WP 22

cfm international

DEVELOPMENT AND CERTIFICATION OF A RUGGED ENGINE RELATIVE TO FOREIGN OBJECT INGESTION

The CFM56

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1. SCOPE - FOREWORD

The design of the CFM56 has been accomplished by SNECMA and General Electric working together under the coordination of CFM International which is a company established and jointly owned by SNECMA and G.E. for the certification sale and support of the CFM56 engine.

The CFM56 engine is of the class of 20 to 27.5 Klb thrust (9257 to 12 728 daN). This high by pass engine is typical of the new generation of medium sized engines.

When this project was initiated, in the early 70's, three main targets were assigned to the engineering groups :

- Low fuel consumption
- Low noise and emissions
- Ruggedness

The choice of an appropriate thermodynamic cycle, joint to an extensive refining, allowed to achieve a high thrust-to-weight ratio, low noise, low emissions and low specific fuel consumption.

The ruggedness was a matter of intensive testing and research in order not only to comply with certification requirements but also to achieve the lowest operating cost and the highest reliability.

The engine design (cross section) is shown in Fig. 1 : it consists of a dual rotor, variable stator, high bypass ratio turbofan powerplant designed for subsonic service.

The design and the configuration of the engine is based on obtaining long life, high reliability and easy access for line-maintenance.

The fan rotor consists of one full-diameter single stage fan and a smaller diameter 3-stage booster for the core engine flow.

All the fan rotor components are made of titanium.

The fan blades are designed for high performance, large

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CFM56 Engine

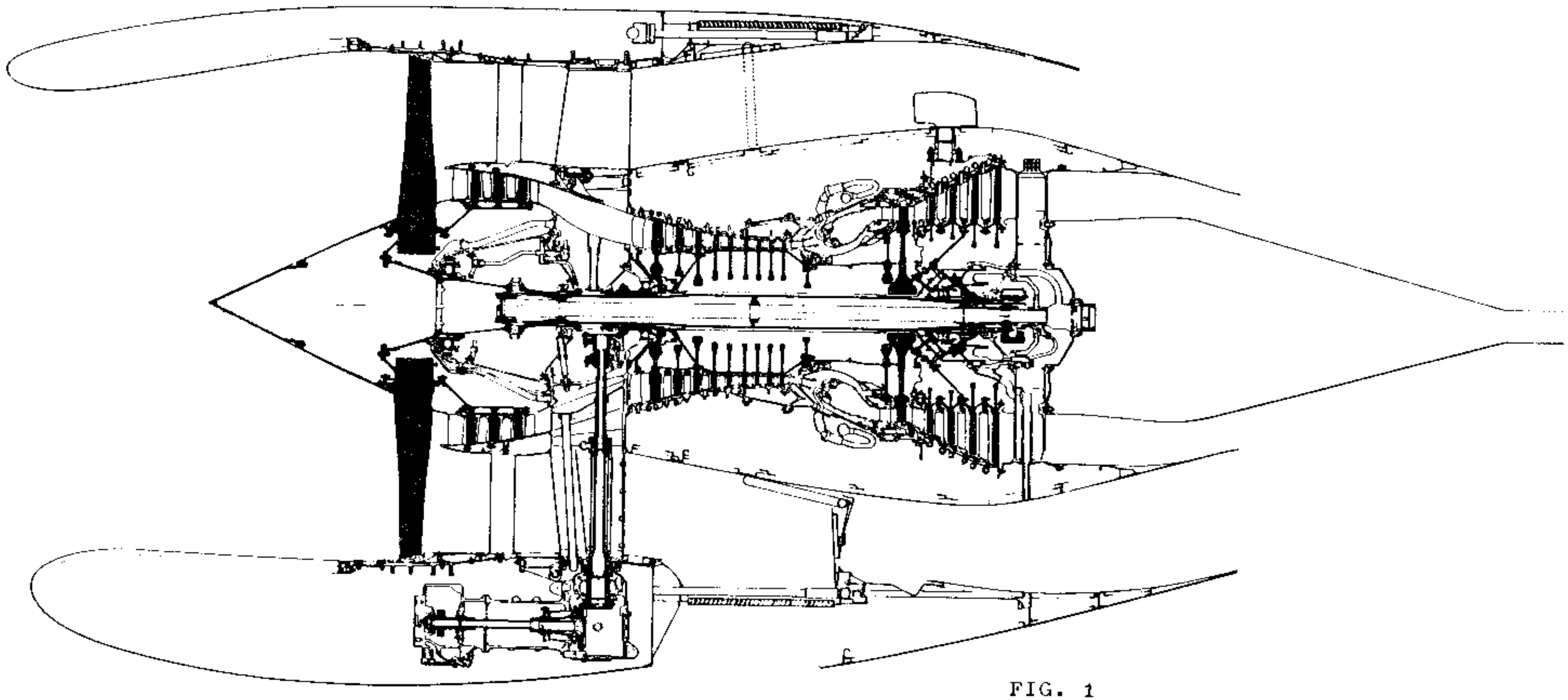

FIG. 1
CFM56 ENGINE
MOTEUR CFM56

stall margin and ruggedness. This difficult compromise was reached by adopting a specific feature, which is to our knowledge the first application in the world on a civil engine, namely the tip shrouds/snubbers.

The HP compressor is a nine-stage design, driven by a single stage HP turbine. The LP turbine consists of a 4 stage-rotor which drives the fan rotor through a concentric shaft.

2. CERTIFICATION REQUIREMENTS

Since the beginning of the project, both American and French Type Certificates were sought.

This implied that satisfactory evidence should be shown to Agencies in order to fullfill specific certification requirements such as FAR Part 33 for F.A.A. and JAR-E for DGAC. .

In other words, the certification programme resulted from the addition of two sets of requirements.

Specifically, the foreign object ingestion activity was set up in order to include all ingestions required by the two Agencies.

The ingestion programme was divided into three families.

(1) -One engine affected : No hazard to the aeroplane.
Engine shut down allowed

- One fan blade
- One 4 lb bird
- One tire tread

It is obvious that the secondary damage that could prevent from fullfilling the above criteria of compliance, were a direct result of the engine total out of balance. It was then agreed by the Authorities that the demonstration could be done by analysis supported by component tests, and by officially running on the engine the most severe of the three above cases.

(2) -More than one engine affected : 75 % of take-off thrust capability

- Seven 1.5 lb (medium) birds in less than 1 second (FAR 33 ; JAR-E required only 5)
- 4.5 OZ of gravel
- 31.5 OZ of sand.

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(3) - <u>More than one engine affected</u> : no power loss

- Hailstones : - 25 off 2 in. diameter (51 mm)
  - 25 off 1 in. diameter (25,4 mm)
  - volley in less than 5 seconds
- Ice from inlet : no deicing during 30 seconds
- Water : 4 % of mass air flow.

It appears immediately that the above list of official ingestions to be performed was highly severe and that in the past no existing engine had to ingest so many foreign objects to comply with two requirements at a time.

But in the mean time it must be said that the potential risk of ingestion incurred by a flying engine is still actual and cannot be ignored ; the certification requirements were considered realistic. But by ingesting all the above objects, CFM INTERNATIONAL considered that this was not sufficient to show the actual ruggedness of the CFM56.

It was decided to widen the ingestion programme by adding extra severity tests, such as : ice slabs, spinner cone, several 4 lb birds etc., to the strictly required tests.

The final target was to show an extremely good margin, in terms of primary and secondary damage to engine parts, so not only certification requirements could be met but also high reliability, low refurbishment cost and high safety, by keeping the damage limited to the impacted components.

