

# 智能化轴流风扇/风机设计

## AIFan

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钱煜平

汽车工程系

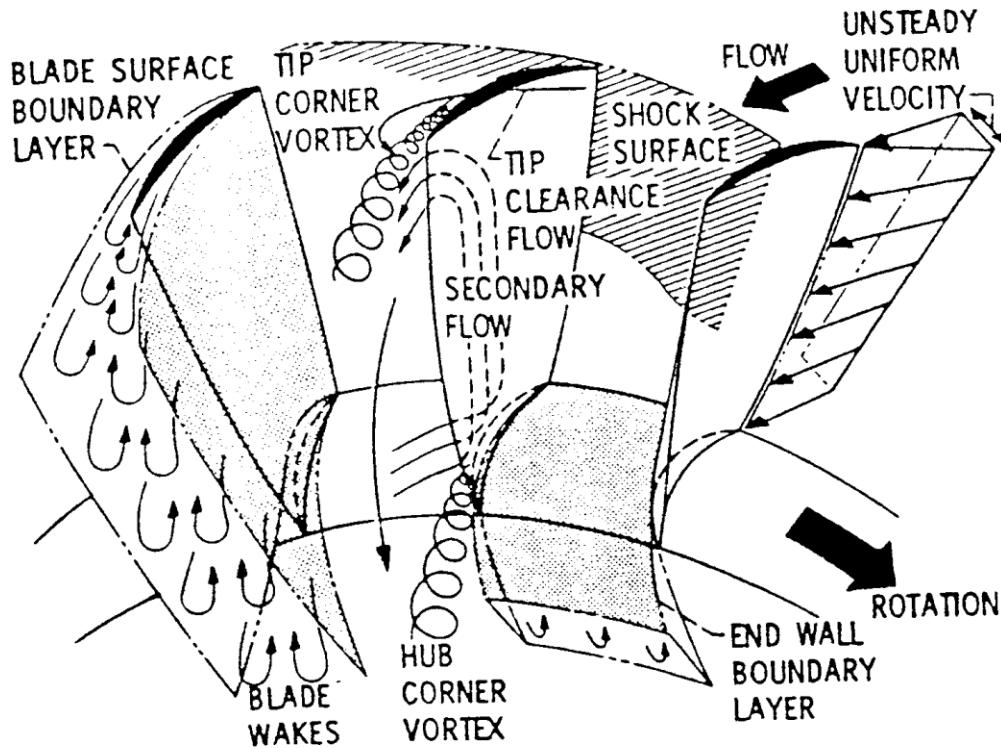
通用航空技术研究中心



清华大学



# 1. 轴流风扇通流设计中的关键模型



- Profile loss 叶型损失
- Endwall loss 端区损失
- Shock loss 激波损失
- Tip leakage, secondary losses, wake mixing loss, etc. 二次流损失

# 2.1轴流风扇一维设计模型—损失模型

损失 基础模型库：

叶型损失模型：

$$\omega = 2 \left( \frac{\theta_2}{c} \right) \frac{\sigma}{\cos \beta_2} \left( \frac{\cos \beta_1}{\cos \beta_2} \right)^2 \left\{ \frac{\frac{2H_2}{3H_2 - 1}}{\left[ 1 - \left( \frac{\theta_2}{c} \right) \frac{\sigma H_2}{\cos \beta_2} \right]^3} \right\}$$

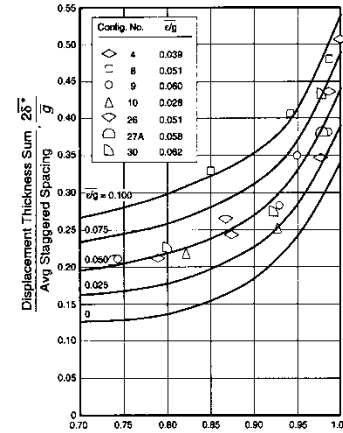
$$\omega \frac{\cos \beta_2}{2\sigma} \left( \frac{\cos \beta_2}{\cos \beta_1} \right)^2 = 0.003 + 0.0237D - 0.05D^2 + 0.125D^3$$

端区损失模型：

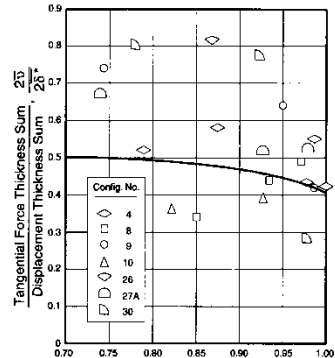
$$\eta = \tilde{\eta} \frac{1 - (2\bar{\delta}^*/g)(g/h)}{1 - (2\nu/2\bar{\delta}^*)(2\bar{\delta}^*/g)(g/h)}$$

叶尖泄漏损失模型：

$$\Delta\eta = \frac{0.7 \left( \frac{\varepsilon}{h} \right) \psi}{\cos \beta_m} \left[ 1 + 10 \sqrt{\frac{\varphi}{\psi} \frac{(\varepsilon/h)(h/c)}{\cos \beta_m}} \right]$$



$$\frac{\text{Pressure Rise Coef}}{\text{Max Pressure Rise Coef}} \left( \frac{\Delta p_R + \Delta p_{ST}}{q_{1e} + q_{1st}} \right) / \left( \frac{\Delta p_R + \Delta p_{ST}}{q_{1e} + q_{1st}} \right)_{\max}$$



$$\frac{\text{Pressure Rise Coef}}{\text{Max Pressure Rise Coef}} \left( \frac{\Delta p_R + \Delta p_{ST}}{q_{1e} + q_{1st}} \right) / \left( \frac{\Delta p_R + \Delta p_{ST}}{q_{1e} + q_{1st}} \right)_{\max}$$

