

螺旋桨飞机缩比模型表面声压预测 的验证试验^{*}

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【摘要】 介绍了在室外进行的螺旋桨飞机缩比模型的噪声测量试验, 目的是验证改进的螺旋桨飞机声场模型, 它可预测任意形状机身边界的表面声压分布。介绍了试验, 噪声测量以及预测方法, 预测和试验结果的比较表明得到了较满意的符合。

主题词: 噪声 螺旋桨 机身 效应 噪声测量

分类号: V216.54

1 引言

文献[1]给出了螺旋桨飞机声场模型的一种改进, 可以精确地预测小马赫数飞行条件下任意形状机身表面的阻塞声压(即刚性机身表面感受的声压)。而以前发表的工作大都限于无限长圆柱机身模型^[2~4], 不能精确地预测实际机身表面的声压分布, 尤其是不能预测表面声压的相位分布。改进的声场模型已得到用刚性球散射声场解析级数解的算例验证, 但在使用螺旋桨飞机缩比模型进行试验验证中遇到了没有消声风洞试验条件的困难。在室外进行的试验中, 由于无法产生均匀来流条件和地面涡的卷入等原因, 在飞行条件下适用的片条理论不再适用于预测螺旋桨叶表面的载荷分布。为此, 由空间声场变换方法得到螺旋桨叶片表面的压力分布^[5], 以此作为自由声场预测的基础。试验使用 Y12 飞机 1/4 缩比螺旋桨模型作为声源, 在 0.5 米直径 1.8 米长的圆柱机身模型壁面上齐平安装 6 只传声器来测量表面的阻塞声压, 测量得到的声压分布与预测结果绘制在同一个等值线图中, 得到了较满意的符合。

2 试验描述和噪声测量方法

国外螺旋桨噪声的地面验证试验是在消声风洞中进行的^[6], 可模拟来流和自由声场环境。目前国内没有可进行类似试验的消声风洞, 因此试验是在露天条件下进行的。为了减小背景噪声的影响, 试验的时间选择在无风的夜晚。

试验使用 1/4 缩比的 Y12 飞机螺旋桨模型, 3 片桨叶可分别改变各自的桨距角。螺旋桨直径 0.66 米, 使用可变速的直流电机驱动, 最高转速可达 3000 转/分。为了减小地面反射的影响, 螺旋桨中心轴线距地面 2.1 m, 如图 1, 曾在螺旋桨正前方 5 米处安放一台低噪声风机, 来模拟来流, 可产生 12~15 米/秒的流速, 但由于无法产生较均匀的流场, 因此只进行无来流的试验。为了模拟刚性机身的影响使用了一个 0.5 米直径 1.8 米长的圆柱型铝板座舱。在模型筒壁上开

了 6 个孔, 在外壁面齐平安装 6 支 CH16 1/2 in 的传声器, 其位置如图 2 所示。试验测量中在周向旋转了 5 个位置, 以便测到在相应截面上沿周向 45° 的表面声压分布。试验中螺桨转速为 2900 转/分, 在桨叶展向 85% 处桨距角取为 20° 螺桨轴线与座舱轴线在同一水平面, 其相对位

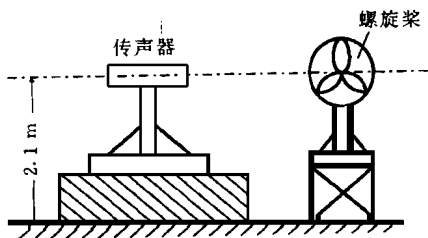


图 1 螺桨及驱动装置

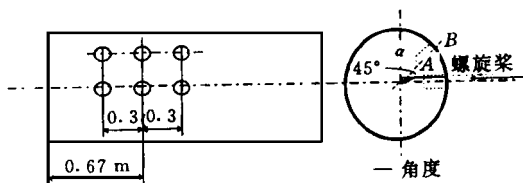


图 2 缩比机身模型及传声器安装位置

置为图 3 所示的 4 个位置(第 1 位置: $y = 0.86$ m, $z = 0.82$ m; 第 2 位置: $y = 0.86$ m, $z = 0.52$ m; 第 3 位置: $y = 1.02$ m, $z = 0.82$ m; 第 4 位置: $y = 1.02$ m, $z = 0.52$ m)。

6 支 CH16 传声器测量壁面声压安装在带有标记的螺桨轴附近的 WT-18-N112 光电传感器产生螺桨每旋转一周的触发脉冲信号。测量中由传声器和光电传感器转换得到的电压信号记录在一台 14 通道 TEAC 磁带上。每次试验前使用 B&K4230 标准声源对噪声测量系统进行标定。