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3. CFM56 INGESTION PROGRAM REVIEW

3.1 Scope - Objectives

The ingestion activity was divided into two main families :

- Development tests, mainly on components to limit the total expenditure
- Certification tests only on engines.

The test period extended over four years (1975 to 1978). All the development tests were performed in France at SNECMA Villaroche plant for rotating components and CEPr SACLAY plant for engine tests and on static cascades.

The objectives were, as said before, of two sorts :

- Certification : to demonstrate compliance with both FAR and JAR-E requirements (which increased the number and the severity of ingestions)
- Cost and reliability : to keep the secondary damage as low as possible and limit the expenditure to the replacement of the impacted parts.

As an exemple, the objective on fan blades under medium (1.5 lb) bird ingestion was : no fragments on impacted blades to avoid secondary damage to remaining blades by debris flying back and forth.

To fullfill the above objectives about 8 sets of 44 each fan blades were destroyed during the tests (i.e. about 350 blades) ; also a complete booster ingested several foreign objects during spin pit tests and at the end it was considered out of service.

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All the bird ingestion tests were carried out using chicken bought from a local farmer : they were fed using wheat, corn, barley (no hormones) and were free in fields. They were killed at the right weight by suffocation using CO_2 gas, thus they kept in their body all matters, including blood. It is therefore considered that the hardness of their bones and the overall density were realistically duplicating actual bird characteristics although a little more severe due to wing lengths which were smaller than actual birds' ones.

3.2 Component tests

3.2.1 Static cascade tests

The first approach to ingestion activity was made by carrying out tests on static cascades of at least seven fan blades. These tests were run at CEPr Saclay using a vacuum gun and the first version of fan blade airfoil. One shot will be shown to you on the movie we have brought with us, and which will be commented by Mr Barrère.

The basic assumption was to duplicate engine running conditions i.e.

- impact velocity relative to blade
- impact angle relative to blade chord
- blade boundary conditions (tip and root)

by constructing the classical triangle of the axial, circumferential and relative-to-blade velocities.

The simulated aircraft speed was a typical take off maximum corresponding to 91 m/s (300 ft/s).

The following shots were performed :

- 6 shots of medium birds (1,5 lb, 680 g) from bottom to blade tips (91 m/s, 300 ft/s simulated)
- 7 shots of ice slabs (1 x 4 x 6 in, 25 x 100 x 150 mm) (sucked-in simulation)
- three shots of heavy birds (4 lb, 1810 g) (155 m/s, 515 ft/sec simulated).

Some fragments were generated at leading edge of blades when struck by the birds at a height of 60 % span or above.

Also tip shroud shingling (overriding) was experienced. Although not fully representative of engine conditions (no centrifugal field, for instance) it was forecasted that spin pin test could result in fragmentation for shots above 60 % span.

Figures 2 and 3 show typical fragmentated blades after bird strike.

3.2.2 <u>Spin pit program</u>

- <u>Objectives</u>

These tests were intended to establish the final design of the engine blading in order to successfully attempt the certification tests on a complete engine.

The two main objectives assigned to spin pit tests were :

. to confirm the static cascade test results in terms of fragmentation

. to define the change in design to blade airfoil, blade root and tip shroud to achieve the non-fragmentation target.

FIG. 2 - 1,5 lb bird strike on a static cascade
- Impact par un oiseau de 1,5 lb sur secteur statique

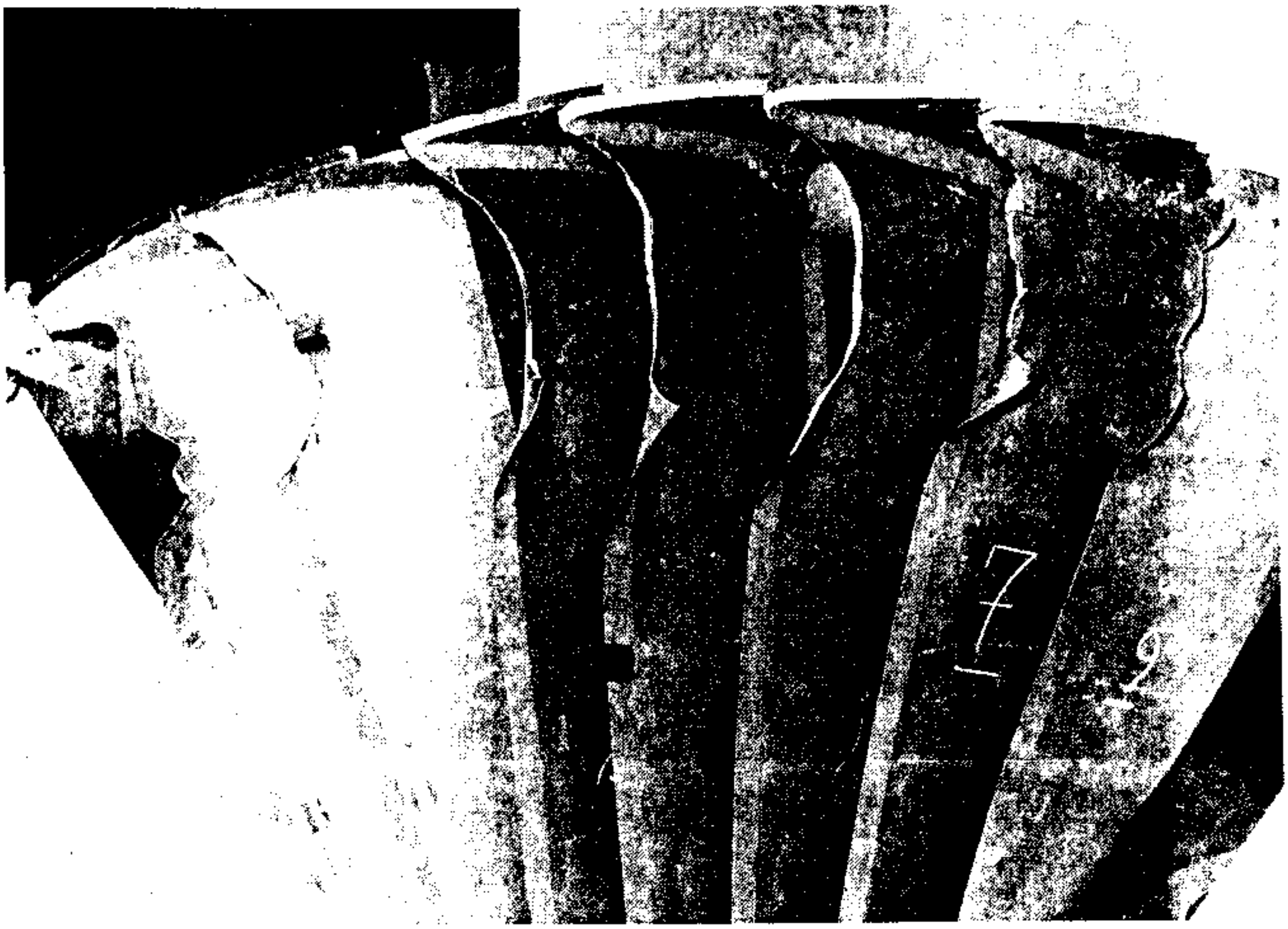


FIG. 3 - 4 lb bird strike on a static cascade

- Impact d'un oiseau de 4 lb sur secteur statique

- Test facility and set up

All the ingestion tests were performed in the vacuum since it was considered the aerodynamic loads were negligible compared to the loads generated by the high energy impacts.

One vertical spin pit was used for all the medium birds, ice slabs, tire tread and hail-stone shots. One horizontal whirligig was used for the heavy bird shots.

The test set up is driven by electric DC motors through a gearbox, thus very accurate driving speed can be set.