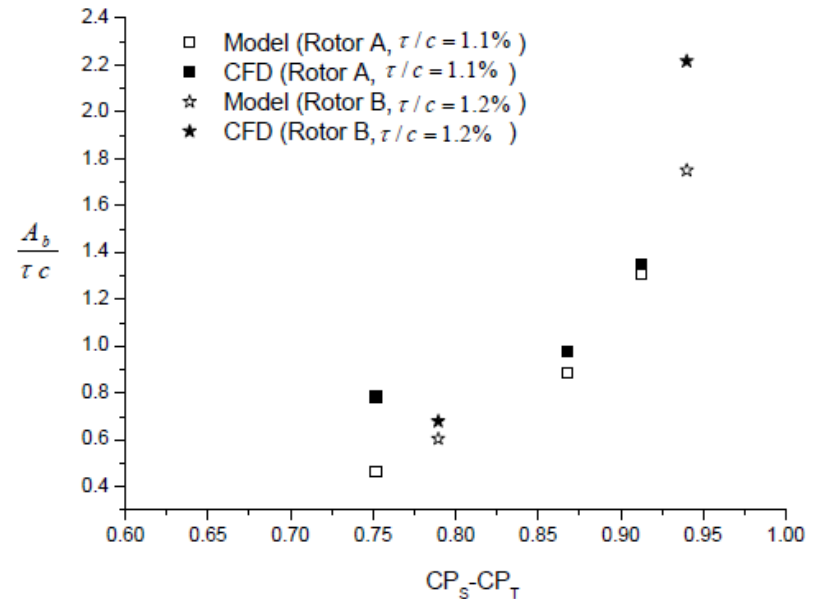
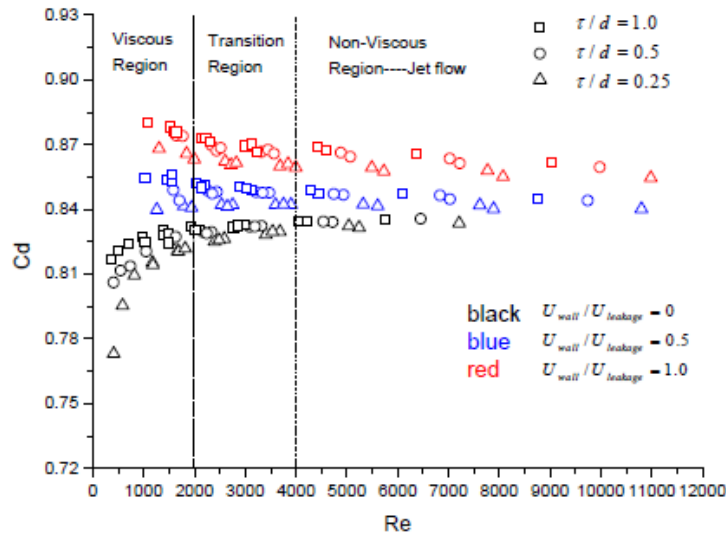
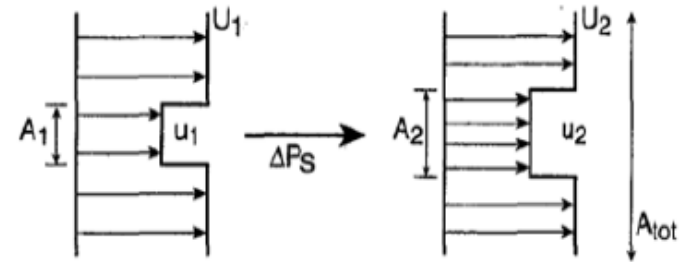
# 2. 2轴流风扇一维设计模型—堵塞模型

堵塞 基础模型库：

$$\frac{A_{b2}}{A_1} = \sqrt{1 + CP_T} \left\{ [1 - (CP_S - CP_T)]^{-1/2} - (1 - CP_S)^{-1/2} \right\}$$

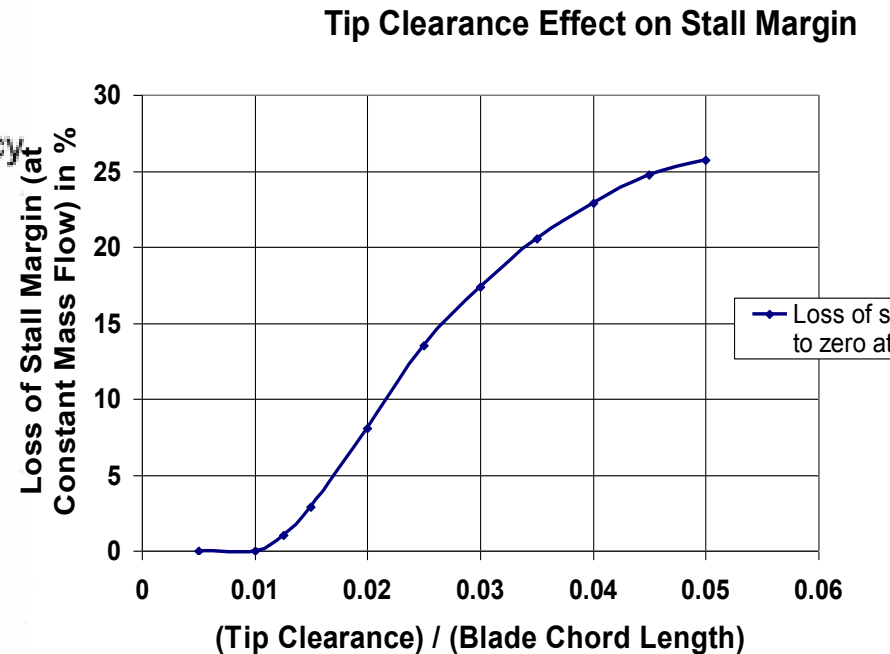
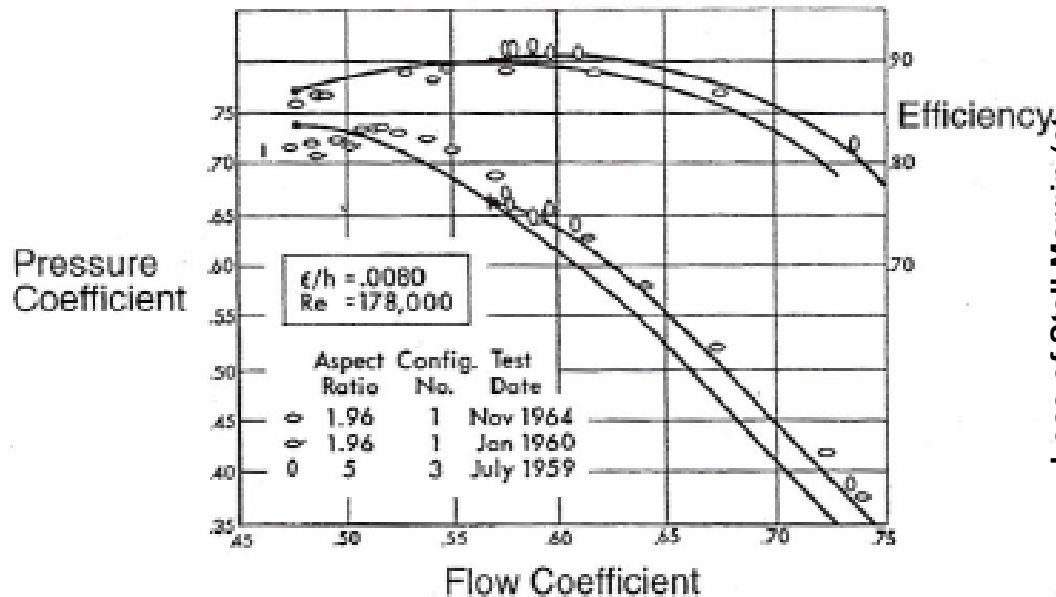
$$CP_S = \Delta P_S / \left( \frac{1}{2} \rho U_1^2 \right)$$

