OBSERVATION OF CONDENSATION SHOCK IN A HIGH DEVIATION BLADE CASCADE BY MEANS OF THE SCHLIEREN TECHNIQUE

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ABSTRACT

The paper presents some experimental results obtained during a series of tests conducted on the steam tunnel of the University of Genova, Energetics Department, concerning a transonic turbine cascade. The airfoils are high deflection root sections of a stator blade typical of a last stage low pressure turbine. The static pressure distributions on the strumented blades at different outlet Mach numbers, are interpreted and correlated to the schlieren flow visualization pictures. In this way it is possible to evidence the shock wave and the condensation shock when the upstream conditions of the steam are characterized by a small degree of superheating. The experimental results are, finally, compared with the theoretical ones obtained by means of a calculation procedure which predicts the condensation onset.

1. Introduction.

The experimental analysis of transonic blade cascades in a wet steam flow began three years ago in the laboratory of the "Dipartimento di Ingegneria Energetica" of Genoa University when the steam tunnel for calibrating subsonic probes was modified and suitable instrumentation was implemented for these tests.

The results here presented refer to a cascade of high deflection transonic blades, such those encountered in the nozzle root section of steam turbine last stages.

The steam at the inlet of the cascade is slightly superheated, and the condensation, that takes place inside the blade channel, is observed both by means of static pressure measurements along the pressure and suction side of two adjacent blades and by the schlieren technique.

2. Test conditions and instrumentation.

The test section dimensions are (223 x 74) mm . The contraction upstream of the cascade is threedimensional. The blades are fixed by means of lugs on the bottom of two rotating cylinders, so that the cascade can turn around its centre.

The cascade under test, shown in fig.1, has the following characteristics:

- blade inlet angle $\beta_1 = 90^\circ$
- blade outlet angle $\beta_2 = 13{,}5^\circ - 20^\circ$

- stagger angle $\gamma = 52.9^{\circ}$
- pitch $p = 44.54$ mm
- chord $c = 98.6$ mm
- throat $g = 7.8$ mm
- blade height $h = 74$ mm
- number of blades 6

The blade profile presents a straight suction surface towards the trailing edge.

The central channel is equipped with a series of 32 (suction side) and 23 (pressure side) static pressure tappings respectively. The pressure tappings are connected through a Scanivalve pneumatic switch to a control panel equipped by electrovalves allowing both the pressure measurement with a differential transducer (Hydronics TH-D) and the intermittent purge of the connecting tubes by means of the ambient air. All the required control operations and timing are performed by Data Analyzer HP 3497A, driven by a computer HP 9816S.

The entire cycle, including repeated checks of pressure readings is completed in half an hour at the worst. The total pressure in the stagnation chamber has been varied between 0.1 and 0.3 bars, and the total temperature between the saturation values and those corresponding to 15 of superheating.

The outlet isentropic Mach number has been evaluated with the aid of 10 wall static pressure taps placed at an axial distance of 6 mm downstream the trailing edge plane.

In the same station the transverse of both the total and static pressure and the flow angles can be carried out by means of a two-directional probe, moving along a slot in the side wall..

Tests have been performed for Mach numbers that vary between 0.9 an 1.7, by varying accordingly the tailboard angle position between 13.5 and 18 degrees.

In order to obtain an acceptable periodicity it is necessary to have an angle of 13,5 for oulet Mach numbers less than 1.3 and greater angles for higher Mach numbers .

In fig. 2 a schematic arrangement of the schlieren system is shown. The light source is a Xenon filled arc bulb operating at a power of 500 W. A system of lenses focusses the light on the source slit, placed at the focal point of the first spherical mirror (diameter 200 mm, focal length 1827 mm). The collimated light, reflected by a plane mirror, passes through the test section and is reflected by a second plane mirror on the second spherical mirror (diameter 200 mm, focal length 913,5 mm). At the focal point, where an image of the source exists , a second adjustable slit is introduced in order to cut off part of the source image light.

The limited space around the tunnel is the reason for the asymmetry of the optical set up and of the consequent deterioration of the image quality. The better visualizations of the shock on photographic film (the camera used was a Nikon F2 Reflex without objective) have been obtained with the slits parallel and perpendicular to the density gradients of the flow under investigation.

Using only black and white film and suitable coloured filters (yellow, red, blue) colour schlieren technique has been employed with Rheimberg's tricolor filter (red-blue-yellow) instead of the slit, placed in the cut off plane. The image on the viewing screen is equivalent to the standard black and white schlieren, except that the grey scale is replaced by a two colour mixture scale (yellow- red) on a contrasting blue background. The coulored filter, positioned after the Rheimberg filter, renders shocks in the black and white photoprints clearer and in better contrast with the background.

In the steam tunnel operation many factors arise making it difficult to obtain good photographic results; surface deposits on the test section side walls alter the optical properties of the windows and produce non-homogeneity. They develop especially when the tunnel starts and are difficult to remove even after periodical cleaning with hot water by means of an apposite air assisted injector. The high values and the strong gradients of temperature in the test section together with the existing low pressures prevent the use of large window (diameter 380 mm), made of plexiglass or glass.