The vacuum is generated by pumps able to maintain the pressure level down to 1 Torr (1 mm of mercury, .040 in) or below.

Figures 4 and 5 show the arrangement of the test facilities.

The major portion of the test campaign was run using only fan blades since these are the engine components due to dissipate all the energy of the impact.

Some tests were performed using the fan and the booster but, as expected, the design changes in the booster were relatively minor and limited to airfoil stack up.

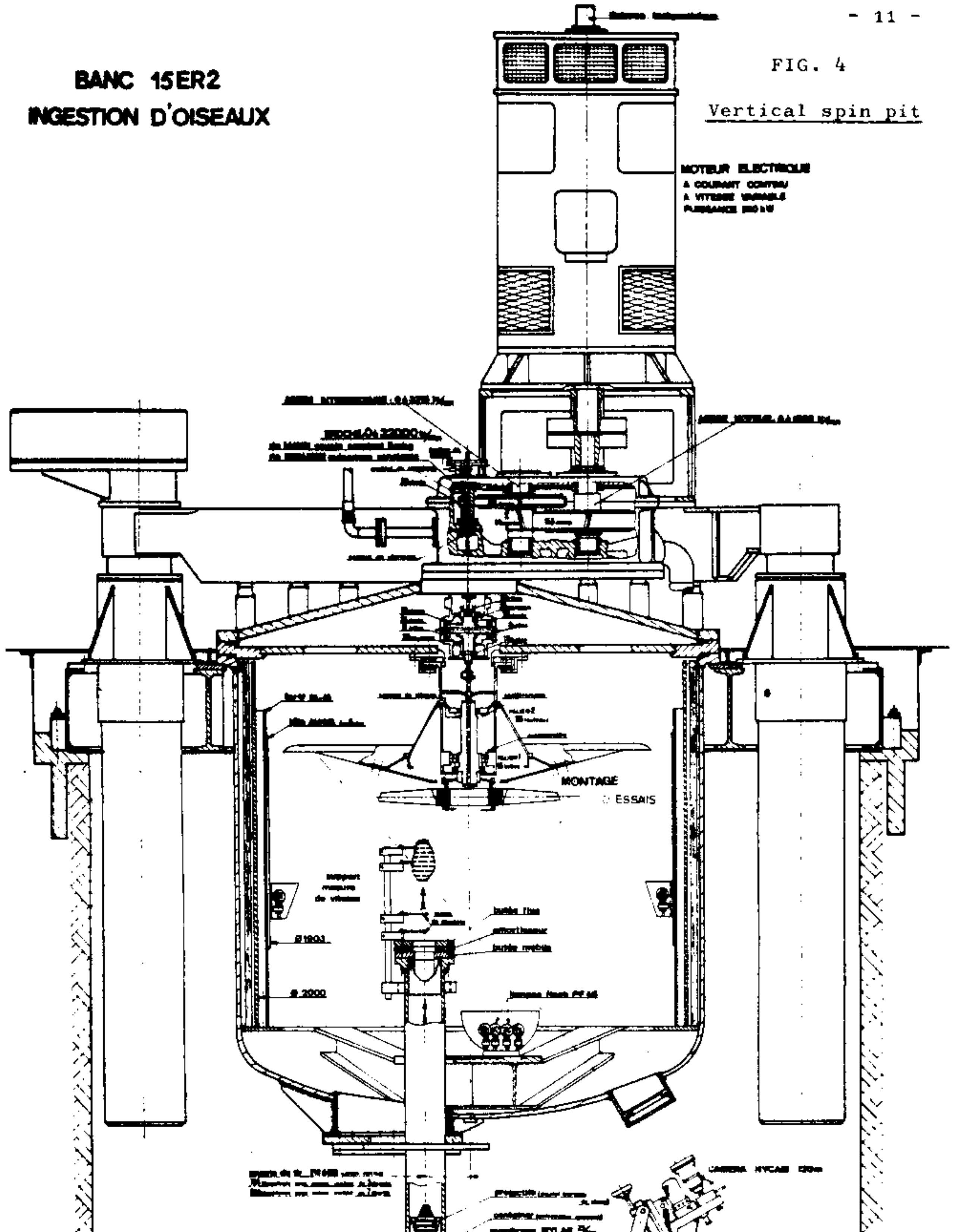
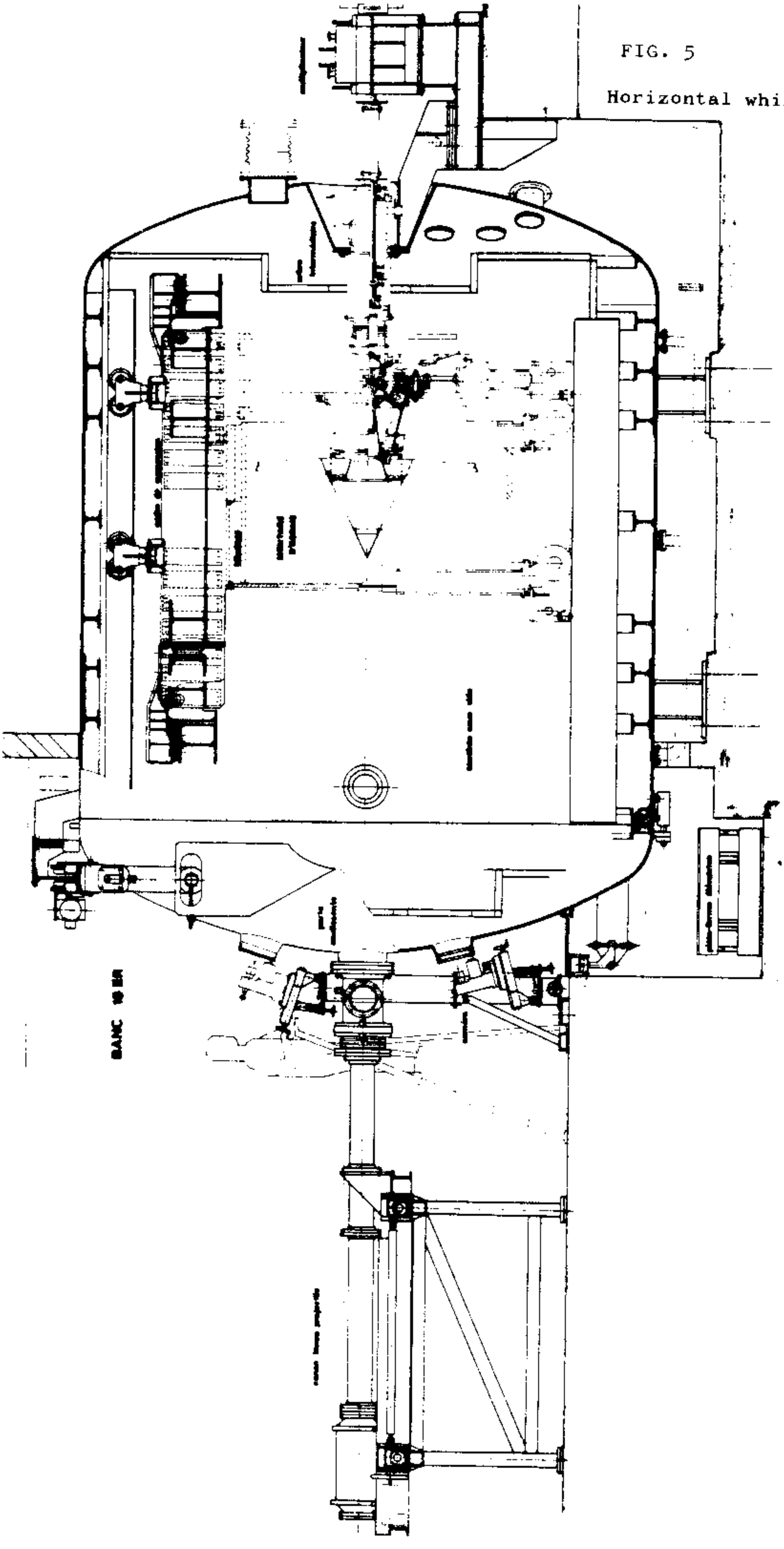