$$CP_T = \frac{\overline{P_{defect}^{*Mass}} - \overline{P_{inlet,main-flow}^{*Mass}}}{Q_{inlet,main-flow}}$$



# 2. 3轴流风扇一维设计模型—失速模型

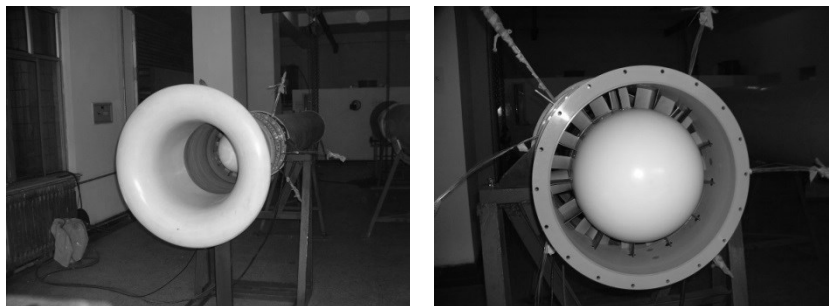
失速 基础模型库:



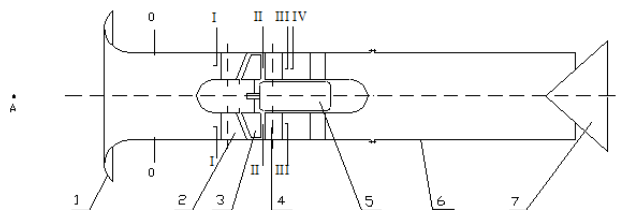
L. H. Smith, Jr., "Axial Compressor Aerodesign Evolution at General Electric", Trans. ASME, Journal of Turbomachinery, Vol. 124, July 2002

# 2. 4轴流风扇一维设计模型—模型验证

- 软件设计模型在北航尾流撞击试验台，针对设计转速3000rpm，流量 $2.9\text{m}^3/\text{s}$ ，全压1500Pa的轴流风机进行详细的试验标定。

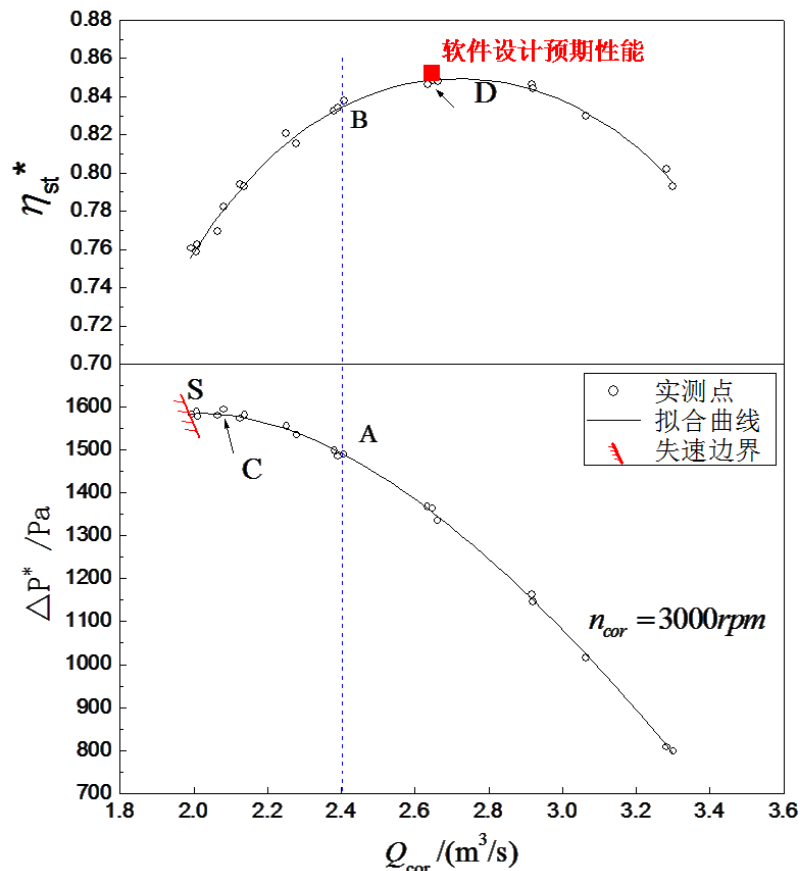


实验台实验规程、设备布置均按照《中华人民共和国航空航天工业部航空工业标准压气机试验标准》以及GB1236-85《通风机空气动力学性能试验方法》执行。



1 进口集流器；2 支撑叶片（3—均布）；3 压气机转子；4 压气机静子；5 异步交流电动机；  
6 排气管道；7 节流堵锥；A 大气参数测试点；O-O 流量测量截面；I-I 进口总压测量截面；  
II-II 级间动态流场测量截面；III-III 出口总压测量截面；IV-IV 出口总压靶测量截面；