In fact the windows, subjected to large mechanical and thermal effects, could easily be distorted especially at the trailing edge of the blades, producing a bright or dark area in the schlieren image. To solve this problem, a stainless steel side wall and a plexiglass wall were installed in the test section, both equipped with a corresponding small circular window of plexiglass or pyrex (diameter 100 mm). These windows,which are inexpensive, easy to replace and not subjected to large stresses, permit the partial examination of only one blade passage and of the area downstream of the trailing edge of two blades of the cascade. An enlargement of the viewing area will be necessary. Plexiglass has very good optical characteristics but the pyrex glass,used for the higher temperature and gradients, is not homogeneous, with internal density gradients appearing as many parallel lines on the photographs. Another difficulty in the shock waves visualization concerns the same steam flow characteristics in the work conditions of the test section : steam density and wetness are very slow and consequently the density gradients of the shock waves are also rather weak.

3.Measurements in the test section.

The blade cascade here examined define a sequence of narrow Laval type nozzle channels, leading the steam to supersonic oulet velocity.

They work, with regard to condensation and aerodynamic shock, similarly to straight nozzles.

For high back pressure values compared to upstream total pressure,a normal shock of considerable strength is established in the divergent passage preceded by a normal condensation shock.

For lower back pressures the aerodynamic shock becomes oblique and in correspondence to the expansion fan attached to trailing edge, an oblique condensation shock might appear under proper conditions.

If the flow were undisturbed by the shock-boundary layer interaction, the position of the condensation shock would be excpected to depend only on the inlet total pressure and temperature, according to the classical nucleation theory.

Indeed in the tests presented a light downstream displacement of the condensation shock has been observed when the back pressure is reduced even if the inlet total pressure and temperature remain constant. This effect seems to be in conjunction with a contraction of the bulk flow, due to the growth of the boundary layer caused by the shock interaction.

Every set of tests has been made at constant stagnation temperature and pressure in the settling chamber, changing only the downstream vacuum pressure by air inflow in the condenser, and keeping the tailboard at a fixed angle to simplify some sealing problems.

The pressure ditribution along the suction and pressure side is shown in figs. 3-4-5 corrisponding to the schlieren pictures in photos 1-2-3-4. It can be observed that the shocks are situated in corrispondence to the pressure jumps, as was expected.

For the test corresponding to photos 2-3 a theoretical comparison has also been attempted, revealing that the calculated condensation shock position agrees closely with the experimental results (figs.6-7-8).

In the last photos presented (5-6-7-8),obtained at constant upstream conditions by varying the condenser pressure, different flow situations are shown. The shocks appear as narrow white zones in a dark background, due to the particular position of the schlieren slits.

4.Acknowledgement

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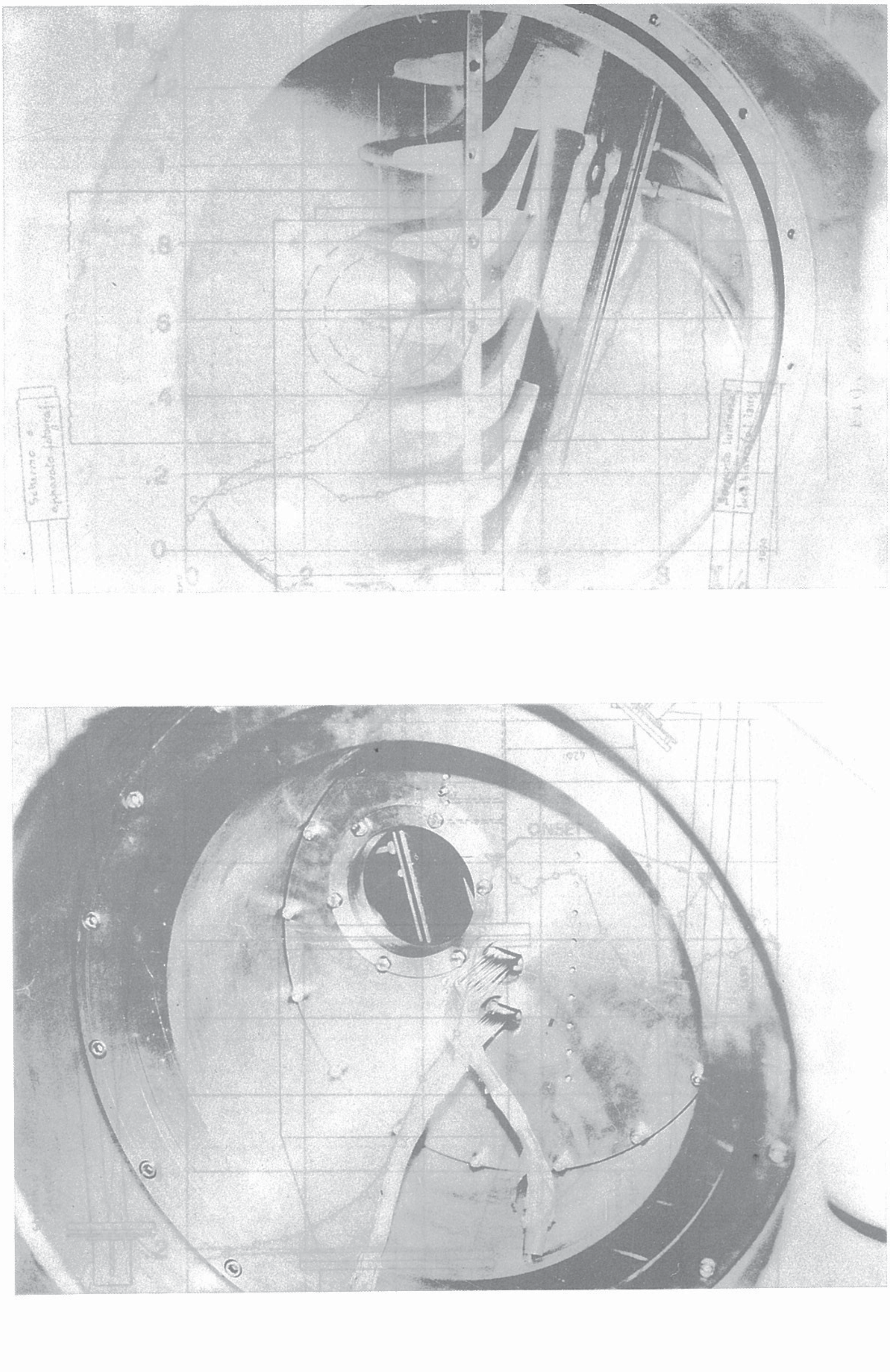

