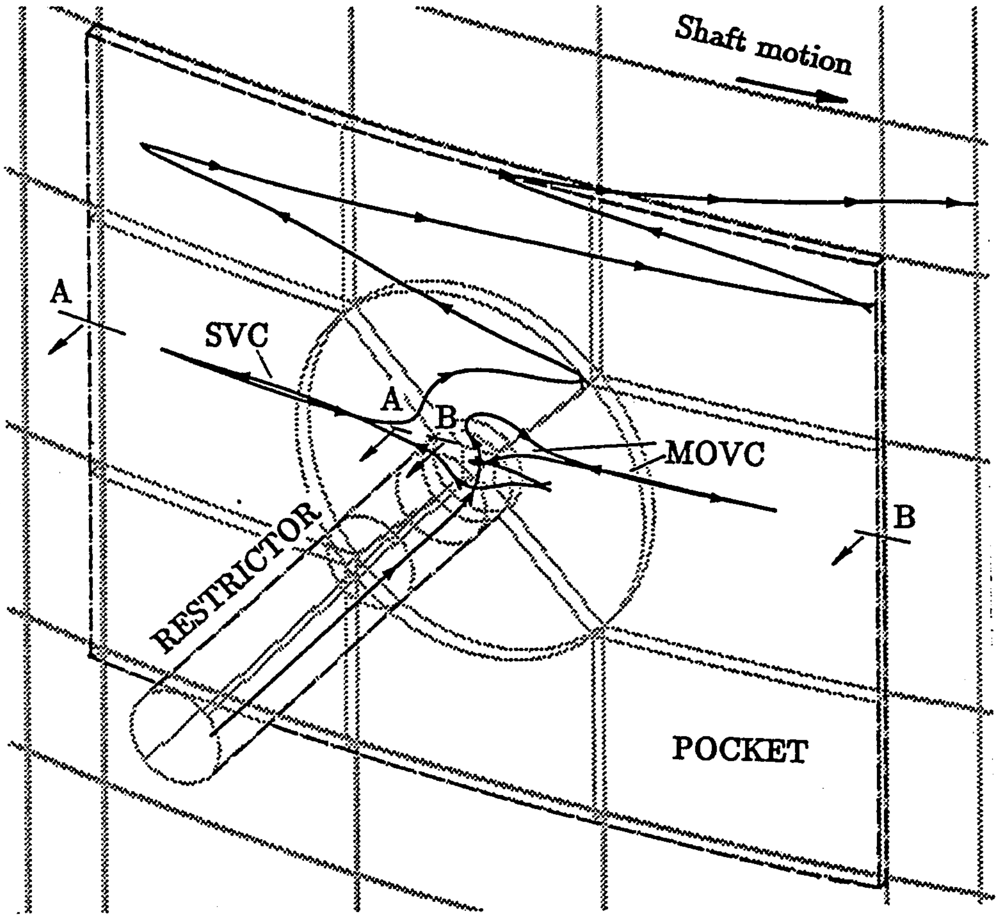
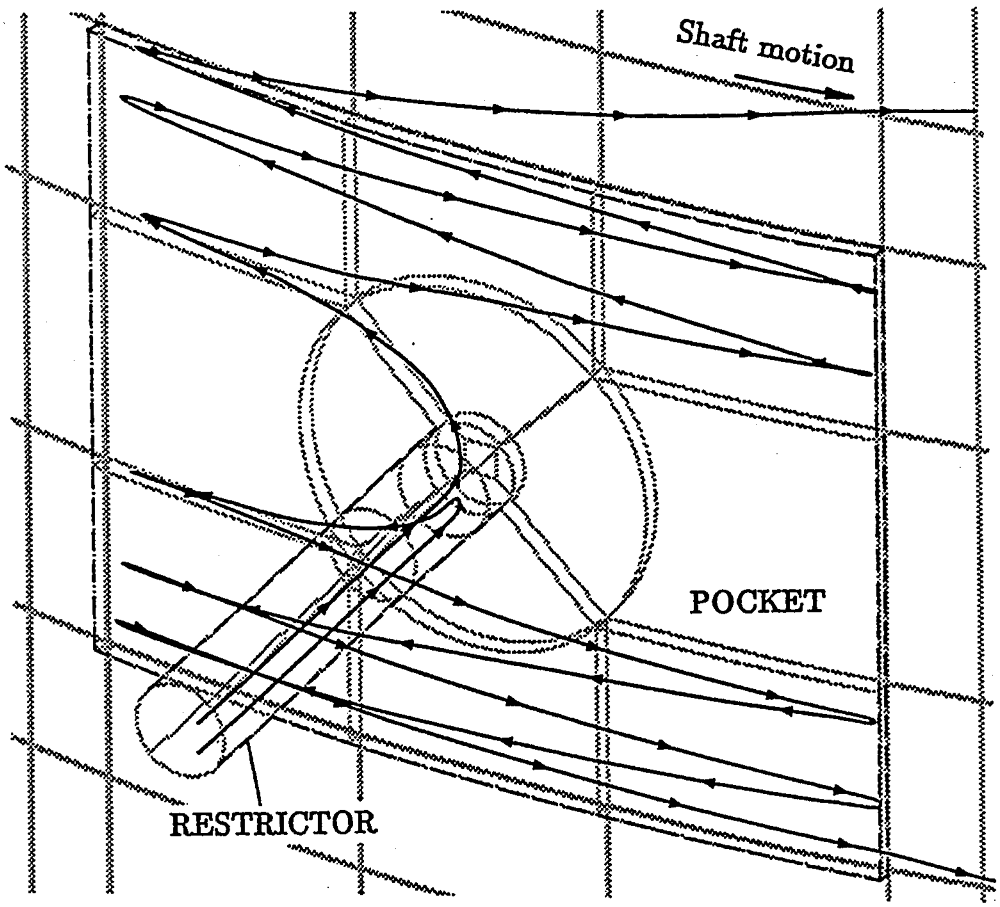