FIG. 4

Vertical spin pit

FIG. 5

Horizontal whirligig



- Test programme

The tests were to be performed at the following conditions :

. vacuum : 1 mm of Hg

. rotating speed : T/O max

. Missile velocity :

- medium birds : 91 m/s (300 ft/sec)
- heavy birds :156 m/s (515 ft/sec)
- hailstones . 2 in dia 156 m/s
  . 1 in dia 217 m/s (715 ft/sec)
- tire tread : 15 m/s (50 ft/sec)
- ice slabs : 15 m/s

. Missile weights or size :

- medium birds:680 g (1.5 lb) minimum
- heavy birds:1814 g (4 lb) minimum
- hailstones :25and 50 mm dia (1 and 2 in.dia)
- tire tread :square piece of typical tire
  (A300B front wheel)
  10 x 10 in, 4 lb
  255 x 255 mm, 1800 g
- ice slabs 1 x 4 x 6 in
  1 x 3 x 16 in

As visible on fig. 4, the birds were wrapped up in a plastic sabot in order to obtain the most severe ingestion effect. All the other projectiles were fired in their natural shape.

The targets were set from spinner cone and blade root up to blade tips.

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3.2.3 Spin pit performed tests

The overall extent of the ingestion activity resulted in the following impressive amount of shots :

- medium birds (1.5 lb)		41	shots
- heavy birds (4 lb)		20	shots
- ice slabs	1 x 4 x 6 in	7	
	1 x 3 x 16 in	1	
- hail stones 1 and 2 in dia		7	
- tire tread		7	shots
- fan blades	reduced size	1	
	actual size	4	
- spinner front cone		1	shot

As said before, the above tests were performed from 1975 to 1978 and about 350 fan blades were necessary to achieve a satisfactory design.
(Note : seven blades are hit at a time by birds or tires).

Also it is to be noticed that about 50 % of the above tests were performed using rotating cascades of at least 7 blades, the remaining being dummy blades. This minimum number of seven blades is necessary to correctly create the boundary conditions during the impact : testing with one or a few blades (less than seven) would have resulted in erroneous conclusions.

In the mean time, the use of rotating cascades lead to an important amount of preliminary tests in order to reach the high accuracy and reliability required

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on timing necessary to attempt a strike onto the first or the second blade of the cascade. The reached accuracy is 0.1 milli-second.

3.2.4 Spin pit test results

- Medium birds

As forecasted, the first series of shots above 60 % span of fan blade resulted in rather significant fragmentation.

Fig. 6 shows the spin pit arrangement and
Fig. 7 the typical fragmentation when the bird is fired at 87 % span.

As a consequence, an intensive redesign activity was set up and new design blades tested in comparative conditions.

By locally adapting the thickness distribution it was possible to achieve a final design able to :

. avoid heavy fragmentation of fan blade L.E.

. keep the same stage performance

. keep the same stall margin

Fig. 8 shows two fan blades to type design after medium bird strike : bending and tears, no fragments.

The booster arrangement was reviewed to avoid axial contact between blades L.E's and vane T.E's. By just stacking up the airfoils in the right manner almost all axial contacts were avoided.

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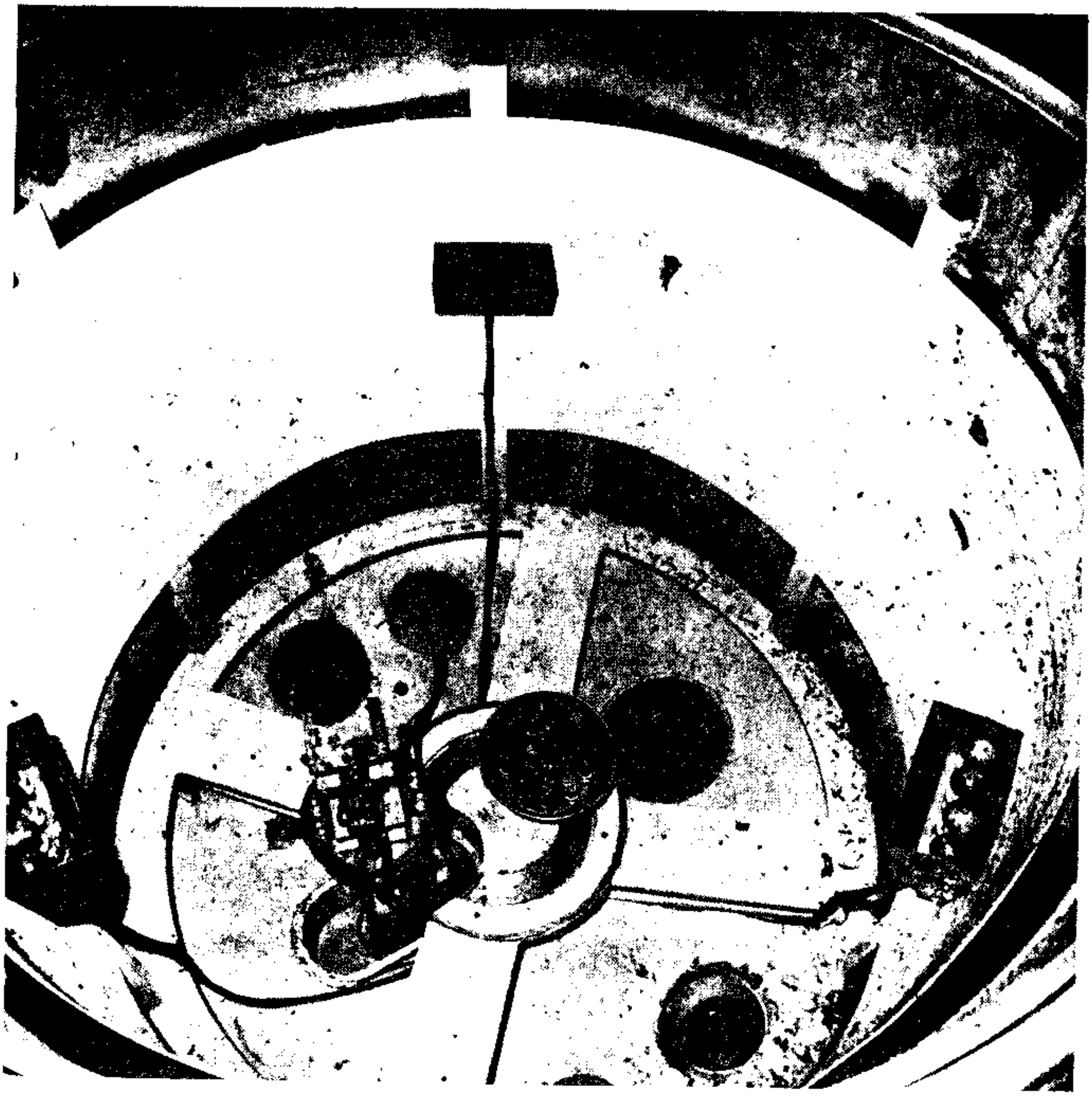

