Design and Development of Distortion Screens For a Gas Turbine Engine Intake

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SUMMARY

In the engine test beds the effect of inlet ditortion on the engine performance is studied by placing a specially designed screens at the engine inlet plane. This paper describes the design, testing and evaluation of two different types of such screens manufactured using different techniques. Laser cut screen showed certain advantages over the conventionally manufactured composite screen with respect to aerodynamic parameter and mechanical strength.. The novel technique of design and fabrication of laser cut screens overcomes all hurdles associated with conventional method using composite screen with wire mesh.

1. INTRODUCTION:

Aeroengines are installed on aircraft's with an air intake duct ahead. This duct produces certain total pressure distortion pattern at the engine inlet plane. The distortion pattern depends on the speed, pitch and yaw of the vehicle. This inlet distortion alters the engine performance notably surge margin. In engine test beds, the effect of inlet distortion on the engine performance is studied by creating required distortion pattern by placing specially fabricated wire mesh screen at the engine inlet plane. Generally the distortion screen is fabricated by a combination of wire meshes with different [1]porosity and welded together at the intersecting places. The screen thus fabricated has certain disadvantages namely, excessive blockage near the welded joints and non-availability of screens to simulate smooth variation of porosity. They also require a thick guard to protect the screen from failure.

A new design and manufacturing technique has been evolved to overcome all the above problems. In this new method the different porosity holes are cut using laser beam in a single stainless steel sheet, hence there is no joints between contours. Varying the web thickness and the hole size generates the required porosity. This porosity holes are generated with the given contour using AutoCad. By suitably designing the web thickness for mechanical strength using NISA analysis package the guard downstream of the distortion screen could be eliminated.

The two types of distortion screens were fabricated, one using welding of different wire gauges and the other cutting holes in a single plate using laser beam. The distortion pattern were obtained down stream of these two screens for the same inlet Mach number. The distortion across the screen is indicated in terms of total pressure loss non-dimensionalised with respect to local downstream dynamic head. It is observed that the laser cut screen has higher distortion index as compared to the wire mesh screen.

. The screen was analysed using finite element method technique for mechanical strength, so that the designed screen will with stand the required pressure difference during distortion tests without failure. For this purpose the Laser cut screen was modelled in an AutoCad environment and ported to the NISA package for stress evaluation using a pre-processor. The regions of maximum stress and displacement were obtained from the analysis.

2. INPUT DATA FOR THE SCREEN DESIGN:

A scale model of the air intake duct was tested in wind tunnel and the total pressure variation at the aerodynamic interface plane called AIP were measured. The measured total pressure at 40 locations of the AIP were specified as input data for the screen design. These forty locations were obtained by dividing the area of the AIP into five equal area rings and eight angular segments. The total pressure

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rake is used to measure the total pressure distortion. The values of the measured total pressure normalised with respect to inlet total pressure at the AIP are used as input data for the screen design. A typical input data obtained from wind tunnel tests is given in Table-I.

3. SCREEN DESIGN

A software developed in-house is used to design the screen for a given total pressure distortion. The software is formulated on a firm theoretical basis and uses experimental data obtained on screens having different porosity's and combination of screens to take effect of neighbouring screen porosity's. Basically the software gives the porosity's at the specified locations namely 40 stations comprising of 5 radial and 8 circumferential stations. From these 40 values of porosity's, contour of constant porosity's are plotted through the software.

Porosity is defined as the ratio of open area to total area. If we assume a square hole of side "L" with web thickness of "t", then the porosity is given by

$$P = L^2/(L+t)^2$$

The required porosity could be obtained either by varying Length "L" or web thickness "t" or by both. To manufacture screen with different porosity's, the co-ordinates of the intersecting boundaries are required. These co-ordinates are extracted digitising using a digitiser. or using AUTOCAD. .