U₀=8
P=0
Y3=0
CLEARANCE
A
Y2
LAYER 3
Y1
Y3
LAYER 2
X2
POCKET RECESS
X3
X1
LAYER 1
RESTRICTOR
OR
P=247.3
P=1235.8
Y2=0
P=0
Y3=1000
LANDS
Y3=325
Y3=675
WL=325
WP=350
DETAIL D
Clearance
DETAIL C
Corner of the Pocket
DETAIL B
Restrictor-Pocket Interface
DETAIL A
Restrictor Inlet
D
C
B

FIGURE 10(c)



(a)



(b)

Fig. 11 (a) Particle streakline visualizing the three dimensional MOVC, the SVC and their interaction

(b) Particle streaklines visualizing the spiral flow moving axially out of the pocket for Couette dominated flow

(3D) || Print || 27 Mar 1995 || 3dhdbopn.plt ||

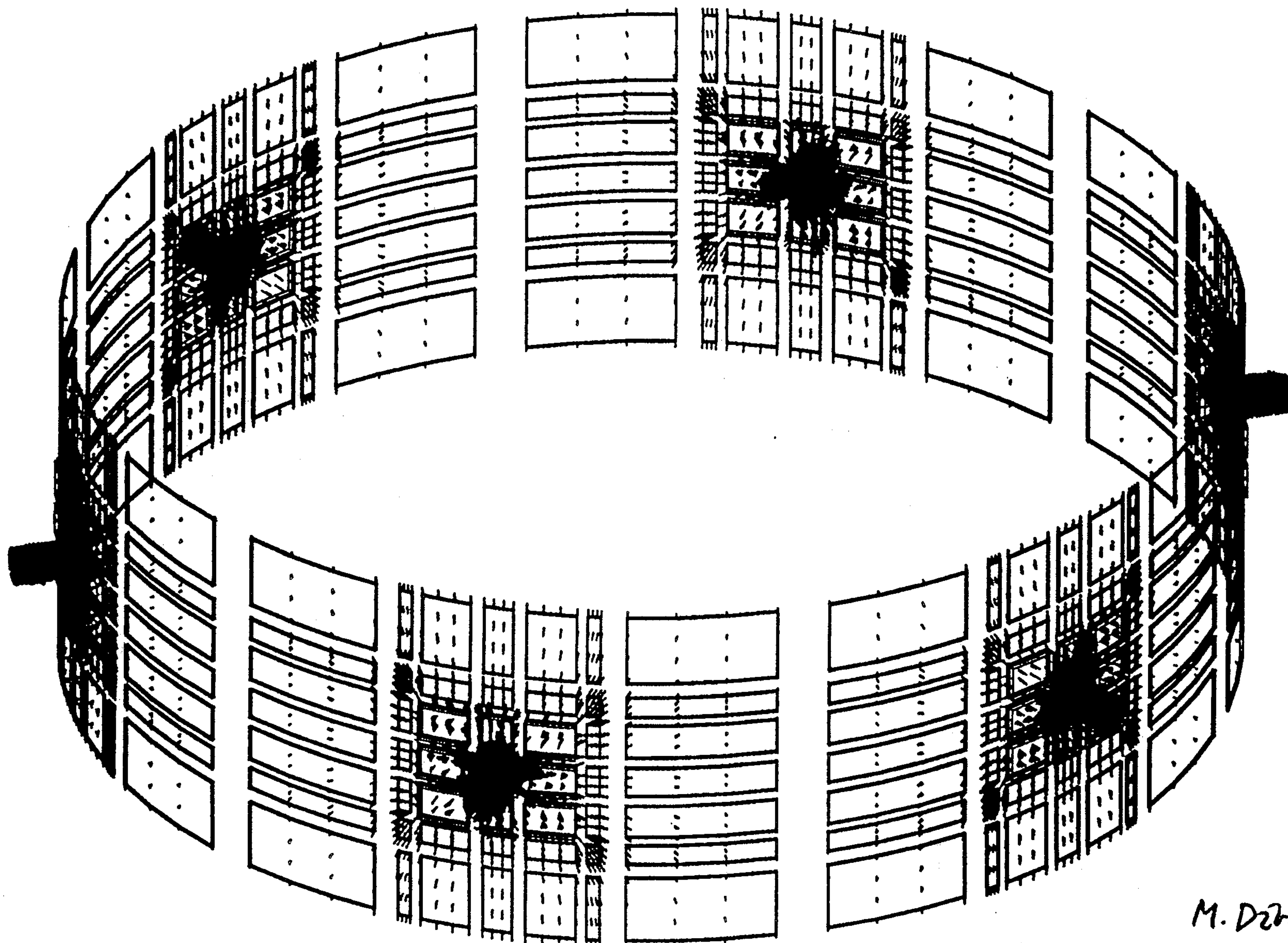


FIGURE 12

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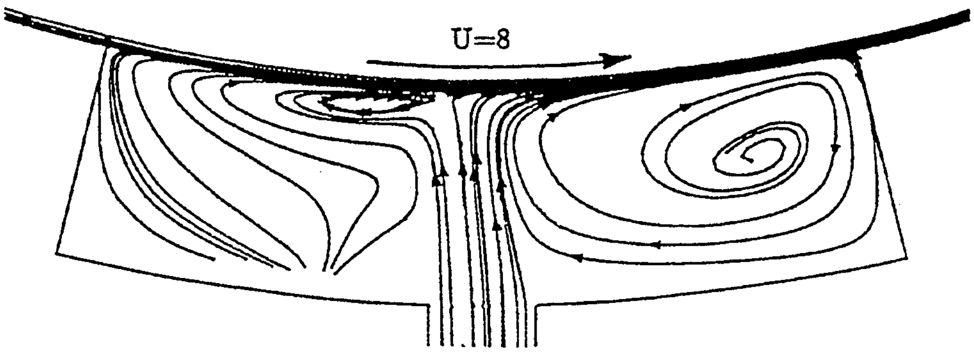


- FLOW PATTERNS IN THE SYMMETRY PLANE OF THE THREE
NSIONAL DEEP POCKET (Re=U=12 P=24.9, C=6.7)