FIG. 1

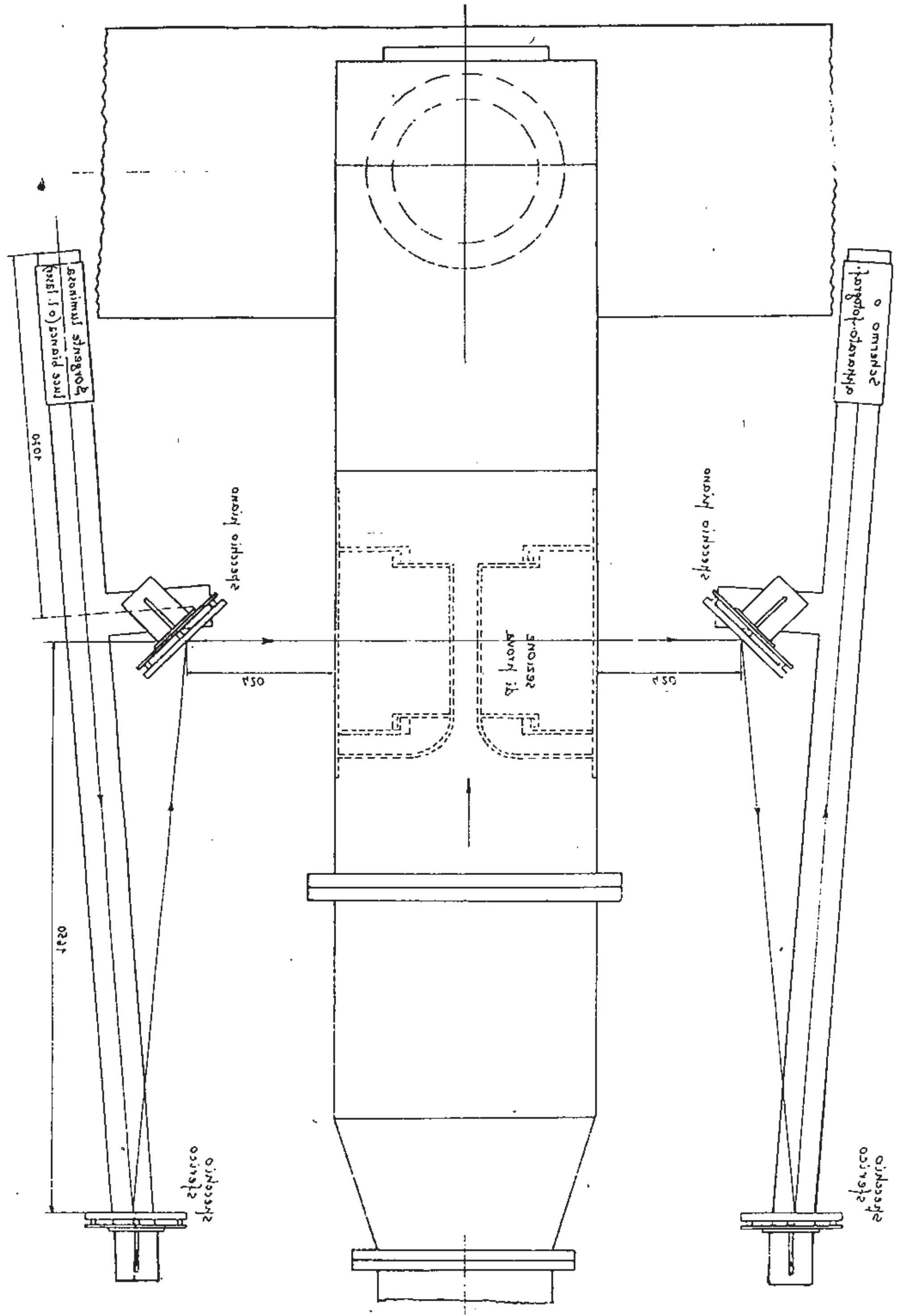
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FIG. 5

