

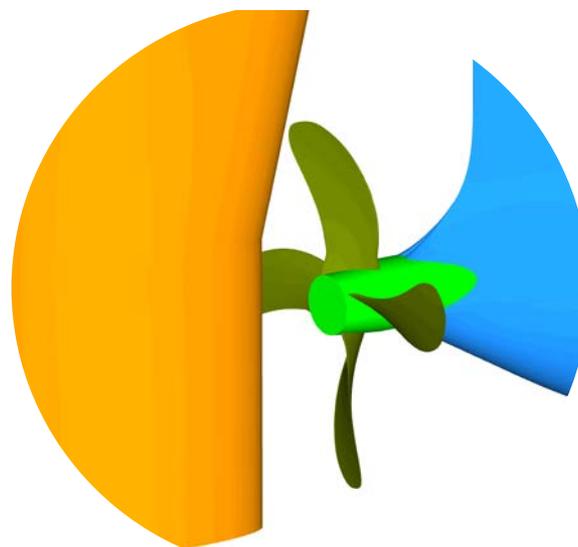
自航条件下螺旋桨的优化

张青山*，杜云龙，杨帆，陈昆鹏，任海奎

航运技术与安全事业部

上海船舶运输科学研究所

2019-06-14





历史沿革

成立，交通部直属科研机构

1962

转制为科技型企业，由中央企业工作委员会管理

2000

由国务院国有资产监督管理委员会领导会管理

2003

经国务院批准整体进入中海集团

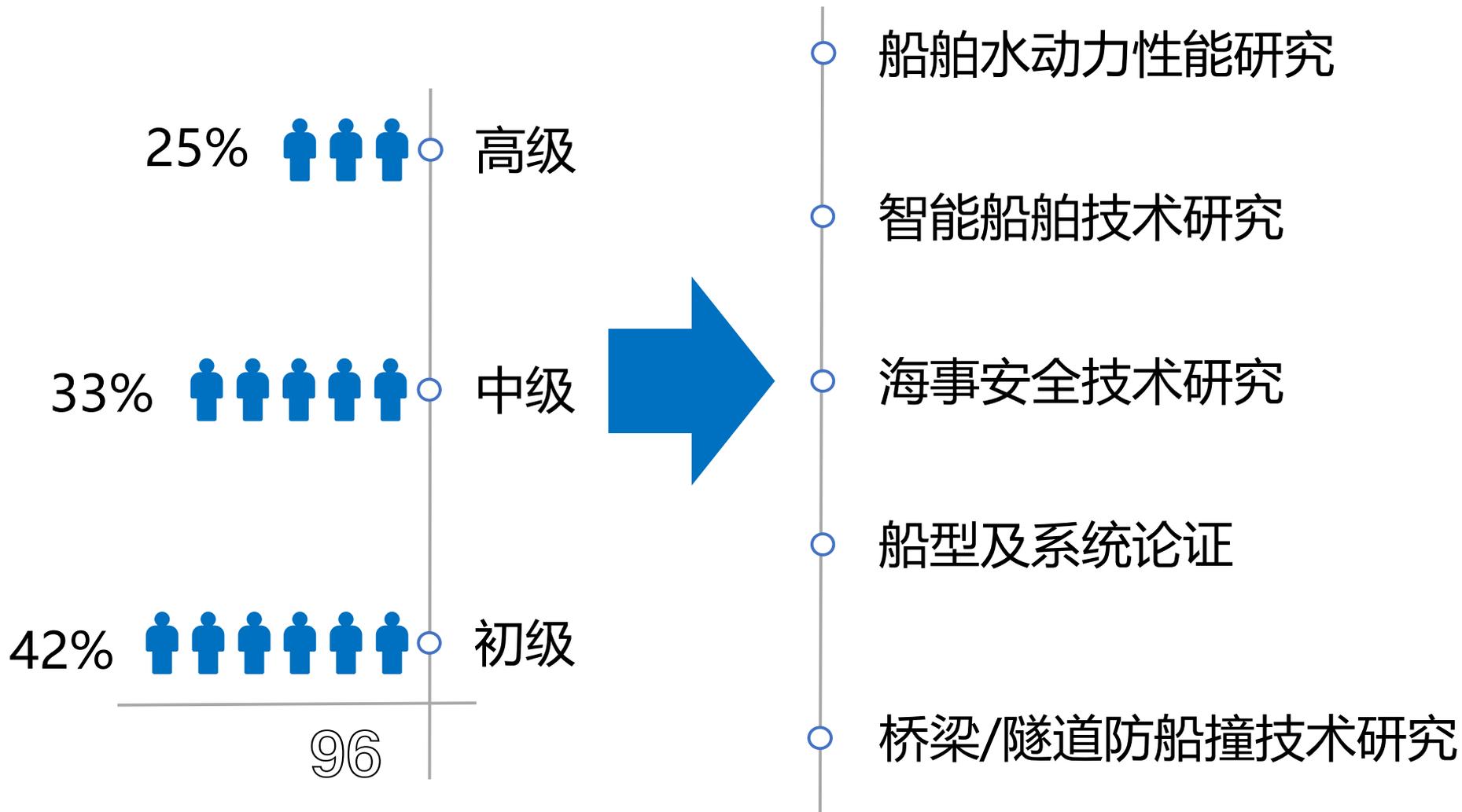
2010

与中远集团重组，为中国远洋海运集团有限公司

2016



人员配置及研究领域





