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SB301超跨音速压气机平面叶栅风洞的超跨音速气动特性

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为了有效地开展对超、跨音速压气机的研究，我们自行设计、制造和调试成功了超、跨音速叶栅风洞。

一、风洞概况及特点

1. **风洞概况**　本风洞为吹气式暂冲风洞(图1)，全长19m，中心高1.2m。风洞最大工作流量为22kg/s，稳定工作时间大于4分钟。风洞进口M_a数可从0.4至1.6，试验段横截面尺寸为160×300mm^2，叶栅的几何进气角β_D（风洞轴线与叶栅额线之间的夹角）为24°～90°，出气角β_2（气体流出方向与风洞轴线之间的夹角）为0～60°，风洞的雷诺数（以叶弦为参考长度）Re＞1.4×10^6。

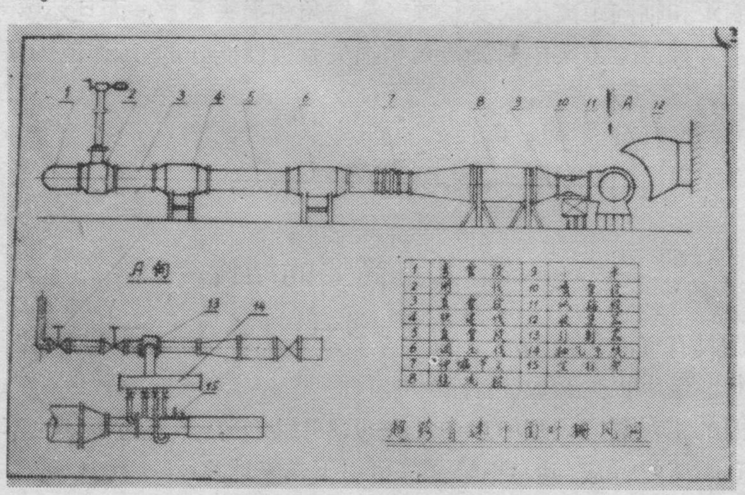

图1　SB301风洞简图

2. **风洞特点**　本风洞与国内同类风洞相比，有以下几个突出的优点。

（1）本风洞集亚、跨、超音速于一体，试验M_a数可从0.4至1.6，只要增加几对喷管，M_a数还可提高到2.0。特别是能在整个跨音速的范围内工作，是我国目前第一台能在这么宽广的速度范围内进行压气机平面叶栅试验的风洞。

（2）有比较完善的引射抽气系统。各抽吸管道分别控制，能方便地调节到栅前所需的工作状态。在试验段圆盘上，叶栅进口前两侧各有一块孔板，用于吸除两侧壁的附面层。喷管出口至叶栅额线处，上下壁设有驻室和孔板，前段为开槽板，后段为开孔板，用于加速气流，

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消除堵塞和减少激波反射等。由于有了这样的抽吸系统，扩大了风洞的试验范围，可使试验顺利地在跨音速范围内工作。同时弥补了固壁喷管马赫数间隔较大的缺点。

（3）在国内叶栅风洞中首次使用栅后带腔室的开槽尾板及节流装置。在没有尾板、节流装置之前的试验中，所需Ma_1和压比P_2/P_1以及栅前流场的周期性，只能用改变进口总压或控制抽气量的办法，经过反复调整来实现。要调整一个合适的状态，需要很长的时间，而且不能满意地达到栅后流场的周期性。为了能在叶栅的上下游以及叶片通道内方便地建立起周期流场和改变反压，先设计了一套平板尾板的节流装置，试验表明，这对改变反压和激波位置，调整栅后流场的周期性有良好的作用。如在跨音性能调试的试验中，装有尾板时，Ma_2的不均匀度由不装尾板时的5％减小到$\delta m2<2\%$，而且操作方便，缩短了试验状态的调整时间，获得了满意的周期流场。

（4）有新型的性能先进的、精度高，速度快的数据采集和处理系统。从美国引进的数据自动采集及实时处理系统，包括压力传感器，扫描阀系统，Auto Data Ten/10微机系统，可与中心计算机PDP-11/70机相连的VT105终端，这个系统可以独立工作，也可以与中心计算机相连作实时处理，处理结果一方面由宽行打印机打印，另一方面再通过调制，解调器返回到VT105终端的屏幕上显示。从数据采集到VT105终端的屏幕上显示出试验结果，所需时间不到一分钟。

（5）将纹影仪图象通过投影装置，投影于操纵间，可随时观察试验时的流场状态，以便及时调整流场。栅后测量采用具有四个自由度（叶栅的轴线，额线，叶高以及绕探针杆轴线旋转）的坐标架，由单板机控制，步进电机驱动探针自动连续移距。主要测量叶栅中间槽道的栅后气流参数，也可以上下延伸一个槽道。移距精度可达0.1mm。