螺桨地面噪声试验中, 地面湍流将与螺桨桨叶相互作用产生非定常的随机载荷, 产生随机噪声, 也使离散噪声有很大增加。这里采用文献[7]介绍的时间同步平均方法来减小非定常随机载荷产生的影响。时间同步平均的数据处理是使用 NI 公司的 AI-MIO-64F 数采板实现的, 同时采集传声器的声压信号和光电信号后, 对各个旋转周期的声压信号进行平均; 然后由 FFT 分析计算各阶谐波。

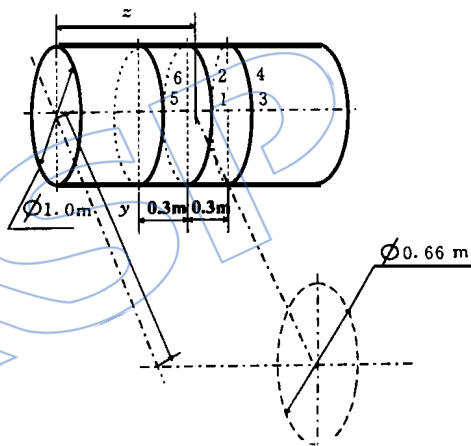


图 3 螺桨与机身相对位置

3 噪声预测

螺桨飞机机身表面的声压分布采用文献[1]给出的改进的螺桨飞机声场模型来计算。模型建立在声类比理论基础上, 导出了机身表面阻塞声压与由螺桨产生的机身表面自由场声压之间关连的积分方程。

$$4\pi \left(1 - \frac{1}{2\beta_n^2} \right) c_n(x) = 4\pi p_n + \int_{\Gamma} \left[\frac{c_n(\gamma) e^{-in\omega/c} in\omega \cos\theta}{cr(1-Mar)^3} \right]_{ret} ds + \int_{\Gamma} \left[\frac{c_n(\gamma) e^{-in\omega/c} [(1-Ma^2) \cos\theta - (1-Mar) Ma_n]}{r^2(1-Mar)^3} \right]_{ret} ds \quad (1)$$

这里 $p_n(x)$ 和 $c_n(x)$ 是螺桨自由场声压和由它引起的刚性边界上阻塞声压的 n 阶付利叶分

量, $f_f = 0$ 为机身表面方程, x 和 y 分别表示观察点和源点坐标, $p_n(x)$ 和 $c_n(x)$ 都是空间坐标的复值函数。

对叶尖速度为亚音速的螺旋桨自由场离散噪声预测须要桨叶表面的载荷分布。在飞行条件下它可使用气动片条理论计算^[3]。在目前的地面试验中, 由于无法模拟飞行条件下的来流条件, 以及地面湍流的卷入产生的非定常载荷的影响, 由气动片条理论计算得到的表面载荷分布与实际的载荷相差甚远, 无法满足预测的需要。为此使用文献[5]的空间声场变换方法, 由实际测量的空间某些点上的自由场声压, 反算出螺旋桨表面的压力分布, 用来预测空间自由场声压分布。李晓东博士提供了螺旋桨表面载荷分布的计算结果。自由场声压的计算使用了北航、南航、沈航三院校共同发展的 PANOPP 程序。

4 试验测量结果分析及预测结果的比较

为了分析背景噪声的影响, 在试验前测量了背景噪声, 总声压级不超过 80 dB, 各个 1/3 倍频程谱分量都不超过 70 dB。

时间同步平均可以有效地去除与旋转周期无关的信号。图 4 给出了平均前后的典型声压时域曲线。图 5 为 4 个测量位置上螺旋桨通过频率一阶谐波的阻塞声压级等值线图, 它们是从机身下面的母线切开后展开的, 横坐标为从机身前端算起的轴线尺寸, 纵坐标为展开的周向尺寸。实线为预测结果, 它包括整个柱面; 虚线为测量结果, 只有所测的 0.6 米长的柱面, 相邻等值线声压级相差 6 dB。图中看出无论是预测结果还是测量结果, 都在螺旋桨相对位置上产生最大声压级, 预测的最大值位置比测量的靠后。