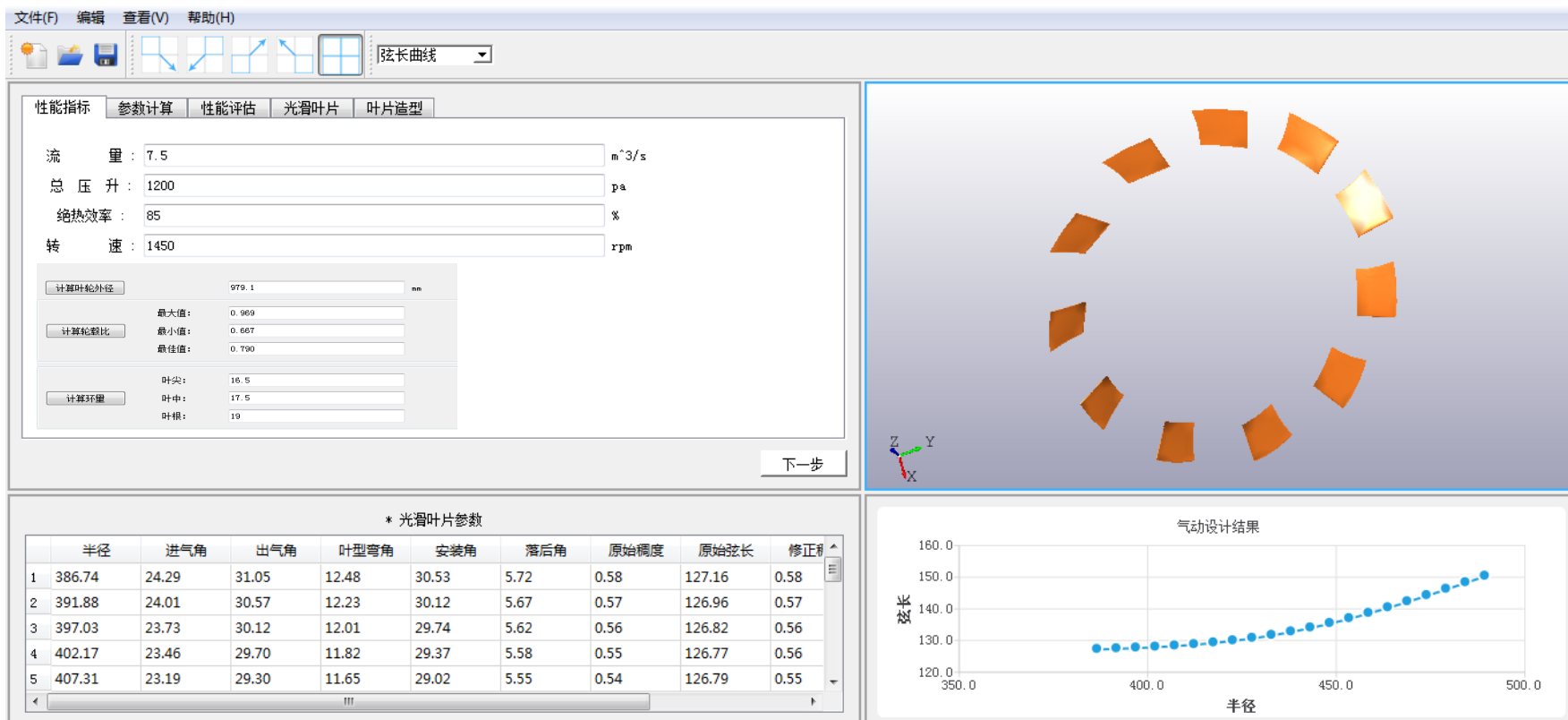
尾流撞击试验台实验低速压气机  
北京航空航天大学



注：A\B\C是几个要求运行点，D为设计点，S为近失速点。

# 3. 轴流风扇/风机快速设计：通流设计

- AIFan是一款**高度验证**的工业轴流风扇/风机设计软件。通过该软件可以根据**流量、压升、转速、外径**等指标快速、精确的设计得到高性能的轴流风扇三维模型，实现风扇的快速设计需求。



The screenshot displays the AIFan software interface, which is divided into several sections:

- Top Bar:** Includes menu options (文件(F), 编辑, 查看(V), 帮助(H)) and a toolbar with icons for file operations and a dropdown menu for '弦长曲线'.
- Left Panel (Parameters):** Contains input fields for flow rate (流量: 7.5 m³/s), total pressure rise (总压升: 1200 pa), adiabatic efficiency (绝热效率: 85 %), and speed (转速: 1450 rpm). Below these are calculation buttons and fields for blade geometry: '计算叶轮外径' (979.1 mm), '计算轮毂比' (Maximum: 0.969, Minimum: 0.667, Optimal: 0.790), and '计算环量' (Tip: 16.5, Middle: 17.5, Root: 19).
- Right Panel (3D Model):** Shows a 3D visualization of a fan blade in a circular arrangement, with a coordinate system (X, Y, Z) at the bottom left.
- Bottom Left Panel (Table):** Titled '\* 光滑叶片参数', it contains a table with 10 columns: 半径, 进气角, 出气角, 叶型弯角, 安装角, 落后角, 原始稠度, 原始弦长, and 修正系数. The table lists 5 rows of data.
- Bottom Right Panel (Graph):** Titled '气动设计结果', it is a scatter plot with '半径' (Radius) on the x-axis (ranging from 350.0 to 500.0) and '弦长' (Chord Length) on the y-axis (ranging from 120.0 to 160.0). The data points show a clear upward trend.