二、超、跨音速流场校测

栅前进口气流的周期性取决于上游拉瓦尔喷管气流的均匀性。在进行超、跨音叶栅试验之前，必须要对拉瓦尔喷管进行校测。

1. **校测方法**　对$M_D=1.2$的喷管校测时，采用超音速静压探针和总压、方向组合探针分别测取校测截面的169点总静压分布，在对$M_D=1.4$，1.5和1.6的三对喷管校测时，用九点总静压耙，在校测截面测取81点总、静压分布。

2. **校测结果**　经校测，$Ma_0=1.2$喷管流场M_a数均匀区为$160\times100mm^2$，而$Ma_0=1.4$，1.5和1.6三对喷管流场M数均匀区为$186\times80mm^2$。这样大的均匀区完全能够满足超、跨音速叶栅试验的需要。经计算，各对喷管流场M_a数均匀区的$\Delta Ma_{max}\%$为6.9～8；均方根偏差$\varepsilon‰$小于1.45，各项偏差小于规定指标，与国内的外流风洞校测数据相比，还优于国内某些风洞，风洞流场的M数分布是均匀的。

三、超、跨音速性能调试

1. **调试件**　在风洞流场校测之后，进行了超、跨音速性能调试。超、跨音速性能调试M_a数分别选为$Ma_1=1.4$～1.6左右和$Ma_1=0.8$～1.25。超跨音速性能调试的试验件代号分别为SJ301-6（选自日本NAL TM-141文献上提供的叶栅）和SJ301-8（选自西德喷气推进研究

所的LO30-6多圆弧叶栅)。

2. 栅前、栅后周期流场的调试 流场周期性的调整是风洞超、跨音速性能调试中的第一位的工作。

在调整栅前和栅后流场的周期性时，栅前要注意进气总压的给定和控制上、下壁，左右侧壁的抽气量；栅前要特别注意控制尾板和节流阀的状态，通过纹影投影仪，在操纵间直接观看栅前、栅后激波波系互相平行与否，并用照相机拍摄激波波系的纹影照片。从图 2 可见，风洞栅前、栅后流场的周期性是良好的。

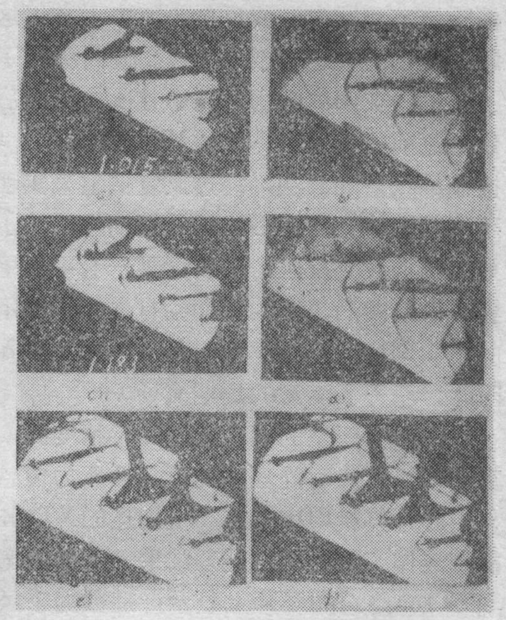

图 2 纹影照片

a) $Ma_1=1.015$ $\beta_1=153.2°$ b) $Ma_1=1.118$ $\beta_1=151°$ c) $Ma_1=1.183$ $\beta_1=151.1°$ d) $Ma_1=1.24$ $\beta_1=151.1°$ e) $Ma_1=1.496$ $\beta_1=58.3°$ f) $Ma_1=1.603$ $\beta_1=58.3°$

因此，在超、跨音速叶栅试验中，只要保证叶片安装正确，叶片安装角误差不大于±0.20°，叶片在气动力作用下不产生明显的变形，适当控制上下壁和左右侧壁的抽气量，以及尾板，节流阀的状态，栅前和栅后气流的周期性是不难达到的。

3. 超、跨音速性能调试 为了便于比较，我们分别选取了与日本和西德试验的数据相近的状态，进行了多次试验，试验结果的比较见图 3 和表 1。由图和表可以看出，各试验点都比较吻合于日本和西德的风洞的试验点，损失还优于这两个风洞，仅在 $Ma_1=1.193$, $\beta_1=151°$ 时，损失系数 $\bar{\omega}$ 大于西德的风洞。这主要由于双方压比和轴向速度密度比 Ω 不同。试验结果表明，本风洞的超跨音速性能是优良的。在国内外所公认的、难度比较大的跨音叶栅试验方面，填补了国内的一项空白。接近国际上八十年代初期的同类设备的水平。

表1 跨音速叶栅性能比较

试验件	SB301 SJ301-8		西德 L030-6	
进口参数	$Ma_1=1{,}0015$ $\beta_1=153.2°$	$Ma_1=1.193$ $\beta_1=151°$	$Ma_1=1.008$ $\beta_1=153.2°$	$Ma_1=1.192$ $\beta_1=151°$
$\bar{\omega}$	6.15%	8.36%	7.5%	7.0%
θ	8.79°	4.69°	9.5°	5.20°
Ω	1.1567	1.089	1.159	1.060
P_2/P_1	1.321	1.472	1.325	1.624