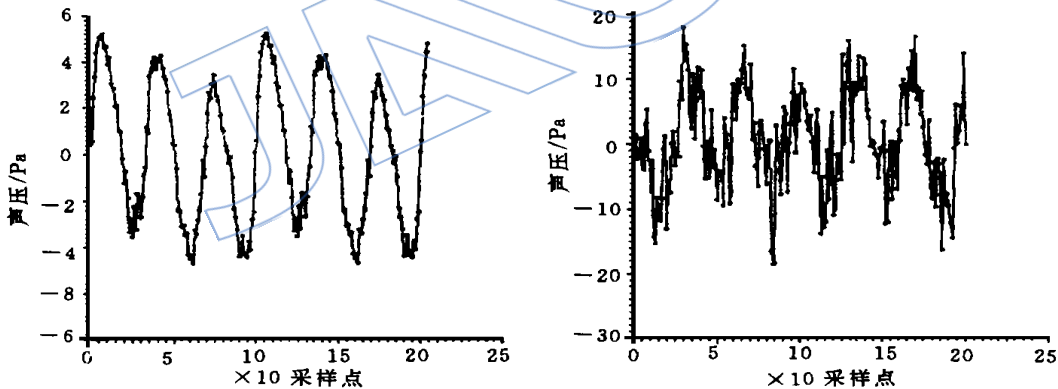


图 4 径与未径同同步平均的声压信号

由预测的声压级等值线图, 可看到声散射现象, 在螺旋桨相对位置处反射声最大, 因此总声压级最大, 随入射角的变化反射声急剧减小, 总声压级也随之减小; 在螺旋桨相对的半个圆柱面内预测的等值线与测量的等值线得到较满意的符合。在背对螺旋桨的机身表面, 预测的声压级等值线图反映了声影和声衍射现象。在相对于螺旋桨的机身背面存在最低声压区, 声压级比最高声压级低 24 dB 以上, 相当于声影区。在按直线传播方式声波无法达到的机身背面, 某些部位仍有较强的声压, 这反映了声衍射的现象。在预测声压与背景噪声有相同量级或更低的位置, 测量得到的主要是背景噪声, 因此预测值与测量值相差很大。

这是国内螺旋桨飞机缩比座舱模型表面声压测量试验的首次尝试, 所验证的是目前最精确的小马赫数飞行螺旋桨飞机表面声压预测方法, 声压级的验证得到初步成功。但是由于未能测量

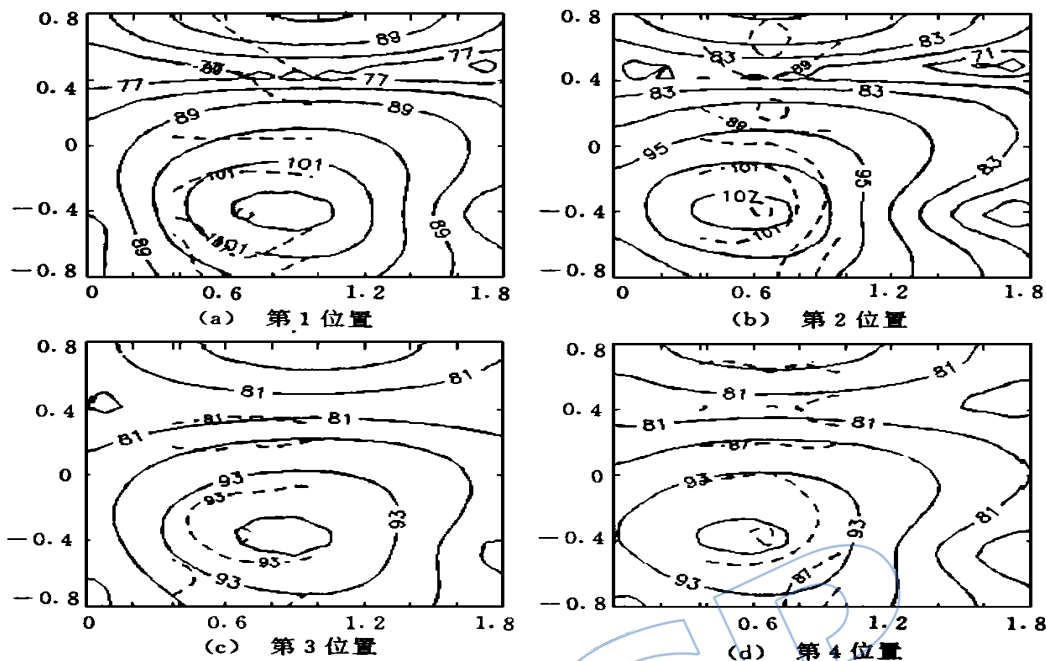


图 5 预测和测量得到的表面声压级等值线图

声压的相对相位, 因此无法比较表面声压相位的分布。模型表面测点较少, 无法对表面声压分布作更详细的测量, 室外测量背景噪声较高, 因此进一步的工作是必要。

5 结 论

(1) 用户外螺旋桨飞机缩比模型的噪声试验为文献[1]发展的螺旋桨飞机声场模型作初步验证是成功的。(2) 增加测点, 作进一步细致的测量是需要的。(3) 为减小背景噪声, 试验可在消声室中进行。(4) 试验方法与预测方法相结合, 为螺旋桨飞机的声学设计提供了工具。