科研设施



拖曳水池



风浪流水池



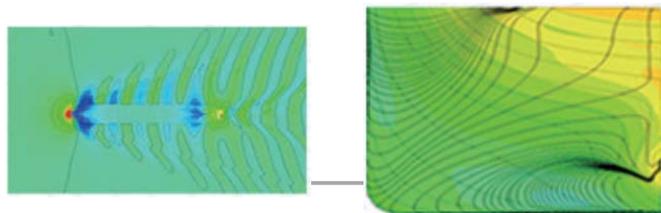
操纵性水池



空泡水筒



应用软件



SIEMENS
Ingenuity for life

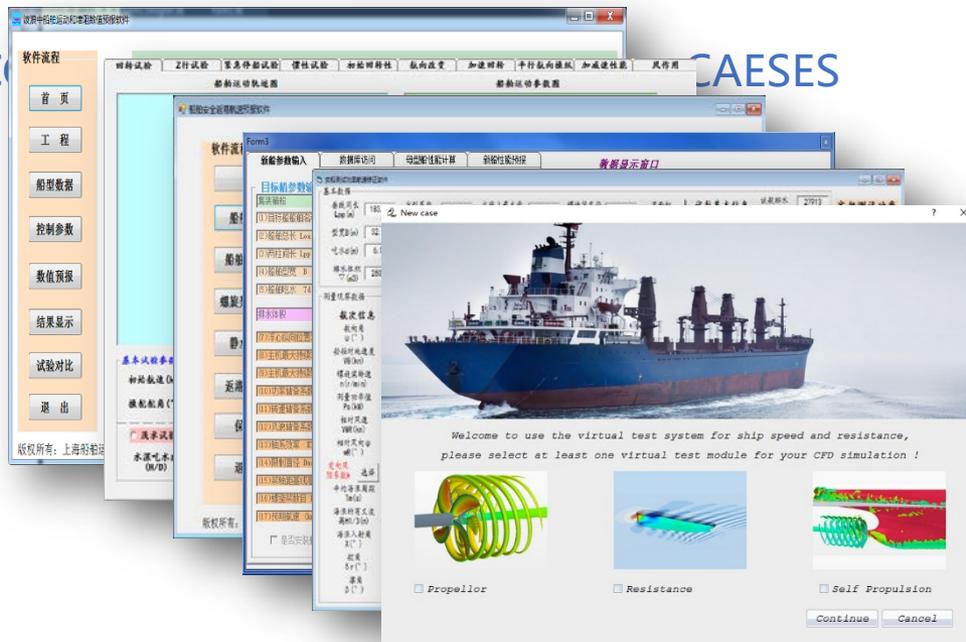
ANSYS[®]
FLUENT[®]

CAESES

- 船舶功率与航速预报系统
- 船舶快速性子系统
- 波浪增阻预报软件
- 船舶操纵运动计算软件
- 船舶安全返港航速预报软件
- 实船测试功率航速修正软件
- 船舶浮态节能应用软件
- 船舶航行性能按数据分析系统