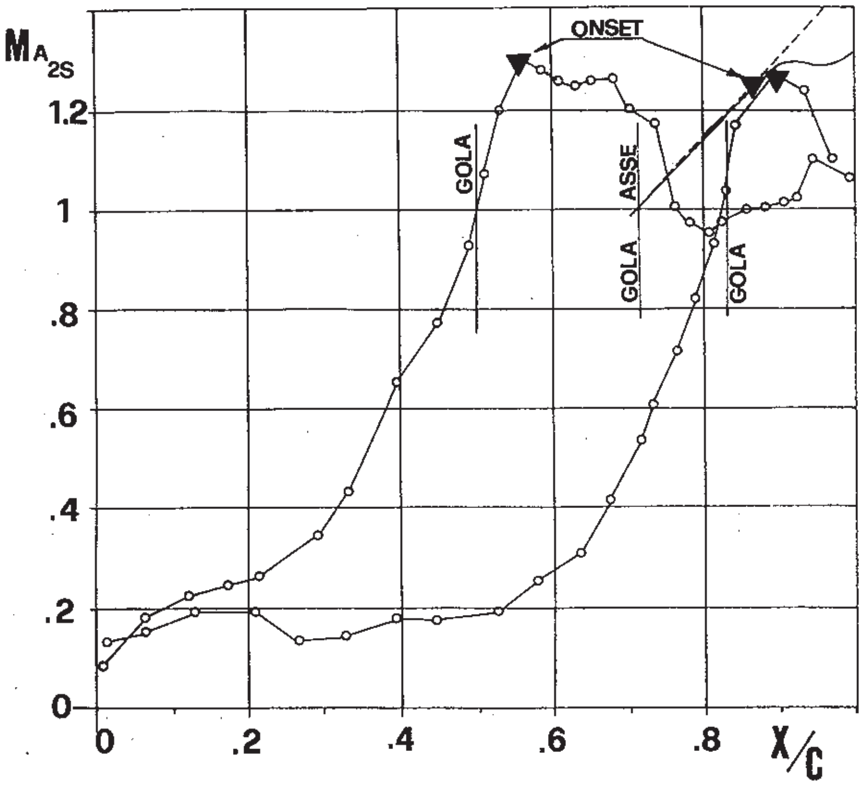
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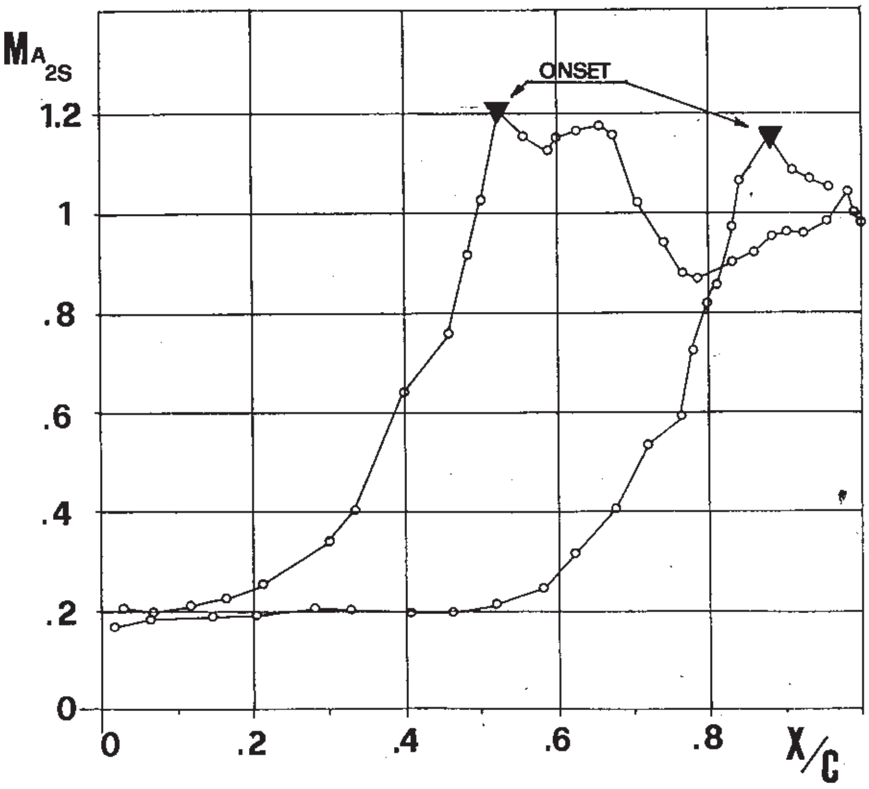
FIG. 3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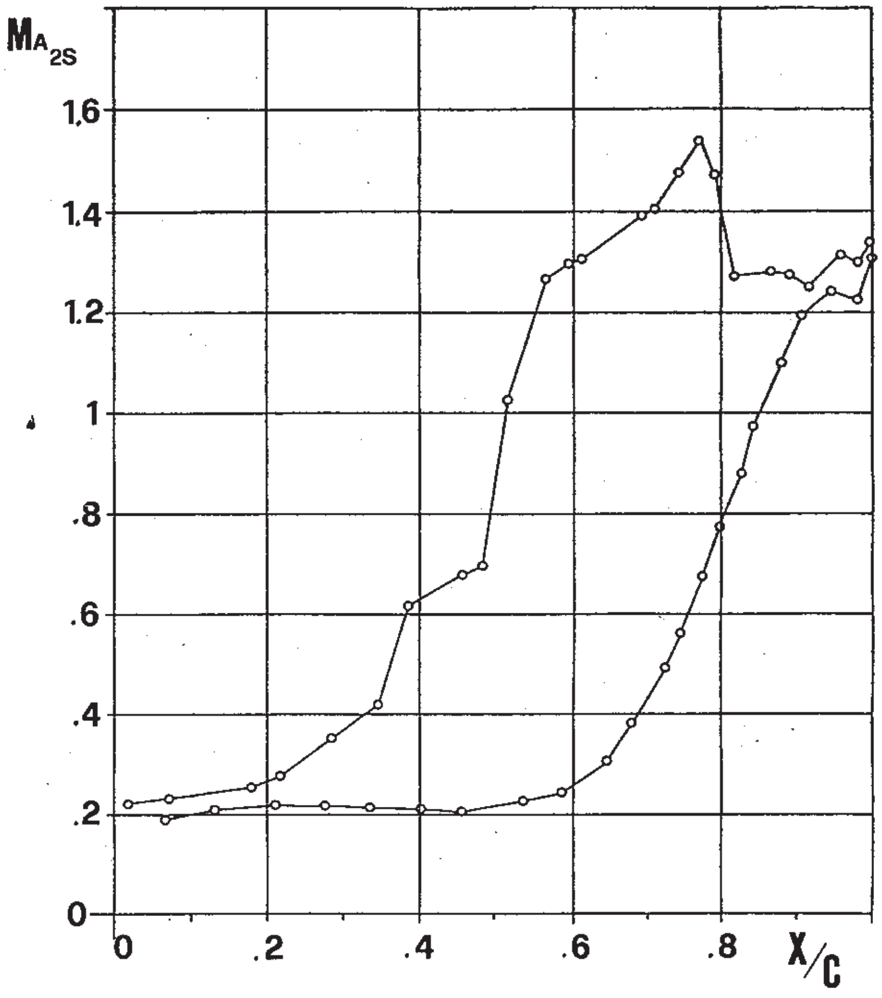
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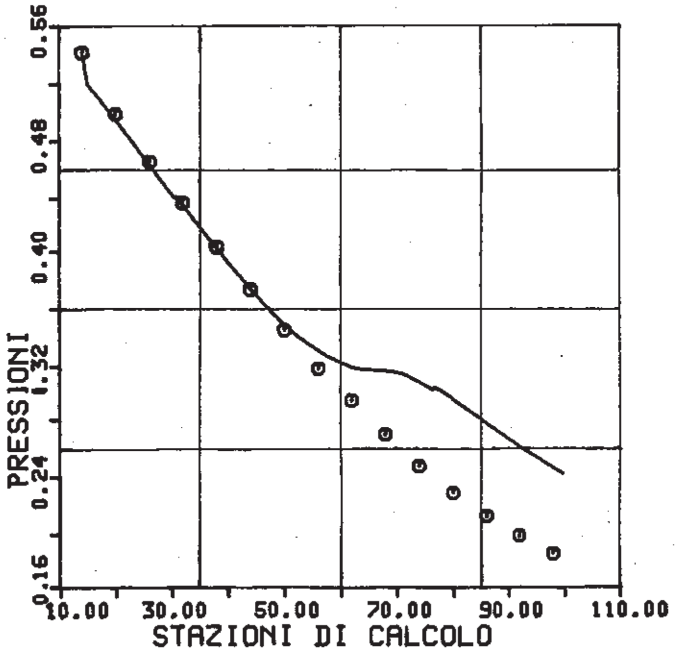
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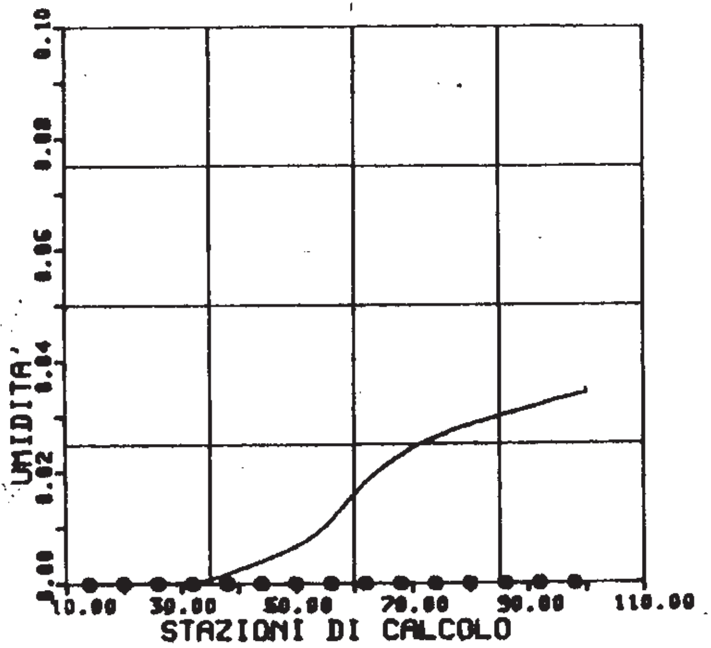
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FIG. 7