4. SCREEN FABRICATION:

Two techniques are adopted to fabricate the screen. Each has got certain merits over the other. In the first method the meshes with different porosity's are cut to the required shape from the commercially available meshes and then they are stitched and welded across the joint to form a composite screen. This method has certain disadvantages like the required mesh porosity being not commercially available and also has large blockage near the joints where it is welded. Due to different gauge wires near the joint , the weld strength at the joints will be very weak. The screen may mechanically fail at the weld joints. For safety purposes this composite screen in the engine test bed requires an additional thick guard downstream. The manufactured screen by this method is shown in Figure-1a

In the other technique the screen will be fabricated by cutting square holes of required porosity using laser beam in a Stainless Steel plate of required thickness. For this purpose the regions of different porosities are filled with square holes of different size using an AutoLisp programme. This is shown in Figure-3. This autocad drawing will be used as input data for laser machine. The laser machine digitises the autocad drawing through a pre-processor and these digitised data will be used for laser beam cutting. The advantages in this method are screens can be designed to withstand the required strength by suitably designing the web thickness. Any required porosity can be achieved by suitably changing side and web thickness. The adjacent region between two meshes are uniform as there is no welded joints. The screen manufactured by this method is shown in Figure-1b.

It is observed that the screen manufactured from laser cutting machine is far superior than the one manufactured using conventional method of joining different wire meshes to form a composite screen. The local porosity values obtained after manufacturing the screen from both the techniques are compared in Figure-2. In this figure the local porosity is plotted against angular position for a given radius. It is observed that for wire mesh screen there is an abrupt change in porosity due to thick welded joints between two meshes, where as for laser cut screen the porosity values varies uniformly with angular distance.

5. TEST FACILITY TO MEASURE DISTORTION PATTERN

The schematic layout of the test rig is given in Figure-3. It consists of a specially built scaled model of straight duct of an engine intake configuration. The duct is installed at the inlet of a centrifugal compressor, such that continuous air supply can be inducted through this system. The compressor unit is capable of delivering mass flow rate of 6 kg/s at 3.5 m of water head. A well designed bellmouth has been provided at the inlet of the duct for ensuring smooth flow. The mass flow measurement through the system is done using this bell mouth. At the downstream of the bellmouth flange, provision has been made to mount the distortion screen. The loss is mapped as total pressure contour downstream of the screen. using the data collected by a pressure rake. It consists of eight radial arms with five total pressure probes in each arm totalling forty measuring locations. The radial five total pressure probes in arms were so arranged that each probe is located at the centre of an equal area annular ring across the duct.

6 INSTRUMENTATION

The measurements were carried out using an on-line data acquisition system HP-3497A . The data acquisition system is connected to a dedicated IBM computer. The 40 total pressure probes were connected to a 48 channel scanni valve. Three static pressure taps at 120degree apart were provided on the wall to measure screen downstream and bell mouth static pressures. These static pressures were also connected to the scani valve ports. The analogue signals from the pressure transducer mounted in the scanivalve were sequentially scanned during the test sequence. An absolute pressure transducer housed in the scani valve is used to measure the pressures by scanning the pressure ports one after the other. The same channel in the scani valve was scanned many times to get time averaged pressure The analogue signal from the pressure transducer is read on the digital voltmeter and the same is recorded on the computer through a general purpose interface bus (GPIB). The total temperature at outlet of the screen was measured using a calibrated cromel-alumel thermocouple. Mass flow rate through the inlet duct has been calibrated against bellmouth static pressure. The Mach number at inlet of the screen is estimated from the measured bell mouth static pressure, total temperature and assuming inlet total pressure as atmospheric.

7. EXPERIMENTAL EVALUATION

The fabricated distortion screen is mounted between two flanges having slots at every 15 degree apart. These slots in the flange helps to rotate the screen in steps of 15 degree with reference to fixed downstream total pressure rake. This arrangement help to take measurements at 120 points with a single pressure rake having 40 measurement points. These 120 measurement points are indicated in Figure-4 in which the radial arms and the rings are shown. The total pressure rake is fixed at a distance of 65mm downstream of the screen to provide sufficient time to mix out the wakes generated by the wires. The required inlet Mach number at inlet of the screen was achieved by passing the known mass flow rate of air into the duct. This is achieved by rotating the centrifugal impeller by a DC motor to required speed. The total pressure down stream of the screen were measured at three different settings (-15 deg, 0deg, +15 deg) of the screen for the same inlet Mach number. At the same Mach number the total pressures of the rake without the screen is also measured. The difference in total pressure with and without screen would give the pressure loss across the screen. The experiments were carried out at two different inlet Mach numbers of 0.15 and 0.22 for both composite screen and Laser cut screens.