致谢 李晓东博士在研究工作中提供了空间声场变换得到的螺旋桨表面载荷。

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Numerical Simulation

PERFORMANCE PREDICTION OF BOWED VANE AXIAL- FLOW TURBINES

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ABSTRACT

A method for the performance prediction of axial- flow turbines with bowed and conventional vanes is presented, which uses flow function as control equation on S2 surface. Profile loss is calculated by numerical method on several S1 flow surfaces. Secondary loss and tip- leadage loss are empirically estimated with pitch- wide average loss- es along the cascade blades. The effect of the blade bowed angle on the secondary loss is tak- en into account. The comparison of the predicted results with experimental data confirms the feasibility of the method.

Key Words Performance analysis Prediction techniques Turbines

MEASUREMENT AND DETERMINATION OF AEROENGINE THRUST

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ABSTRACT

It is difficult to measure the flight thrust of Aeroengine directly. It is determined now by calculation with mathematical relationships of the flight thrust to the physical quantities which can be measured directly. According to the definition and the expression of the thrust, as well as the conditions derived from them, a method of aeroengine thrust determination and its program are provided on the basis of engine part tests, model tests, engine ground test, altitude- simulation tests, and flight tests. At the same time, the important function of the altitude- simulation facility is also analyzed in respect of correct flight thrust determination.

Key Words Aircraft engines Thrust Measurement method

VALIDATION TESTS WITH A SCALE- MODEL FOR SURFACE SOUND PRESSURE PREDICTION OF PROPELLER AIRCRAFT

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ABSTRACT

An experimental research with a propeller aircraft scale model has been completed to obtain reasonably comprehensive data for validating its improved sound field model. Instead of the tests in anechoic windtunnel as abroad, the scale- model tests was accomplished in outdoor conditions. In the predicton of propeller noise in free field with the improved sound field model, the load data on the propeller blade surface were obtained from calculation of inverse problem. The measured results of sound pressure on the scale- model have been compared with that predicted by the improved sound field model in a reasonable a-

greement.

Key Words Noise propellers Fuselages Effect Noise measurements

COMPARISON BETWEEN TWO KINDS OF CONVENTIONAL LABYRINTH

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ABSTRACT Straight- through and stepped labyrinths are often used in aircraft engine. According to large amounts of experimental data, the empirical formulas of mass flow factor for these two kinds of labyrinth have been provided which are superior to their theoretical formulas due to various corrections. The seal characteristics of the two kinds of labyrinth were compared and analyzed in detail so that their features and reasonable conditions of their application were found out. Finally, the new empirical formulas for calculating their critical pressure ratio were derived too.

Key Words Sealing Flow coefficients Leakage

MULTISECTION LINERS FOR NOISE REDUCTION OF COUNTER- ROTATING FAN

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ABSTRACT It has been found that multisection liners not only attenuate the sound waves in ducts, but also to suppress sound wave through the wave reflection at impedance discontinuities. As a consequence, the maximum noise reduction in a duct of given length can be realized by designing each section liner and different combination. In the present investigation, different combinations of multisection liners have been designed to suppress the discrete noises generated by a counter- rotating fan. The experimental results testified that, the noise was reduced by 9 dB in far field under the condition of 60 cm liner length.

Key Words Fans Perforated plate sound absorption Noise reduction

DIGITAL SIMULATION ON TOOTH CUTTING AND MESHING OF SPIRAL BEVEL GEARS

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ABSTRACT The conventional methods for determining the tooth geometry and tooth contact of spiral bevel gears are based on differential geometries of rigid body movement, and consequently make description of tooth surface and analysis of tooth contact behavior very complicated. In this paper, the authors work out a digital simulation method for tooth cutting and meshing of spiral bevel gears. A numerical model of tooth surfaces is set up by digital simulation of tooth cutting. The analysis of tooth contact behavior is completed with the numerical model of tooth surfaces. Solution of the meshing equation $\mathbf{v} \cdot \mathbf{n} = 0$ in conventional methods is replaced by minimizing the normal distance between points on the tooth