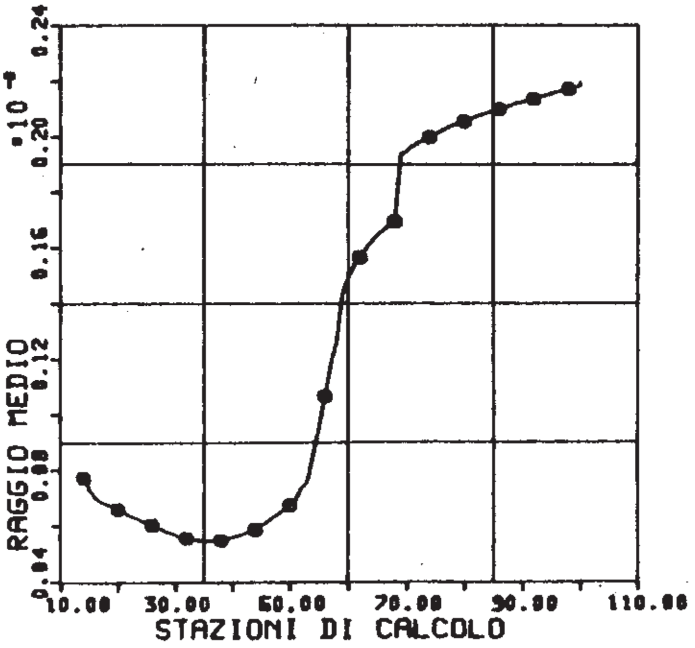
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FIG. 8