FIG. 6 View of spin pit after bird shot
Vue de la fosse après un tir d'oiseau

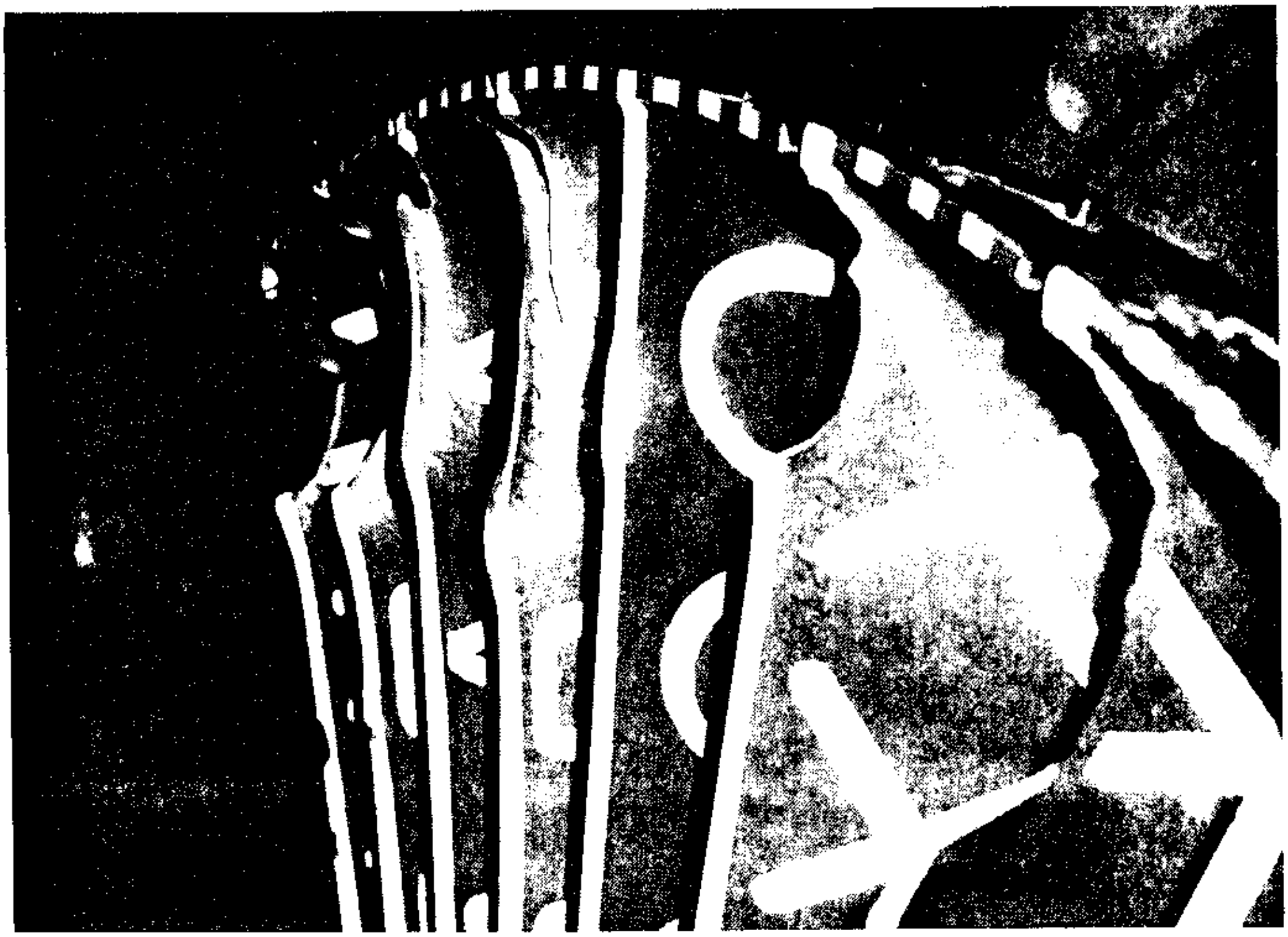

FIG. 7 - Fan blade initial version
Typical fragmentation by medium bird strike

- Aube de soufflante version initiale
Fragmentation typique par un oiseau moyen

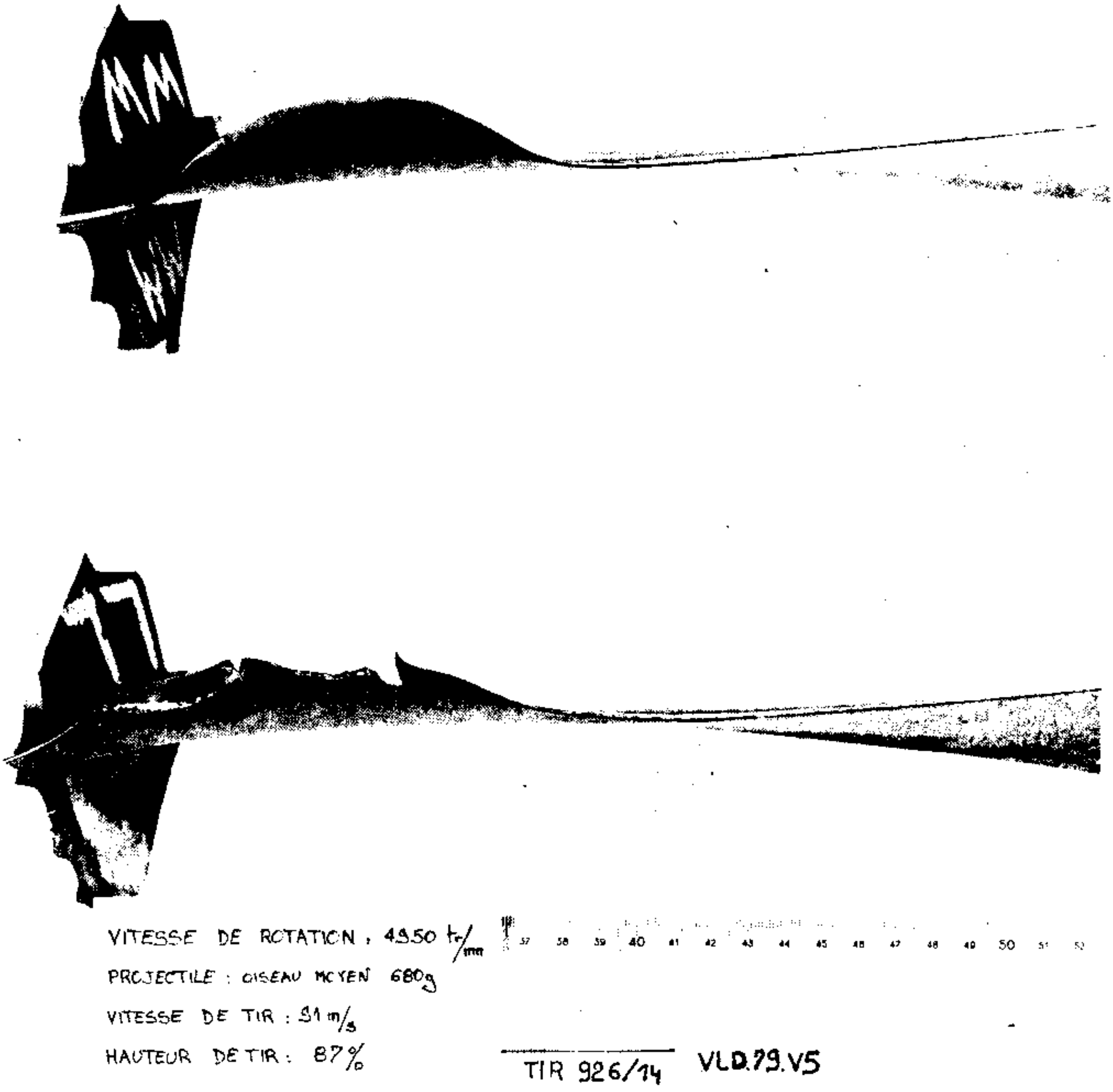

FIG. 8 - Fan blade to type design
Bending and tears by medium birds. No fragments.