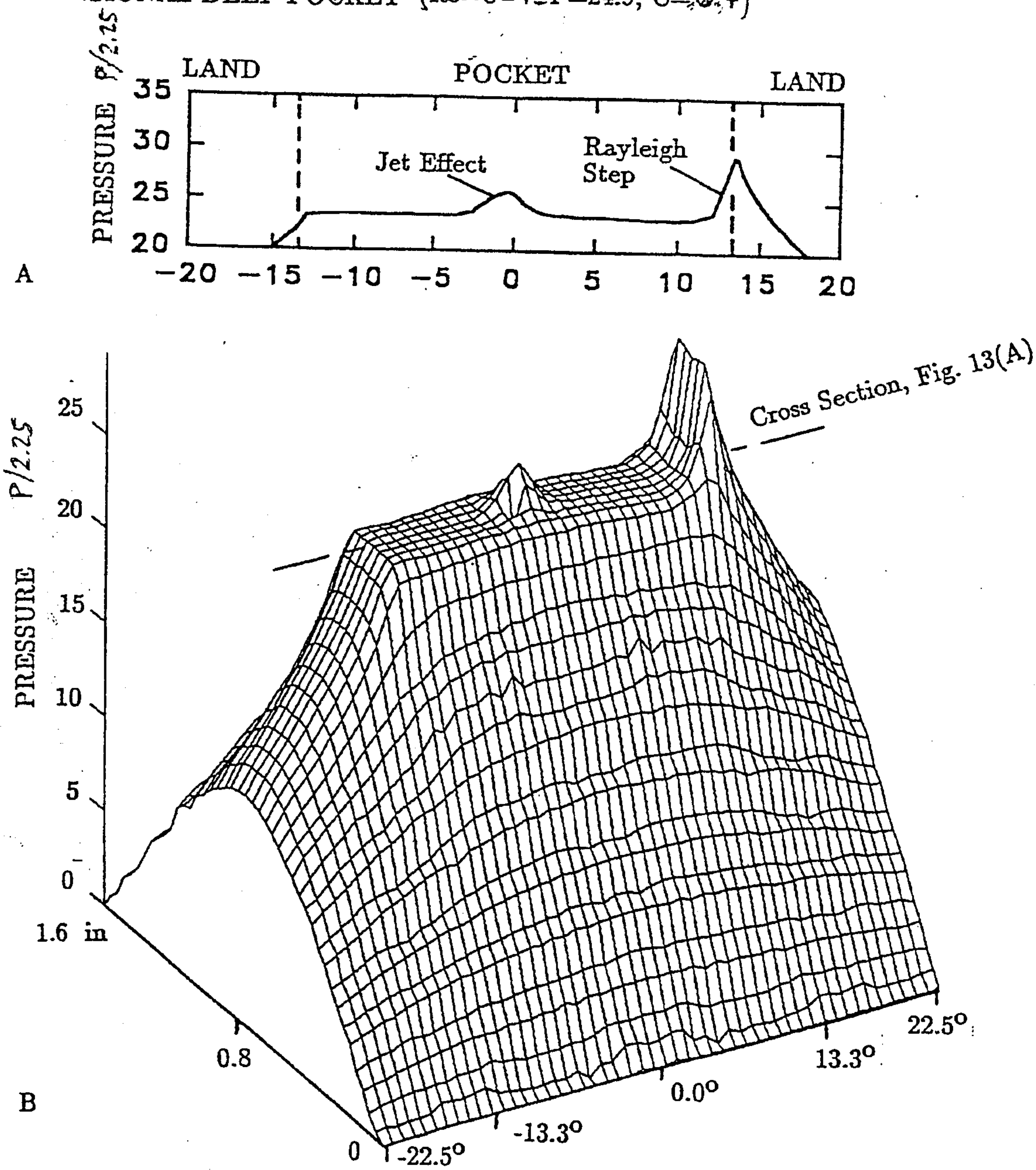
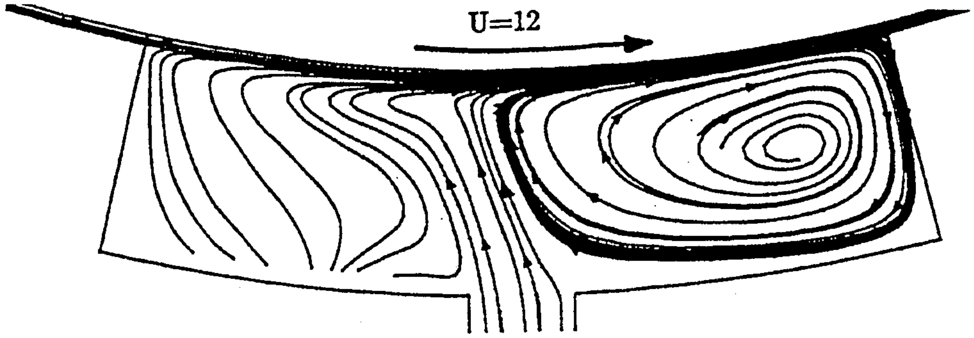
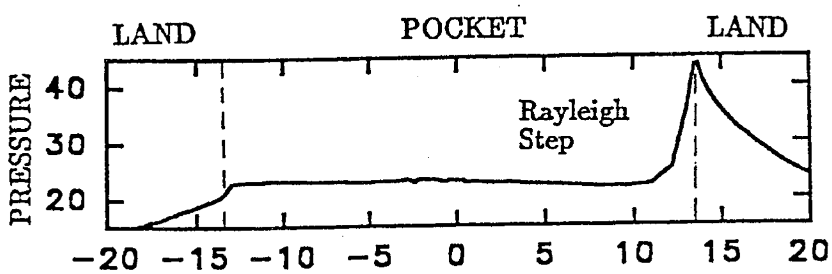