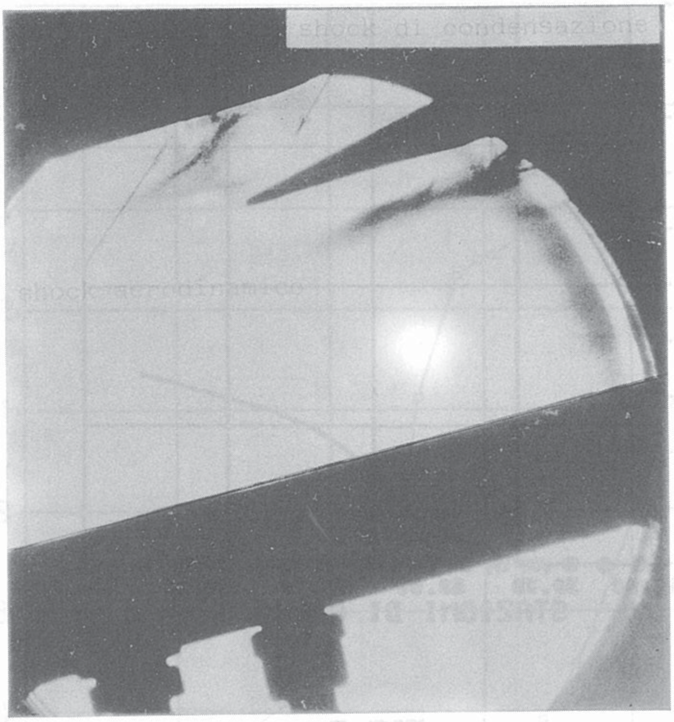
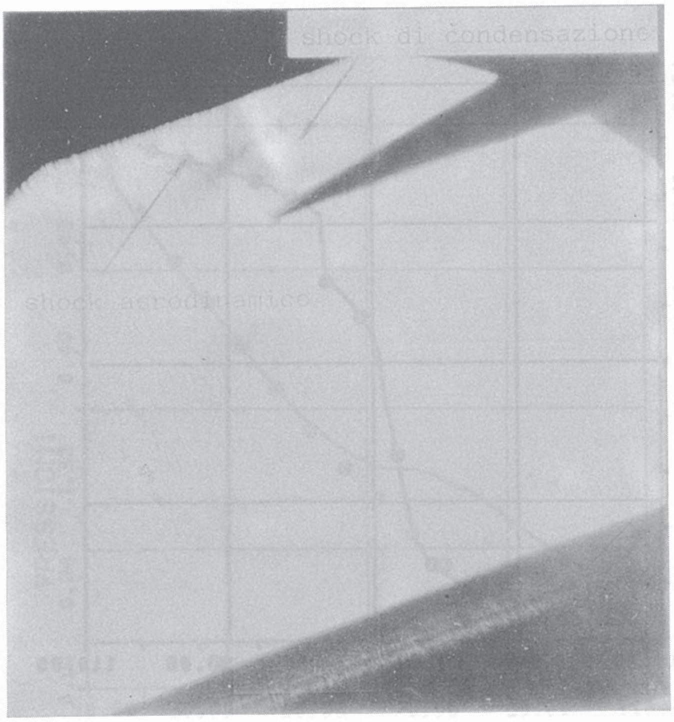