- Aube de soufflante de certification
Pliure et déchirure par un oiseau moyen. Pas de fragments.

- Heavy bird

The fundamental improvement designed for the medium birds was also beneficial to heavy bird strike results : the fragmentation was obviously not avoided but the extent of it was considerably reduced and the total rotor out of balance limited to 11 % of an equivalent fan blade (5 to 7 blades are hit at a time). It is to be noticed that there is no fragmentation when the bird hits the fan blades at 50 % span or below.

Fig. 9 shows the typical fragmentation, limited to a small portion of the L.E., for a shot performed at 83 % span (the most severe).

When the 4 lb bird was fired at the blade root it was able to enter the booster flowpath. The resulting damages were : axial contacts between blades and vanes (bending is large when the chopped bird goes through), 4 blades broken at third stage.

When the bird was fired at the spinner rear cone (made of aluminum) the damage was such that the cone broke into hundreds of fragments thus allowing the front cone (made of kinel) to be ingested by the fan.

To evaluate the potential risk created by this supplemental "foreign" object the following extra severity test was decided.

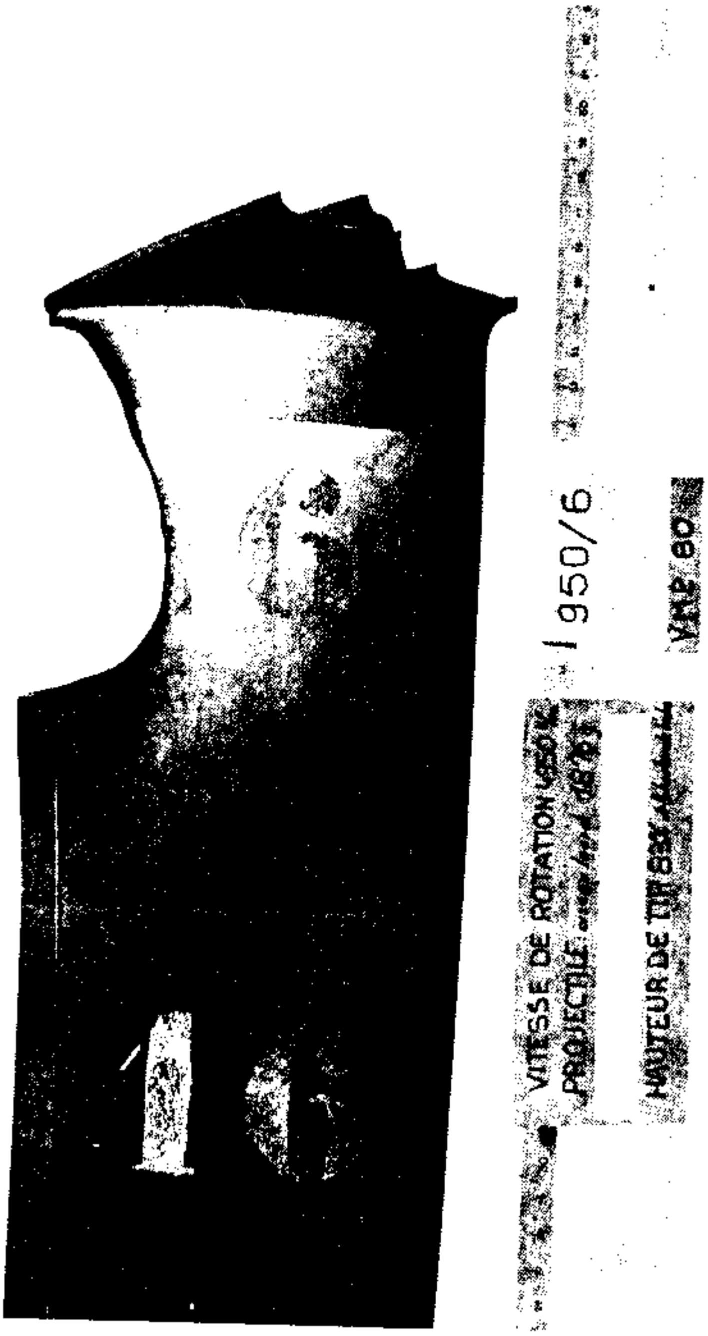

FIG. 9 - Fan blade to type design
Typical fragmentation by heavy bird (4 lb)

- Aube de soufflante de certification
Type de fragmentation par un oiseau lourd (1810 g)

- Spinner cone

This test is in the film which will be shown to you later.

The cone ingestion velocity was about 15 m/s (50 ft/sec) as if it were sucked-in. Bolted to the base there was the front flange of the rear cone made of aluminum. This is a very realistic duplication of the actual case, should this happen.

As it is visible from the film, the cone is chopped up by the blades and at the end a big fragment (about 1/4 in weight) is ejected forward.

Fig. 10 shows the main fragments of the ingested cone after the test.

The damage to the fan blades was limited to small fragments of the leading edge. The total out of balance was below the 4 lb bird level : 7 % of an equivalent fan blade.

- Ice slabs

Seven shots were performed using the 1 x 4 x 6 in slab to establish the effect of the slab attitude when the fan blades are hit. Tests were done on first blade versions.

Fig. 11 shows the way the tests were run and the slab attitudes. One shot resulted in a small fragment but the slab velocity was higher than required (40 m/s instead of 15 m/s).

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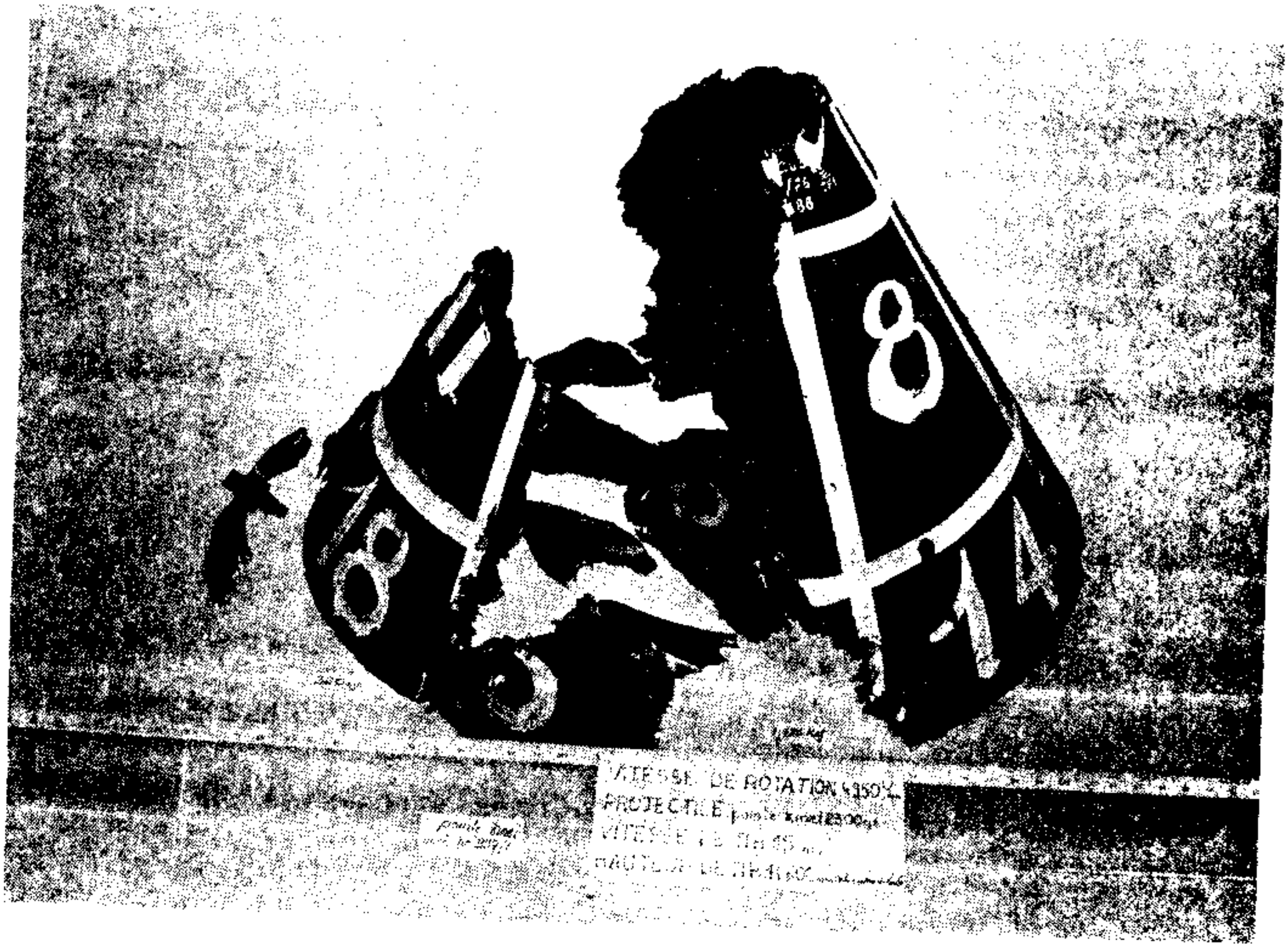