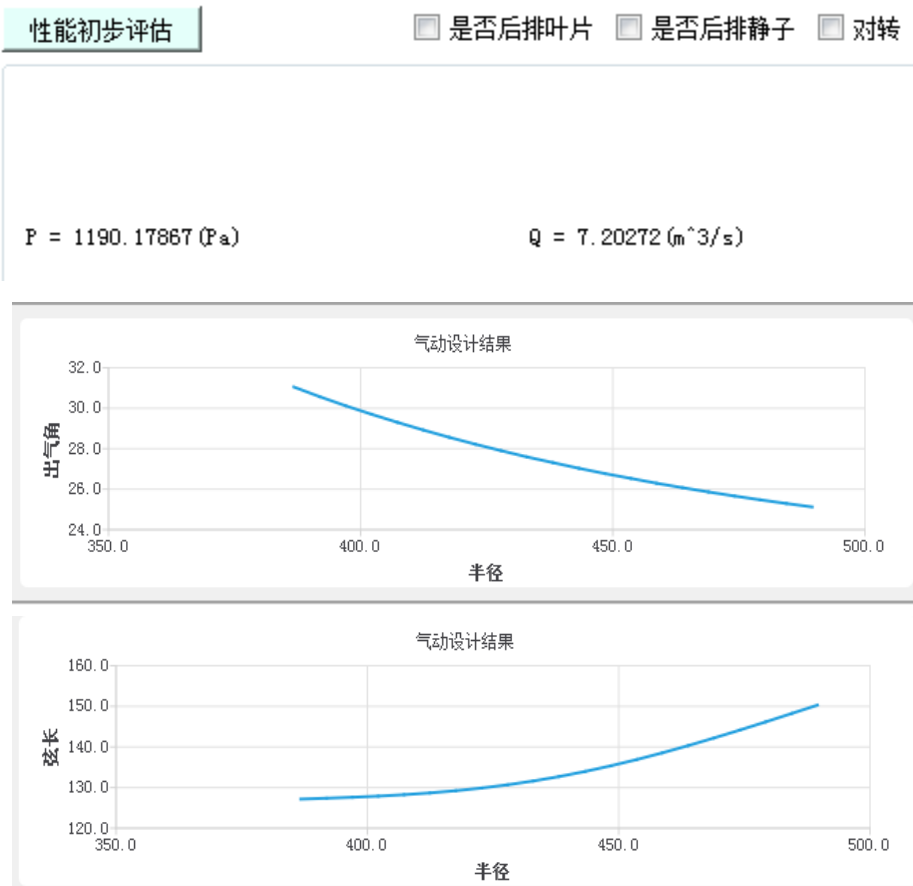
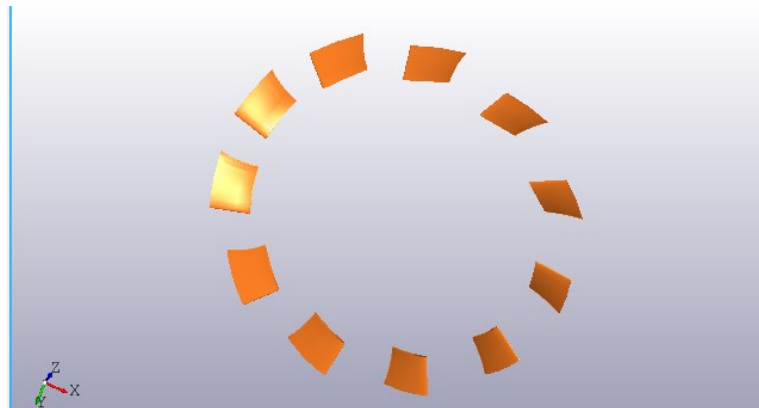