8. RESULTS

8.1 LOSS CONTOUR AND DISTORTION INDEX

The distortion downstream of the screen is represented in the form of non-dimensional pressure loss contour or as a global parameter, which is given by the term called INLET DISTORTION COEFFICIENT (IDCL). The IDCL for each ring, say ring "i" is expressed as

$$\mathbf{IDCL_i = (P_{av} - P_{min})/P_{fav}}$$

P_{av} = average total pressure of ring i
P_{min} = Minimum total pressure in ring i
P_{fav} = Face average of all 120 total pressures

If maximum IDCL occurs in ring i. Then one can calculate the adjacent ring having next lower maximum (I+1), then IDCL is given by

$$\mathbf{IDCL = (IDCL_i + IDCL_{i+1})/2}$$

The local Mach number downstream of the screen was calculated from the measured wall static pressure and the local total pressure. The corresponding local velocity was calculated from the measured total temperature and the local Mach number. The local pressure loss across the screen was normalised with respect to local dynamic head. The normalised pressure loss values at the outer and inner most radius were linearly interpolated from the measured values. The local normalised pressure loss contour across the screen for two different Mach numbers 0.145 and 0.22 are shown in Figure-5 for the distortion screen manufactured using laser cutting. It is observed from this figure, representation of normalised local pressure loss contours across the screen becomes independent of inlet Mach number.

The calculated local pressure loss contour from measurements for two different screens manufactured by different techniques as explained earlier are shown in Figure-6 Both the screens were tested for the same inlet Mach number. The value of distortion index is also indicted in these figures. Both the screens were designed for same total pressure distortion. The local geometric porositys for both the screens were chosen to be identical, except abrupt blockages in the wire mesh screen due to poor manufacturing quality. In the laser cut screen the web thickness was maintained constant equal to 1mm, whereas the web thickness in the composite screen are different at different porosity locations, these differences lead to variations in aerodynamic characteristics of the two screens. The local aerodynamic porosity is altered from geometric porosity in different ways for the two screens. It is noted that the pressure loss normalised with local dynamic head (as explained above) could not be used to compare the distortion distribution. Hence in this case of comparing screens of different manufacture, the normalisation was changed to reflect the porous hole geometry. This new parameter made the pressure loss characteristics universal for comparision amongst different screens. This parameter is different from the earlier parameter used for normalisation of total pressure loss at different Mach numbers. The total pressure was normalised by considering the local outlet Mach number and the ratio of web thickness to the power of certain index. It is observed that the screen manufactured by laser cut method provides higher distortion index, IDCL of 0.034 as compared to 0.022 for the same inlet Mach number of 0.22. Thus indicating the advantage of using laser manufacturing technology as against conventional weld technology. Similar trend in the screens are observed even at lower Mach number of around 0.145 as indicated in Figure-6a. In both the cases the local pressure loss contours were found to be identical.

8.2 FINITE ELEMENT ANALYSIS OF DISTORTION SCREEN

The stress analysis was carried out on the distortion screen manufactured using laser cut screen as well as composite screen The laser cut screen was manufactured using 1mm thick stainless steel plate. The plate thickness was selected equal to the web thickness. The composite screen fabricated out of different wire mesh porosity's was assumed to be made out of 1mm thick wires of square cross section. The static analysis was carried out to locate the weakest part in the screens. An AUTOLISP programme was used to generate the required mesh geometry in the autocad environment. The generated mesh geometry from autocad is ported to NISA analysis package through an IGES translator. The required Finite element model is generated in the analysis package using DISPLAY-III pre-processor.