FIG. 10 - Spinner cone after being ingested by the fan
- cone de capot après avoir été ingéré par la soufflante.

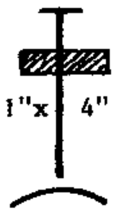
FIG. 11

- Ice slab ingestion
- Ingestion de barreaux de glace

PERFORMED SPIN PIT INGESTION TESTS

ICE SLABS

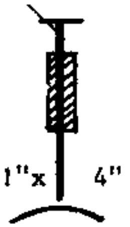
1. 1 IN X 4 IN X 6 IN



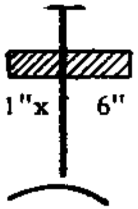
1 - 20 M/S = 66 FT/S : MODERATE L.E. BENDING (3 BLADES)

2 - 22 M/S = 72 FT/S : MODERATE L.E. BENDING (1 BLADE)

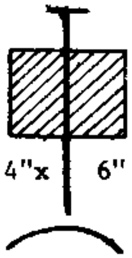
3 - 30 M/S =100 FT/S : MODERATE L.E. BENDING (2 BLADES)



4 - 17 M/S = 56 FT/S : NO DAMAGE

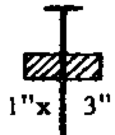


5 - 17 M/S = 56 FT/S : NO DAMAGE



6 - 40 M/S =132 FT/S : 1 FRAGMENT (33 GRMS) + 1 RADIAL CRACK (1 BLADE)

2. 1 IN X 3 IN X 16 IN



7 - 18 M/S = 59 FT/S : MODERATE L.E. BENDING (3 BLADES)

It is therefore difficult to find out wether the fragmentation was due to the slab aspect ratio.

- Hailstones

The shots were performed stone by stone to study the damaging effects at various shot spans.

They never generated significant damage.

- Tire tread

The tests were performed using the tread of a tire left on CdG runway by an A 300 B of Air France. By cutting off square pieces which size is the width of the tread we obtained a batch of real tires to be fired at fan blades.

The weight of the tire treads resulted to be 4 lb (1800 g) each.

Seven shots were performed at different spans on fan blade. The most severe damage was found for a shot at 75 % span where the resulting out of balance was 0,5 % of an equivalent fan blade.

Fig. 12 shows one of the tire treads used for this series of tests : the piece of tire is rolled up and fitted in the plastic sabot, similar to the one used for firing the birds. A clever and simple system makes it to get deployed before hitting the rotating blades. After the test only chopped up slices are found at the bottom of the spin pit.

FIG. 12 - Tire tread before and after ingestion
- Chape de pneu avant et après l'ingestion.

- Fan blades

Several development tests of fan blade containment/ ingestion were performed before attempting the official test on a complete engine.

All the testsgave similar results.

Fig. 13 shows the released blade fragmentation as found after the test. The three blades correspond to three different tests.

The damage caused to the remaining blades were rather minor. The total out of balance resulting from such tests was limited to 1.1 to 1.48 equivalent fan blades.

3.3 Engine tests

Engine tests were fully carried out at CEPr facilities near Saclay (France). A specific open test bed was built to run ingestion and containment tests. Fig. 14 shows an overall view of the test site.

After the intensive development testing on components, the engine tests confirmed that the final design of the CFM56 was appropriate to cope with the severity of the F.O.I.