# 4. 轴流风扇/风机快速设计：三维造型

- 通流设计结果可视化显示与调节
- 多样化造型方式：

1个方案设计=5分钟！

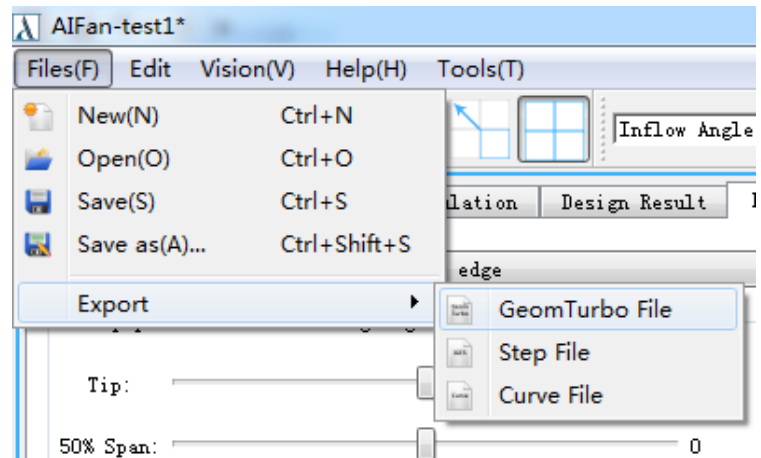
重心积叠、前缘弯掠积叠、尾缘积叠



# 5. 轴流风扇/风机快速设计：文件传递

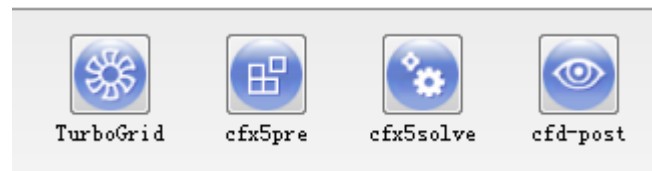
## ➤ 格式输出：

- 三维模型（step等）
- Tecplot 格式
- Numeca /Turbogrid格式
- 叶片加工数据
- 其他定制格式

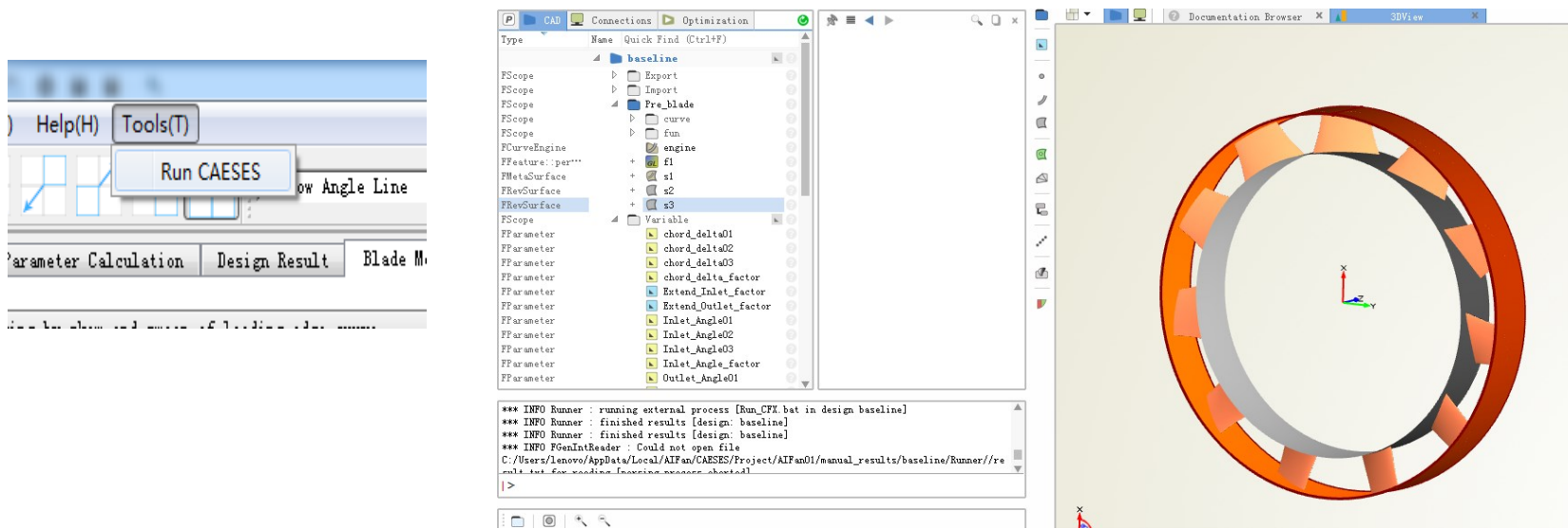


## 6. 轴流风扇/风机快速设计：流程传递

- 基于AIFan的设计结果，可以与其他优化分析工具结合，实现一键式设计及全三维优化功能。比如可以直接调用CFX组件进行网格划分及仿真分析，内置网格生成及边界条件模板。

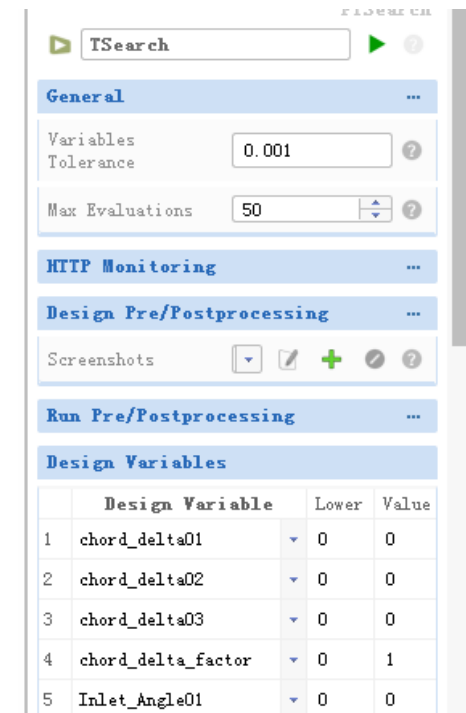
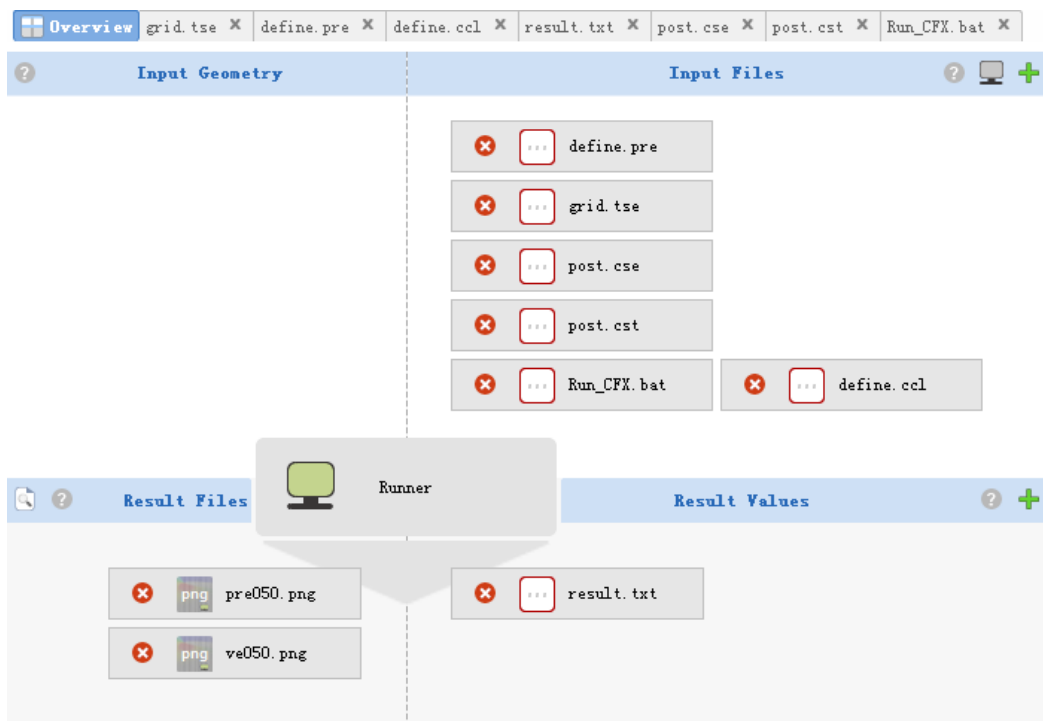