Photo 1



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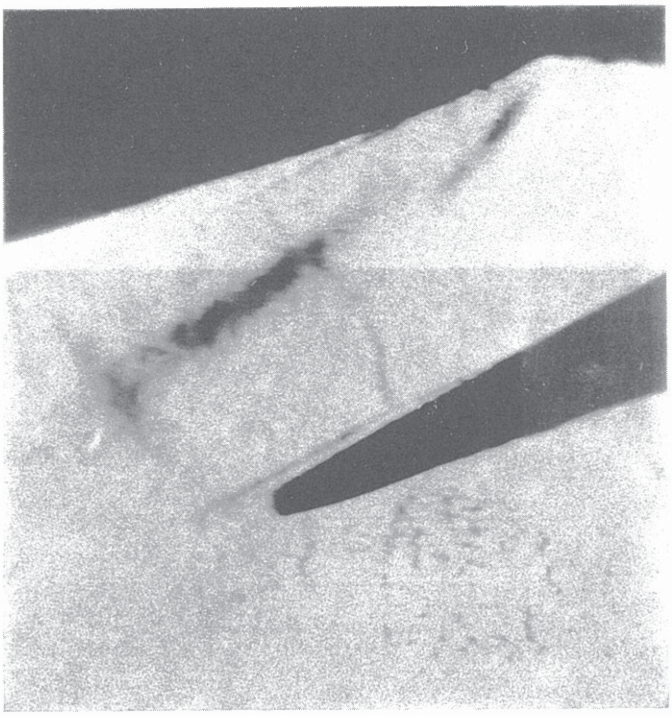

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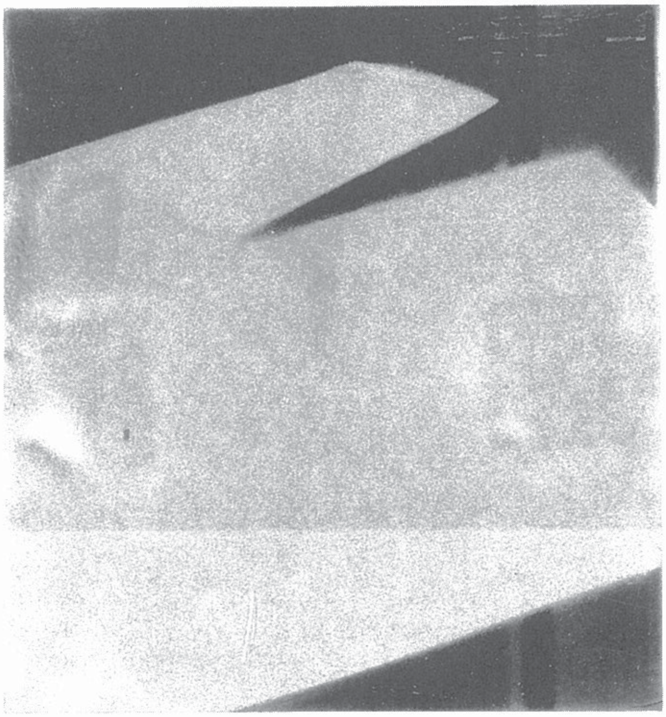

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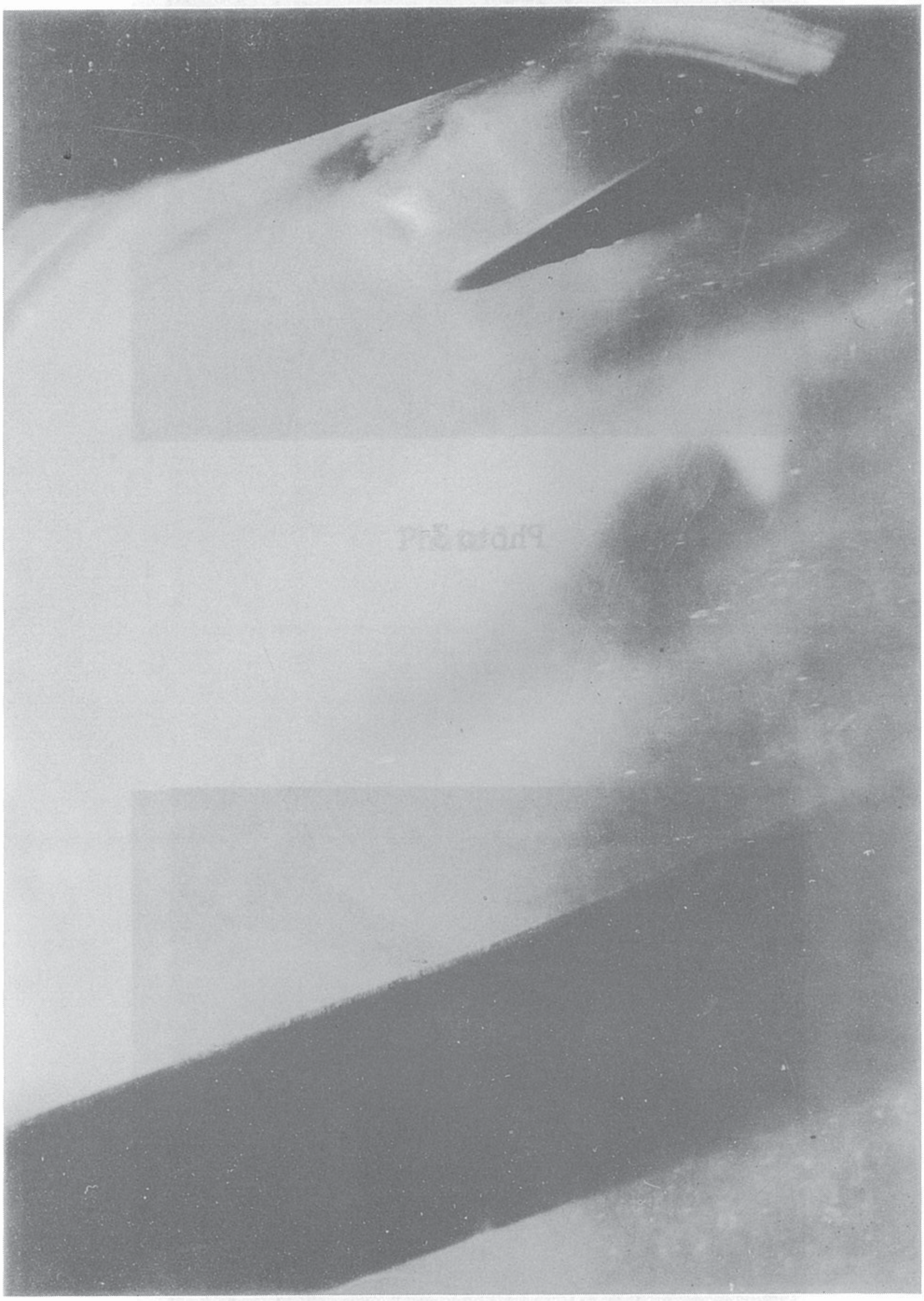