The ported autocad drawing on the Display-III was used to generate the required mesh. The mesh was manually generated to provide hexahedral elements. All the nodes are merged together using a tolerance of 0.001mm to ensure that the model created does not have any disjointed parts. The elements were verified for distortion if any, aspect ratio, boundary check etc,. The maximum aspect ratio in the present model was <4. For the present screen there are about 50,000 nodes and 10,000 elements. The finite element model of the composite screen was carried out through complex process by laying the wires one over the other.

The required boundary conditions and loads at the appropriate nodal points were applied. Since the mesh is held between two flanges and is subjected to pressure difference at only the regions where the porosity's are present, the displacement at the edges of the mesh outside the porous regions were made zero in all the three directions. Regarding loads , constant uniform pressure was applied on each element up stream of the screen and an experimentally measured minimum pressure was applied on each element down stream of the screen so that the results obtained on strength will be conservative. With the above boundary conditions and loads the model is subjected to static analysis. Figure-7a shows the contours of Von-mises stases obtained from the analysis for both the screens. It is observed from this figure that the maximum stress of around 149 mPa occurs in the region of intersection between two porosity's. This is because near this region the differential pressure is large. These regions become critical for the design of the screen. . This maximum value, of stress obtained, is 50% lower than the yield strength of the material. By suitably altering the web thickness or by altering the elements the stress could be brought down to further lower values.. The maximum displacement achieved in the direction of flow is around 1.3 mm. The displacement in the X direction negligible as compared to deflection in Z-direction and is symmetrical about Y-axis. The displacement in the Y-axis is also negligible and is symmetrical about X-axis. For the composite screen the maximum stress of 393mPa occurs in the region close to the rim as shown in Figure-7b, which is close to the fixing flange. The maximum displacement in the direction of flow is 2.2mm. The stress value and displacement are higher than that of laser cut screen.

9. CONCLUSIONS

Expertise has been built in the CLOCTER facility of propulsion division in design, fabrication and analysis of complicated distortion screens. This has been found very useful in the study of compressor performance of the aeroengines with inlet distortions. The novel technique of design and fabrication of distortion screens overcomes all hurdles associated with the conventional method using composite screen with wire mesh.

10. ACKNOWLEDGEMENT

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11. REFERENCES

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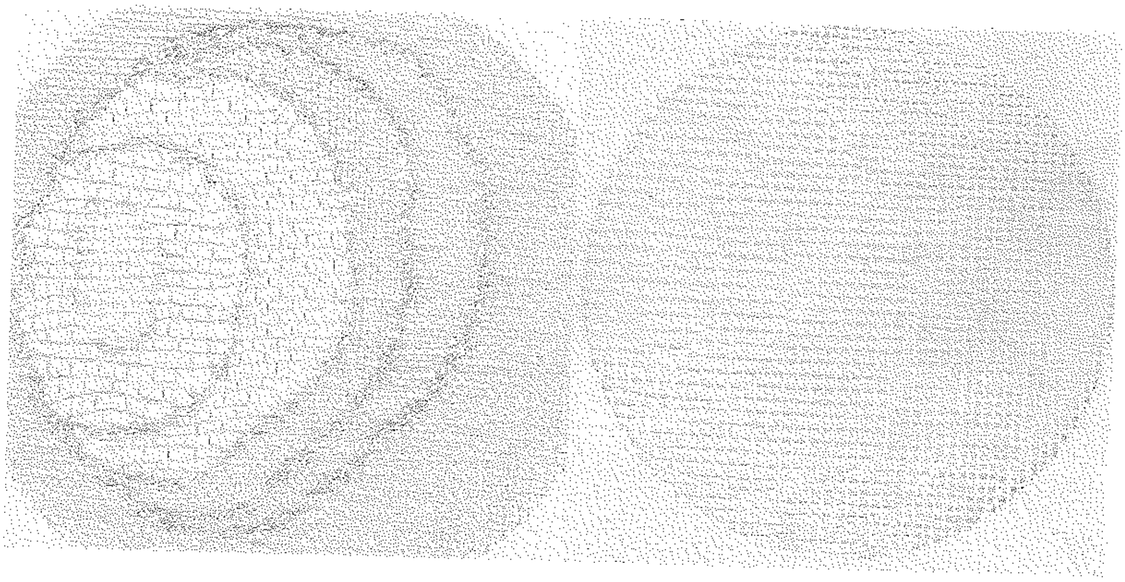
TABLE - I