- 直接调用CAESES软件，基于设计结果生成全参数化叶轮模型。



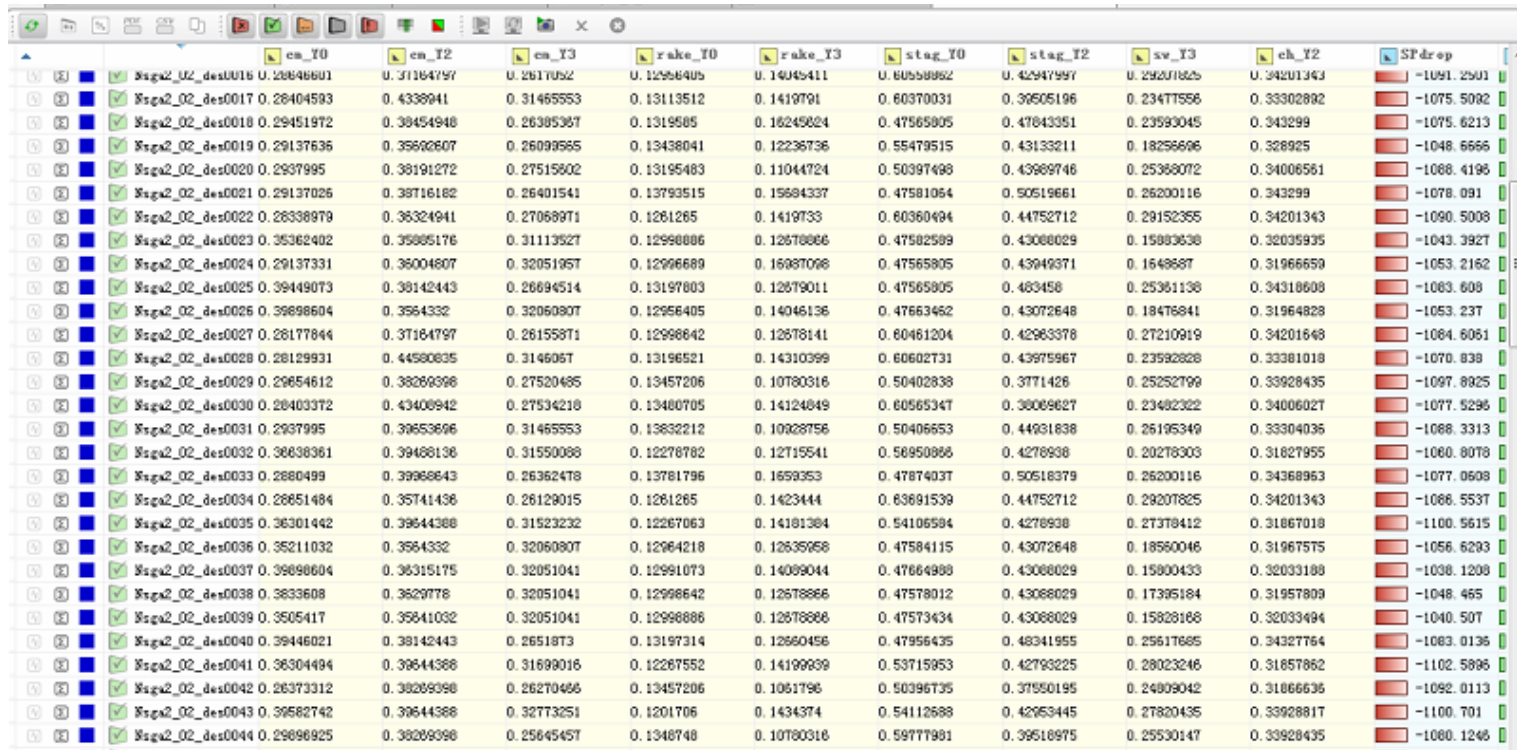
# 9. 轴流风扇/风机快速设计：优化设计

- 并在CAESES中设置好自动仿真分析的连接，以及相关的优化算法，直接一键启动相关仿真优化。



# 7. 轴流风扇/风机快速设计：设计模型库

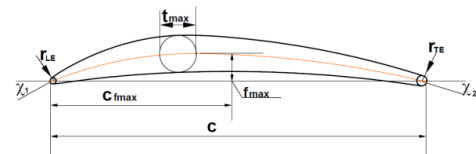
- 基于AIFan快速设计+CAESES的参数化模型处理，得到批量的设计模型及其性能参数，可以建立设计数据库，基于数据库可以进行智能选型优化。