Photo 5

Photo 6

Photo 7

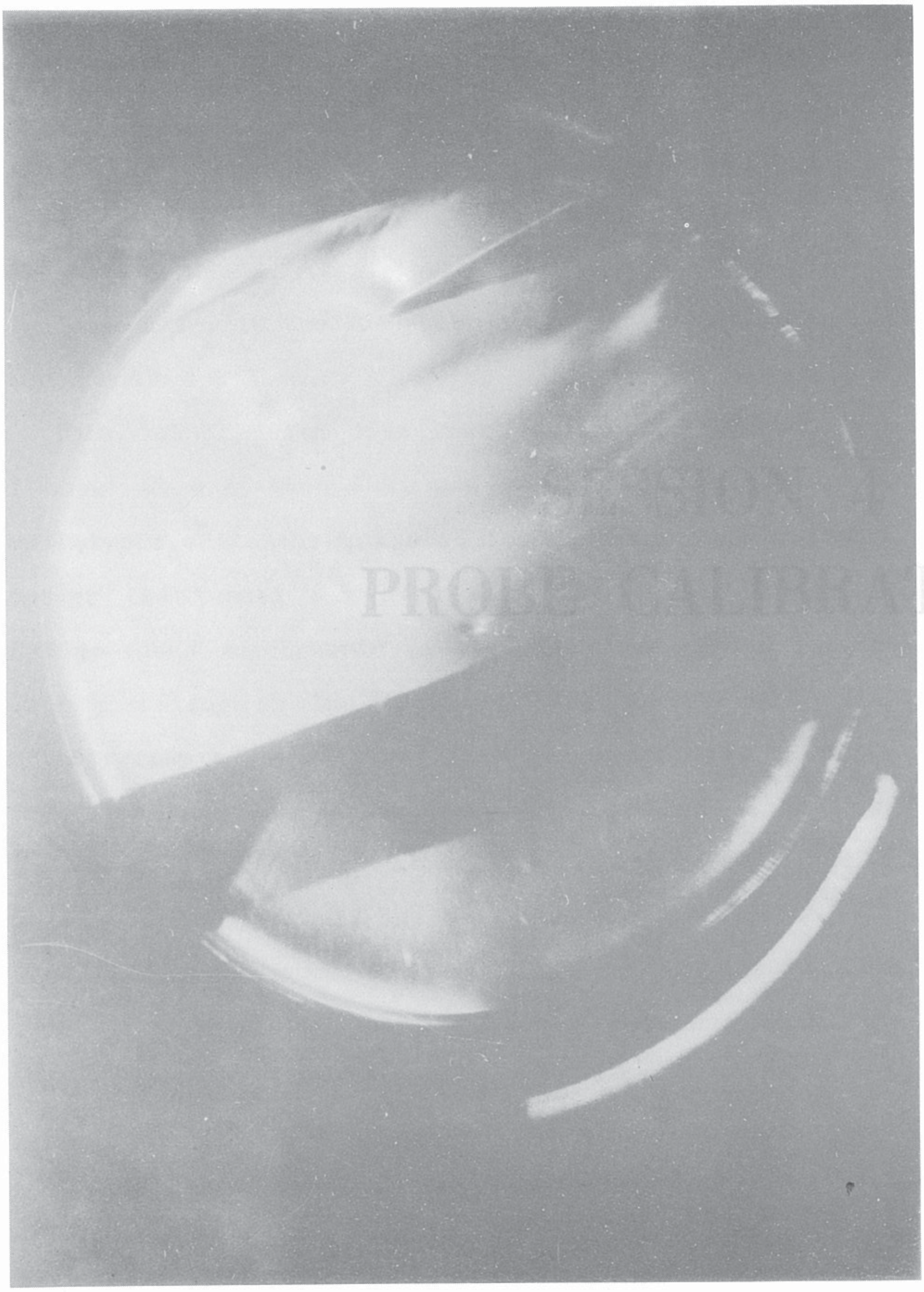

Photo 8