Radius (mm)		25.096	44.543	57.596	68.51	77.76
	THETA (deg)					
Probe 1	22.5	0.8747	0.8473	0.8351	0.8250	0.8131
Probe 2	67.5	0.9084	0.9069	0.9064	0.9017	0.8821
Probe 3	112.5	0.9273	0.9354	0.9332	0.9165	0.8894
Probe 4	157.5	0.9088	0.9088	0.9067	0.8965	0.8765
Probe 5	202.5	0.8882	0.8822	0.8853	0.8701	0.8481
Probe 6	247.5	0.8668	0.8668	0.8627	0.8541	0.8361
Probe 7	292.5	0.8714	0.8438	0.8291	0.8291	0.8040
Probe 8	337.5	0.8623	0.8406	0.8278	0.8191	0.8074



Welded wire Laser cut

Fig.2 Screens manufactured by two different techniques

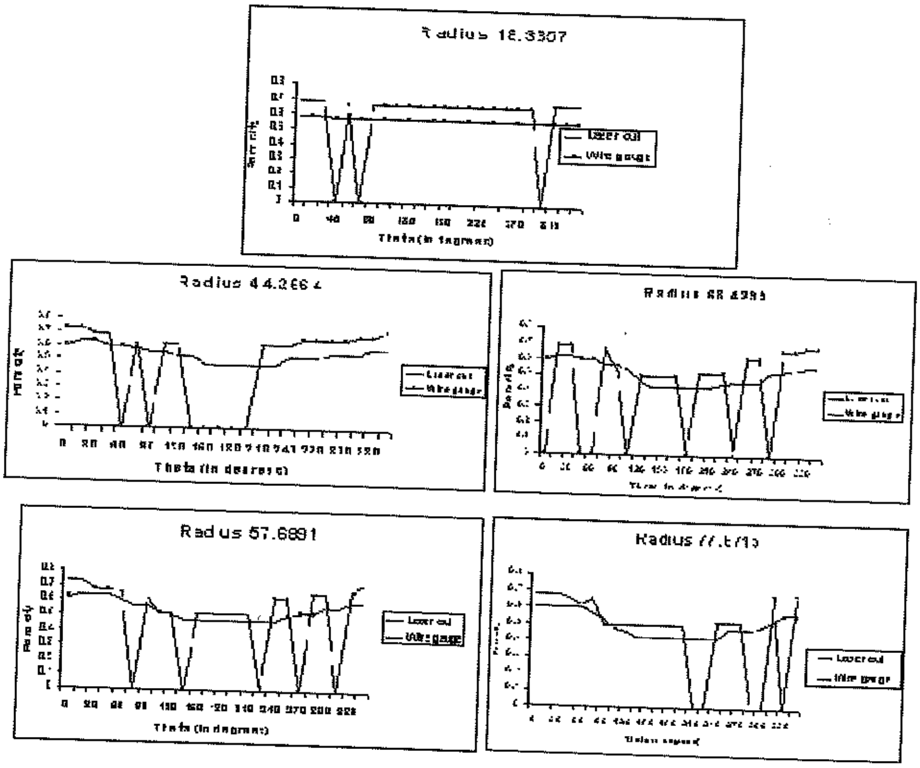
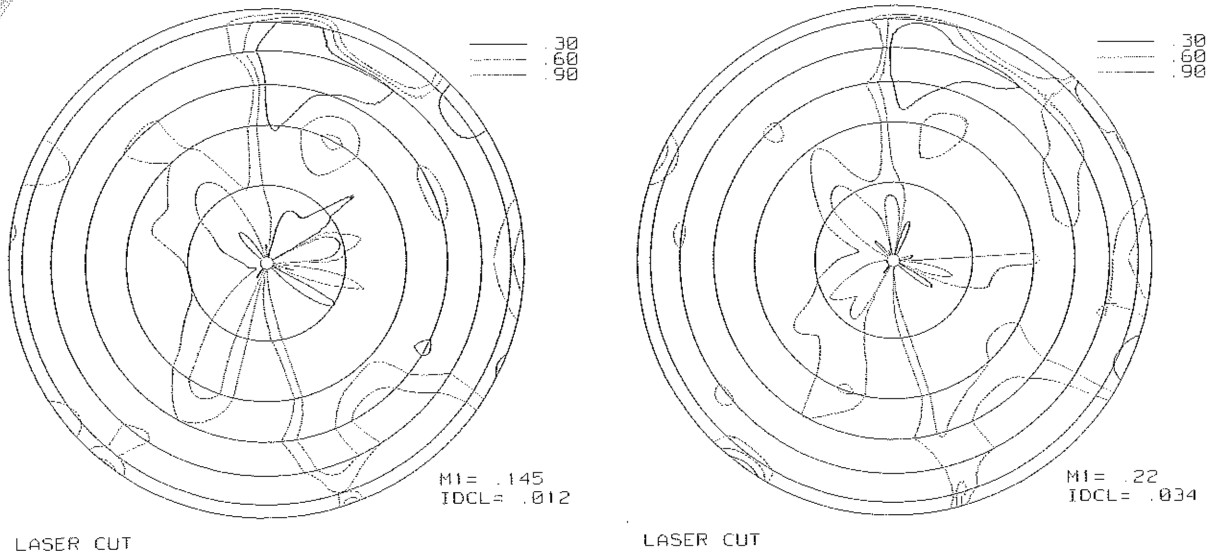
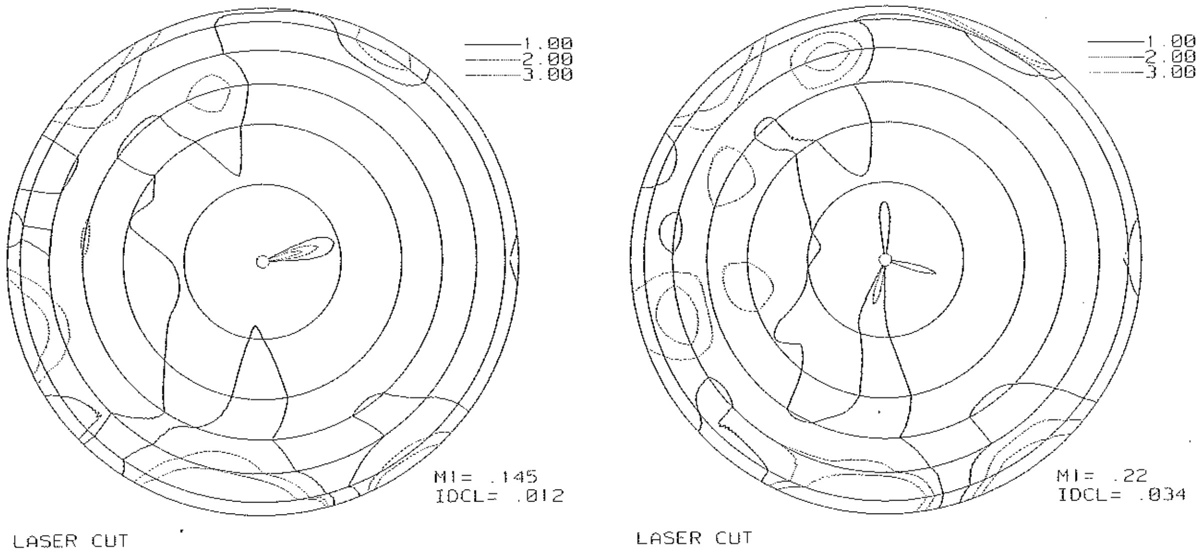