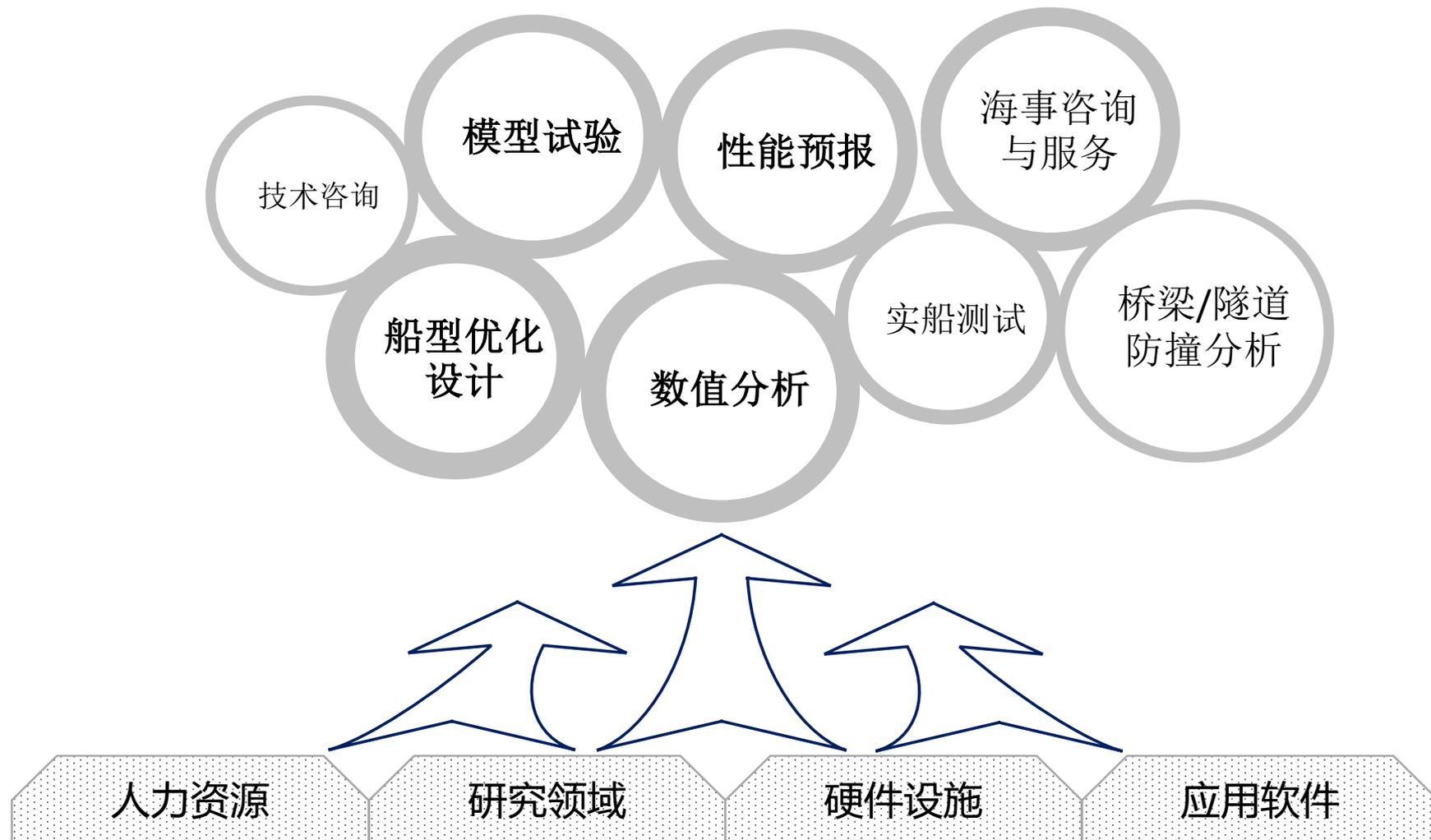
STAR-CC+

CAESES





服务范围





报告议程





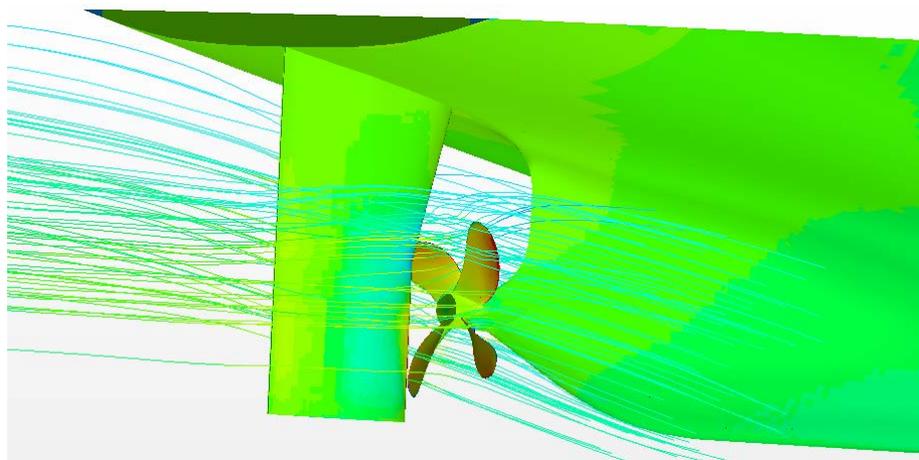
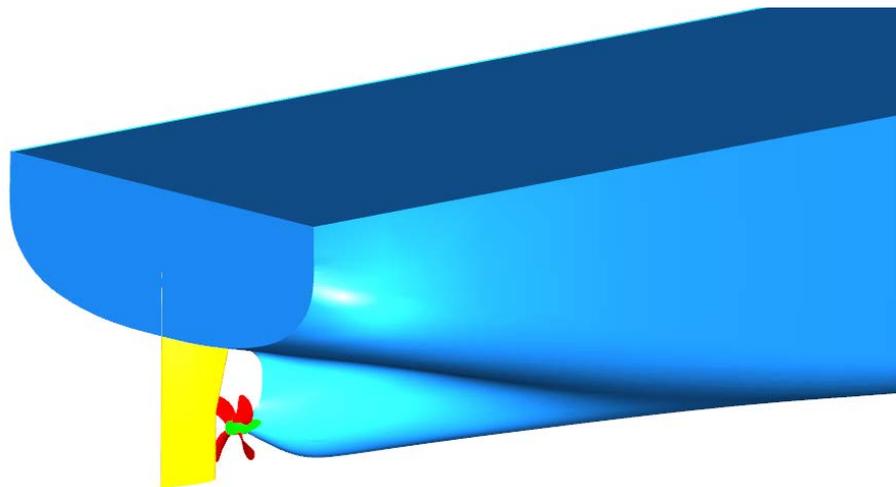
螺旋桨优化简介

设计需求:

- 对象为某油船的对应螺旋桨;
- 固定转速下, 功率不超过8300kW;