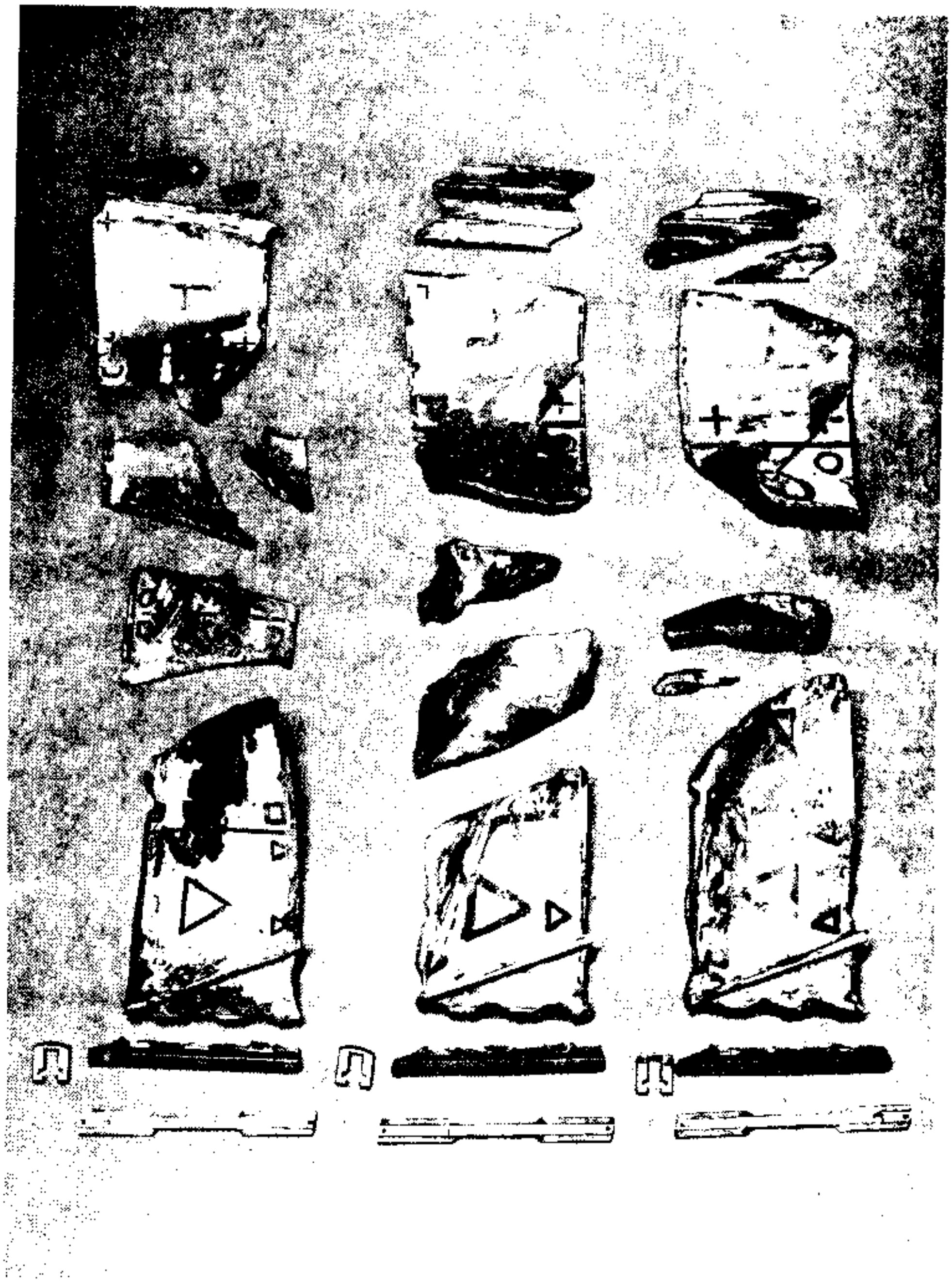


FIG. 13 - Released fan blades during three different containment tests

- Aubes de soufflante éjectées pendant trois essais de rétention différents.

The following tests were run over a period of three years :

- 4 medium birds up to 53 % span,, essentially into the primary flowpath
  2 ice slabs 1 x 4 x 6 in
  These tests showed that the duplication in the spin pit was almost identical : no fragmentation of fan blades, very limited damage to core blading.

- Seven medium birds, certification test.
  The test was extremely successfull : the engine recovered 98 % of its initial thrust with no throttle movement for 1 minute, then the engine demonstrated a 20 minutes endurance at 75 % of take off thrust. Excellent engine handling was also shown by acceleration and deceleration from idle to 75 % T.O. and back. Finally the engine was shut down and restarted with no difficulty.

- 50 hailstones (25 of each size) in a volley of less than 2.5 secs, certification test.
  This test was also successfull : no damage to the blading no power loss.

- 2 heavy birds (4 lb), essentially into the primary flow path.
  The engine behaved very well : no fragmentation of fan blades, all damage to core blades were contained, no fire.

- One fan blade out, certification test.
  The test was successfull. The total out of balance was limited to the released blade and the damage to the remaining blades limited to nicks and tears (several of them within repair limits).
  The engine showed no fire, no mounting loads in excess of specified limits, it was shutdown normally
  (This test is also shown in the movie).

- wooden shield
- pare-éclats (bois)

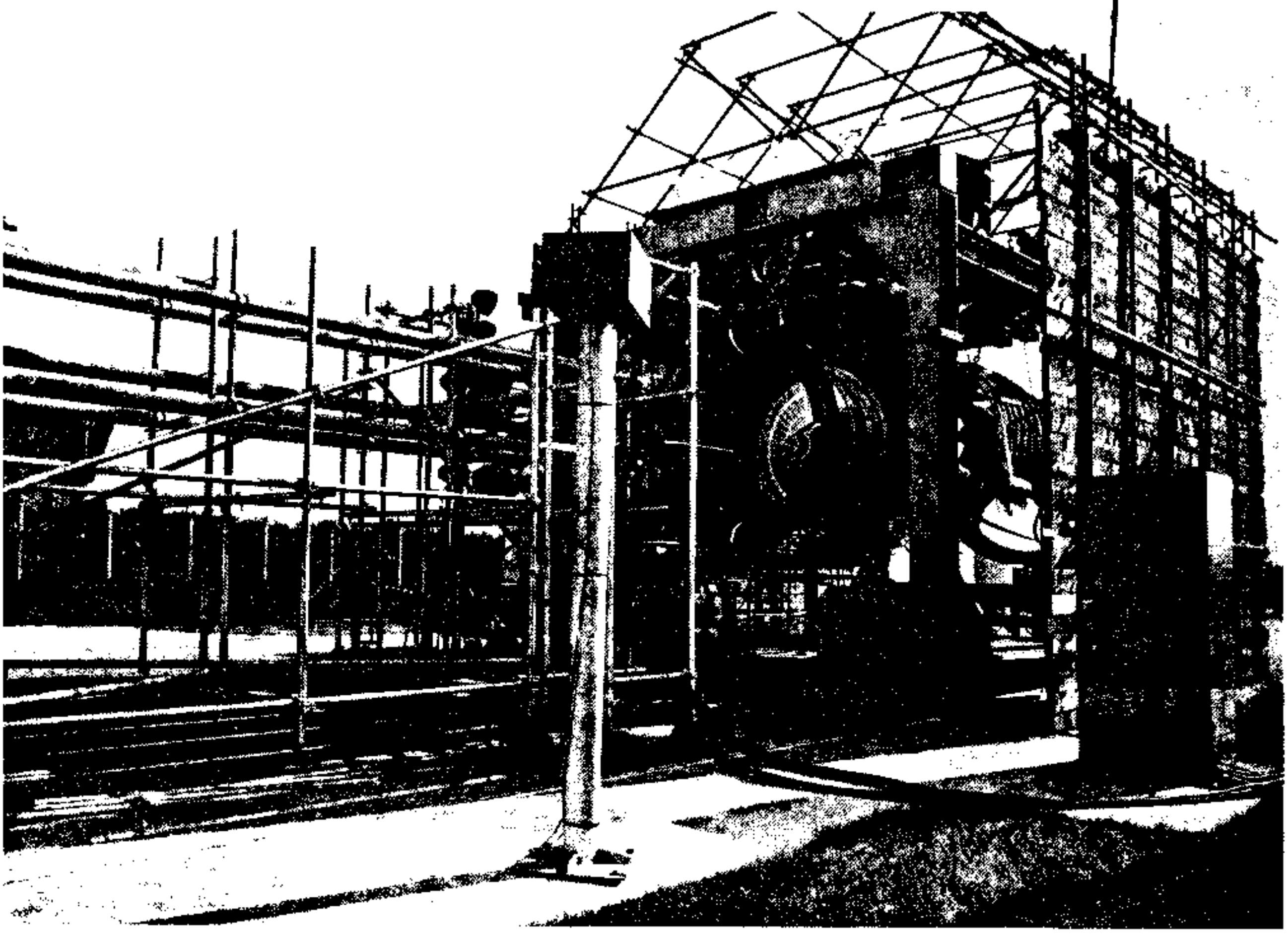


FIG. 14 - CEPr engine ingestion/containment test bed
- Banc moteur d'ingestion/rétention au CEPr.

4. CONCLUSION

We, at CFM International have always been very conscious of the hazards caused to engines by foreign object ingestion, and more specifically by bird strikes on fan engines.

The Certification Authorities have also recognized these hazards and that is why the current regulation are so stringent.

We have also looked upon it as very important to comply 100 % with these stringent requirements, not only for safety, but also for economical reasons. The necessary development tests to achieve these objectives has cost us a lot of time and money, but we believe that we are now entitled to affirm that with regard to F.O. ingestion as in all other respects, the CFM56 has been developed and tested without any kind of indulgence, and more severely than any other previous commercial engine.

Therefore you can see that the CFM56 engine has now achieved its third target : ruggedness.

Ruggedness is synonymous with safety and reliability for airlines and passengers.

Ruggedness means low operating cost through low maintenance costs.

Ruggedness also means minimum unscheduled removals due to F.O.D., with less impact in the form of aircraft departure delays or rescheduling.

The CFM56 is now a reality and is ready for a safe, reliable and long, long service.

This is what this engine is designed and built for.