Fig. 2 Local Porosity Values of Fabricated Screens

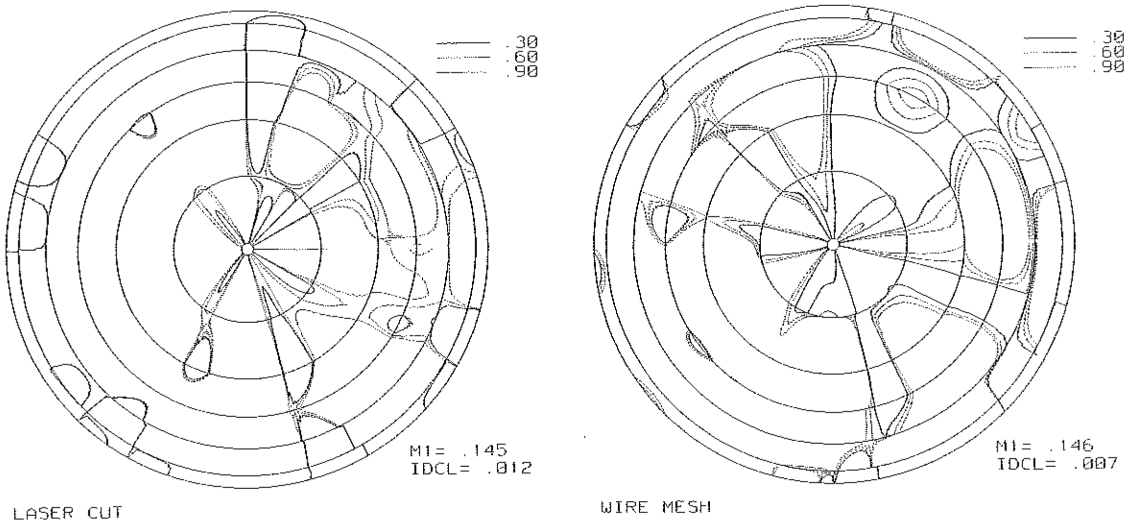


A - Loss numbers less than

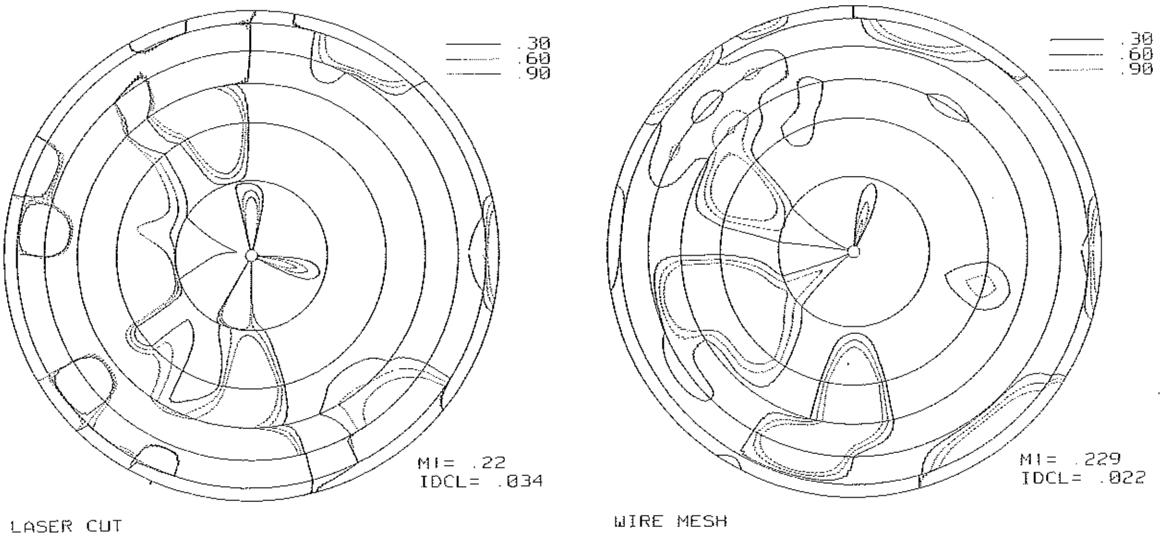


B - Loss numbers greater than

Fig. 5 Comparison of local total pressure loss contours for two different Mach numbers



A) Inlet Mach Number =



B) Inlet Mach Number =

Fig. 6 Comparison of local total pressure loss contours for Laser cut screen and Wire mesh screen.