注：θ——气流转折角 $\theta=\beta_1-\beta_2$

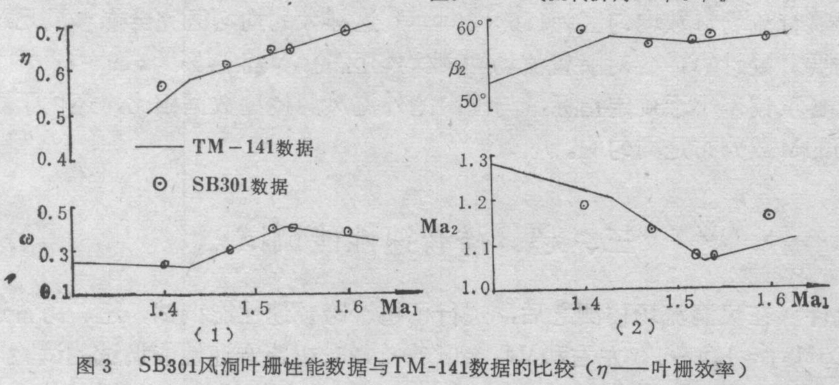

图 3 SB301风洞叶栅性能数据与TM-141数据的比较（η——叶栅效率）

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ment with those of the experiments. It is shown that this technique meets the requirements for quantitative estimation.

ANALYSIS OF HEAT TRANSFER OF FLUIDS OSCILLATING WITHIN PIPES

Zhu Gujun, Zhao Lingde, Cao Yuzhang

(Beijing Institute of Aeronautics and Astronautics)

Abstract

Heat transfer can be enhanced when fluid oscillates axially within pipes. A numerical analysis is given using the finite difference method. The relationship derived from differential equations and unambiguous conditions is written in the form of

$$\frac{a_e}{a}=f\left(\text{wom}, \frac{\Delta S}{R}, \Pr, \frac{L}{R}\right)$$

where a_e – the effective thermal diffusivity, a – the thermal diffusivity, ΔS – the tidal displacement of oscillation, R – the radius and L – the length of the pipe. The results obtained show that a_e/a is independent of L/R as $L \gg \Delta S$ and proportional to the square of $\Delta S/R$, and its value increases with an increase in Wom or Pr. The numerical solution is in good agreement with the data of experiments.

TECHNICAL NOTES

EXPERINENTAL INVESTIGATION ON FLOW PERFORMANCE OF TANDEM BLADE CASCADES WITH DOUBLE CIRCULAR ARC PROFILES

Zhuang Biaonan, Wu Guochuan, Guo Bingheng

(Nanjing Aeronautical Institute)

Abstract

Wind tunnel experiments have been made with 24 types of tandem blade cascades with different geometrical parameters. Under the conditions that the inlet Mach number is 0.3 and the Reynolds number is 2.7×10^5, the main flow characteristics of tandem cascades have been obtained, and the operation ranges of main geometrical parameters under optimum conditions have been found.

SUPERSONIC AND TRANSONIC AERODYNAMIC CHARACTERISTICS OF SB301 TWO-DIMENSIONAL CASCADE WIND TUNNEL

Jiang Zhengli and Ma Jinxian

(Gas Turbine Establishment)

Abstract

SB301 wind tunnel was designed to test two-dimensional cascades of compressor in subsonic,transonic and supersonic flow. The wind tunnel has been equipped with advanced instrumentation and enables to accomplish a wide range of experimentation. It is first successful one for testing the two-dimensional cascades of compressor in transonic and supersonic flow in China by now. It provides a new test rig for research and development of aeroengines with high performances.

COMPUTER-AIDED EXPERIMENTAL INVESTIGATION OF AXIAL-FLOW COMPRESSORS

Zhu Nianguo and Chen Maozhang

(Beijing Institute of Aeronautics and Astronautics)

Abstract

An approach has been developed to evaluate some important aerodynamic parameters such as air-flow angle, blockage factor and loss coefficient, at unmeasurable surfaces. It can be used for two cases of measurement of multi-stage, axial-flow compressors. In order to testify this approach, several examples have been calculated and the results show that this approach provides reliable data for further performance improvement.

AN EXPERIMENTAL STUDY ON THERMAL STRESS IN CYLINDRICAL CASE

Shang Weijun and Zhang Weixin

(Nanjing Aeronautical Institute)

Abstract

This paper describes temperature and thermal stress distributions as well as measuring technique and method to generate these two parameters. The temperature distributions are produced by iodine-wolfram lamps and measured by thermocouples. The temperature fields which are steady and symmetrical have both axial and radial temperature gradients. The experimental curve has been fitted with the aid of the least square method in form of algebraical polynomials. Under such temperature distributions,the measurements of thermal stresses in cylindrical case with fixed ends were carried out by mid-temperature strain gauge,and the profiles of thermal stresses versus the case axial distance were obtained.

In addition,thermal stresses were calculated numerically employing the finite element method,SAP-5 program. The calculated results are compared with the test data satifactorily.