FIG. 13(a) PRESSURE DISTRIBUTION UNDER THE RUNNER FOR THE THREE DIMENSIONAL DEEP POCKET. (Re=U=12 P=24.9, C=6.7)



FLOW PATTERNS IN THE SYMMETRY PLANE OF THE THREE DIMENSIONAL DEEP POCKET (Re=U=12, P=24.9, C=6.66)

A



B

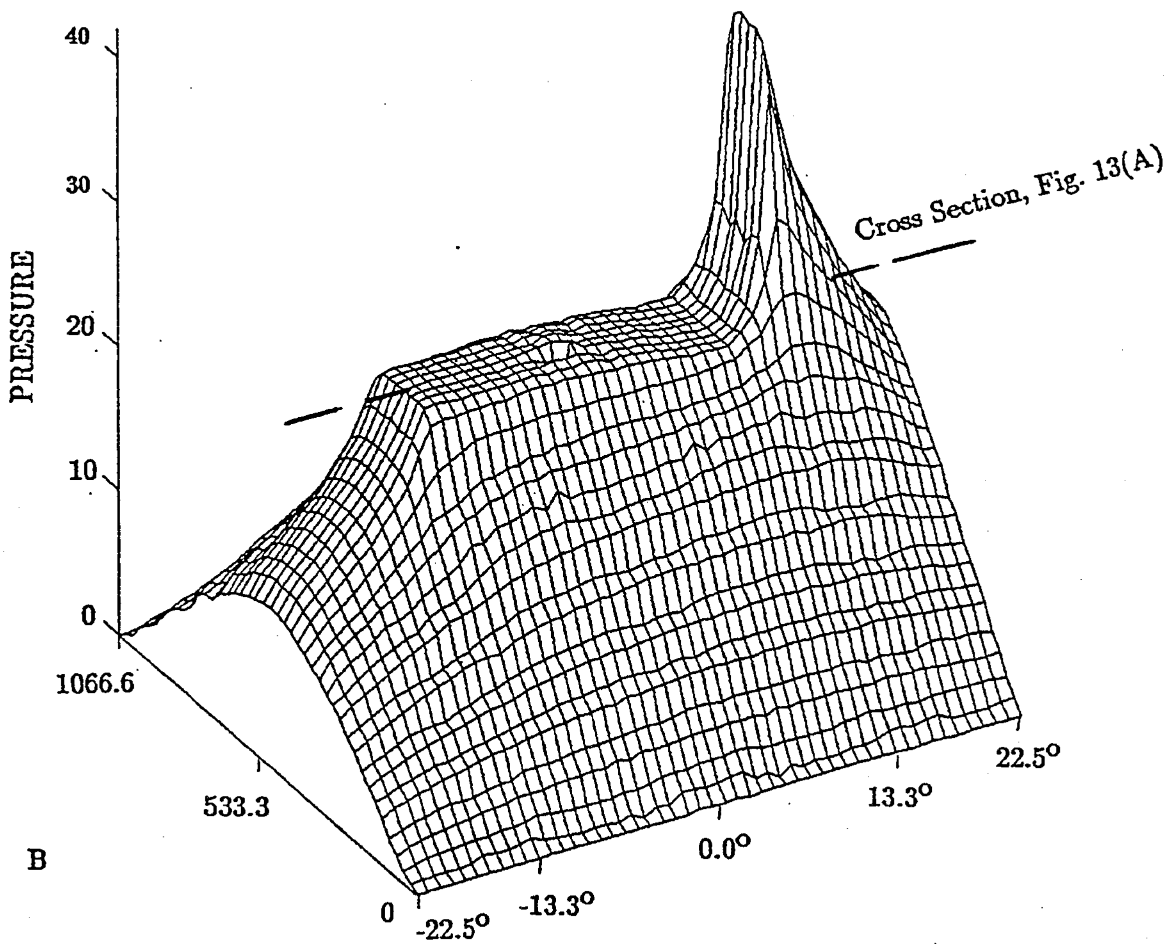


FIG. 13 PRESSURE DISTRIBUTION UNDER THE RUNNER FOR THE THREE DIMENSIONAL DEEP POCKET (Re=U=12 P=24.9 C=6.66)