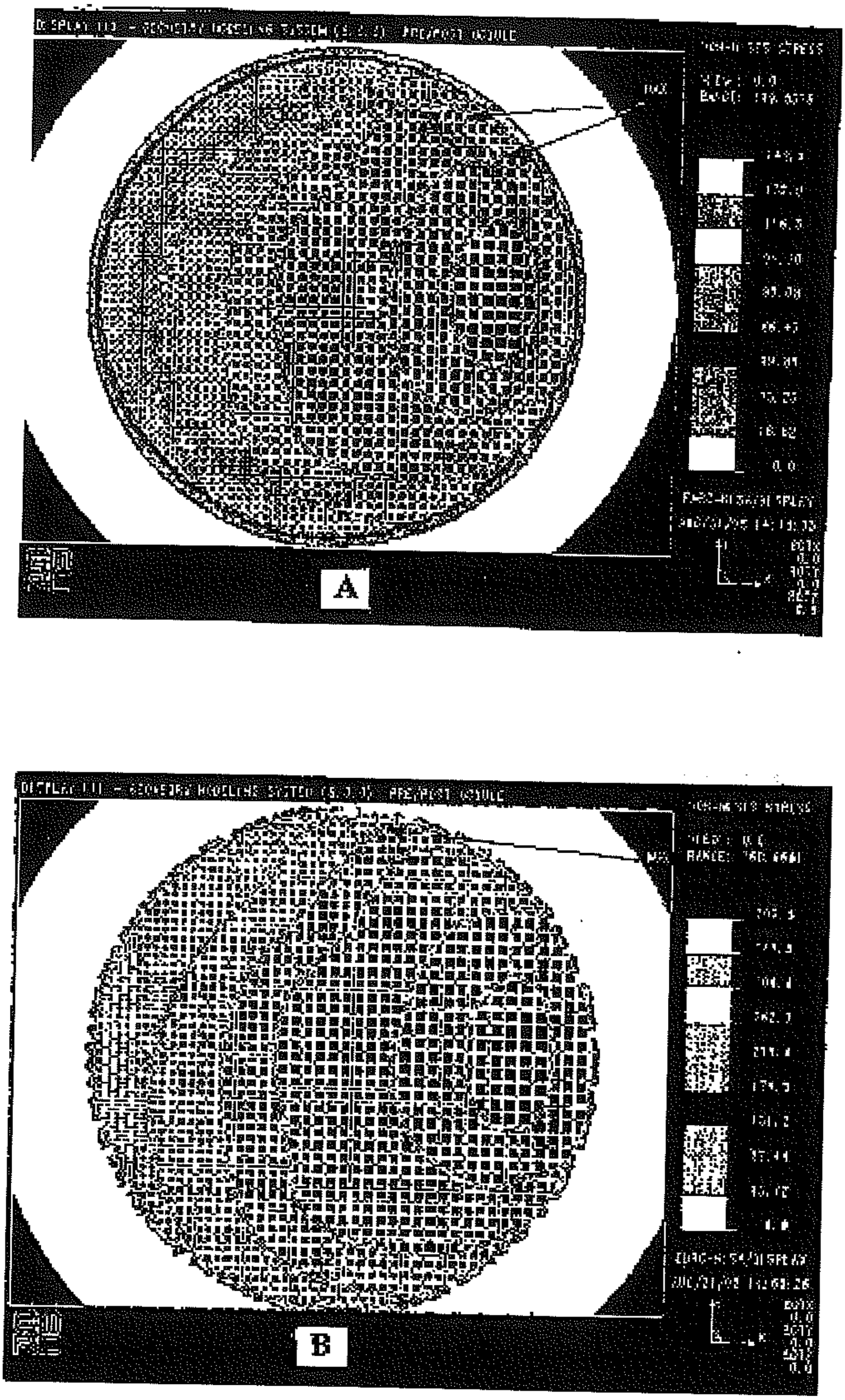


Fig. 7 Stress Distribution