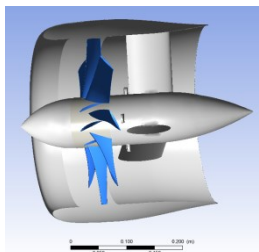
	cm_Y0	cm_Y2	cm_Y3	rake_Y0	rake_Y3	stag_Y0	stag_Y2	sv_Y3	ch_Y2	SP_drop
✓	Xsga2_02_des0016 U. 20848601	U. 31164797	U. 2617052	U. 12566405	U. 14045411	U. 60558962	U. 42947997	U. 29201825	U. 34201343	-1091. 2501
✓	Xsga2_02_des0017 U. 28404593	U. 4338941	U. 31465553	U. 13113512	U. 1419701	U. 60370031	U. 30505196	U. 23477556	U. 33302892	-1075. 5082
✓	Xsga2_02_des0018 U. 29451972	U. 39454948	U. 26385367	U. 13195805	U. 16245624	U. 47565905	U. 47843351	U. 23593045	U. 343299	-1075. 6213
✓	Xsga2_02_des0019 U. 29137636	U. 35602607	U. 26099585	U. 13438041	U. 12236736	U. 55479515	U. 43133211	U. 18256696	U. 328925	-1048. 6666
✓	Xsga2_02_des0020 U. 2937995	U. 36191272	U. 27515602	U. 13195483	U. 11044724	U. 50397498	U. 43989746	U. 25368072	U. 34006561	-1068. 4196
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✓	Xsga2_02_des0025 U. 39449073	U. 38142443	U. 26694514	U. 13197803	U. 12879011	U. 47565805	U. 463458	U. 25361138	U. 34318609	-1063. 608
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✓	Xsga2_02_des0027 U. 28177844	U. 37164797	U. 26155871	U. 12998642	U. 12678141	U. 60461204	U. 42963378	U. 27210919	U. 34201648	-1064. 6061
✓	Xsga2_02_des0028 U. 28129931	U. 44580635	U. 3146067	U. 13196521	U. 14310399	U. 60602731	U. 43975967	U. 23592828	U. 33381018	-1070. 838
✓	Xsga2_02_des0029 U. 29654612	U. 38269396	U. 27520485	U. 13457206	U. 10780316	U. 50402838	U. 3771426	U. 25252799	U. 33928435	-1097. 8925
✓	Xsga2_02_des0030 U. 28403372	U. 43400942	U. 27534218	U. 13480705	U. 14124849	U. 60565347	U. 38089627	U. 23482322	U. 34006027	-1077. 5296
✓	Xsga2_02_des0031 U. 2937995	U. 30653696	U. 31465553	U. 13832212	U. 10928756	U. 50406653	U. 44931838	U. 26195349	U. 33304036	-1068. 3313
✓	Xsga2_02_des0032 U. 38638361	U. 39468136	U. 31550098	U. 12278782	U. 12715541	U. 56950866	U. 4278938	U. 20278303	U. 31827955	-1060. 8078
✓	Xsga2_02_des0033 U. 2880499	U. 39968643	U. 26362478	U. 13761796	U. 1659353	U. 47874037	U. 50518379	U. 26200116	U. 34368953	-1077. 0608
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✓	Xsga2_02_des0035 U. 36301442	U. 39644388	U. 31523232	U. 12267063	U. 14181384	U. 54106594	U. 4278938	U. 27378412	U. 31867019	-1100. 5615
✓	Xsga2_02_des0036 U. 35211032	U. 3564332	U. 32060807	U. 12964218	U. 12639568	U. 47584115	U. 43072648	U. 18560046	U. 31967575	-1056. 6283
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✓	Xsga2_02_des0038 U. 3833608	U. 3629778	U. 32051041	U. 12998642	U. 12678866	U. 47578012	U. 43068029	U. 17395184	U. 31957809	-1048. 465
✓	Xsga2_02_des0039 U. 3505417	U. 35641032	U. 32051041	U. 12998686	U. 12678866	U. 47573434	U. 43068029	U. 15828168	U. 32033494	-1040. 507
✓	Xsga2_02_des0040 U. 39446021	U. 38142443	U. 2651873	U. 13197314	U. 12660456	U. 47956435	U. 48341955	U. 25617685	U. 34327764	-1063. 0136
✓	Xsga2_02_des0041 U. 36304494	U. 39644388	U. 31699016	U. 12267552	U. 14199939	U. 53715953	U. 42793225	U. 28023246	U. 31857862	-1102. 5896
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✓	Xsga2_02_des0044 U. 29696925	U. 38269396	U. 25645457	U. 1348748	U. 10780316	U. 59777981	U. 39516975	U. 25530147	U. 33928435	-1060. 1246

# 8. 电动涵道风扇推进系统应用（清华大学）

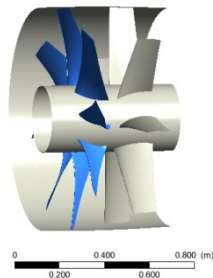
## 前转捩叶型数据库



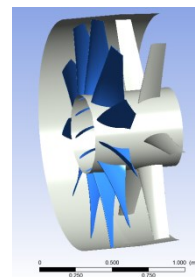
系列化  
涵道风扇



RS-10kgf/ 4kW



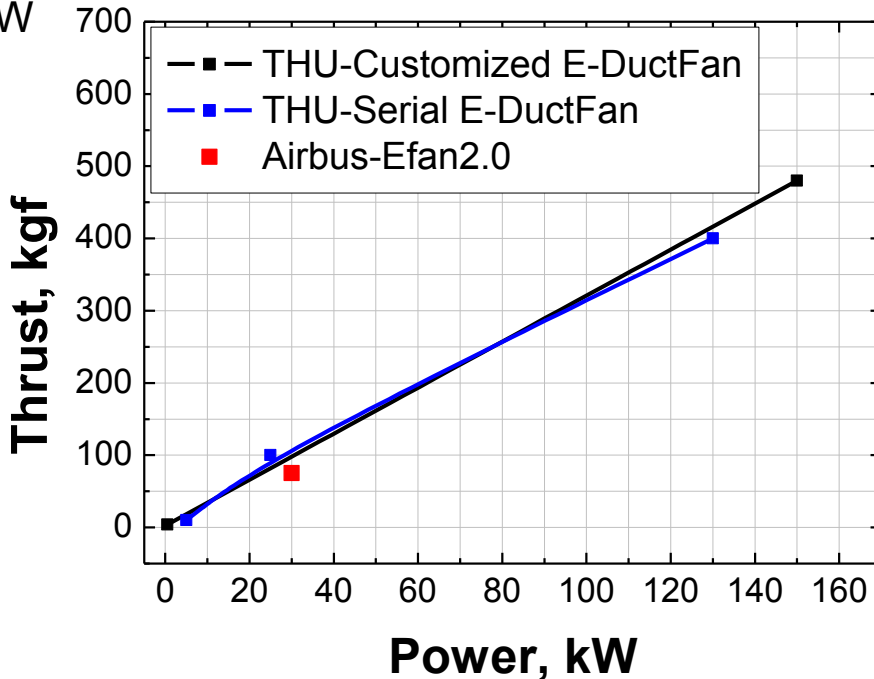
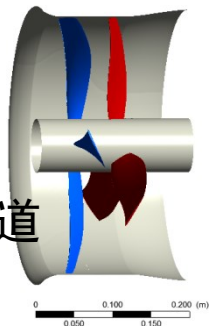
RS-100kgf/ 25kW



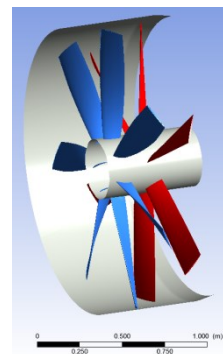
RS-400kgf/ 130kW

CR-4kgf/ 0.5kW

定制化  
对转涵道  
风扇



CR-480kgf/ 150kW



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**谢 谢!**