- 直径为6.12m;

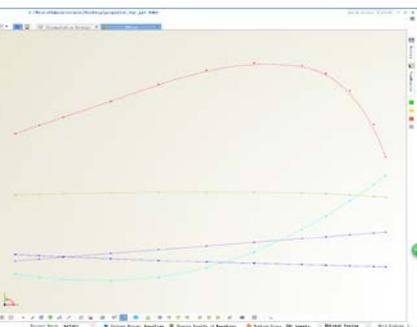
螺旋桨参数化研究:

- 相关性较强的设计变量;
- 设计变量相应的变化规律;



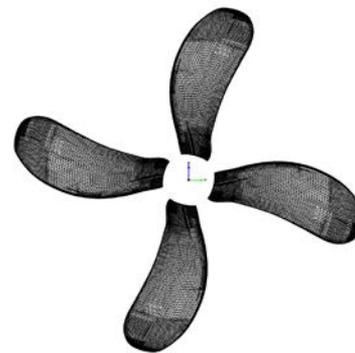


螺旋桨优化简介



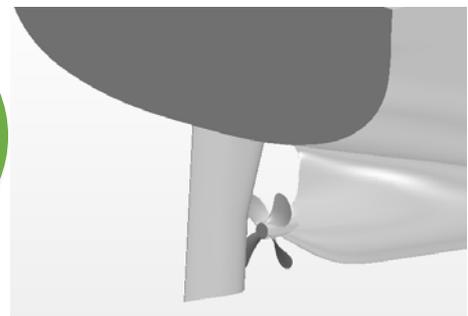
参数化建模

参数化变形



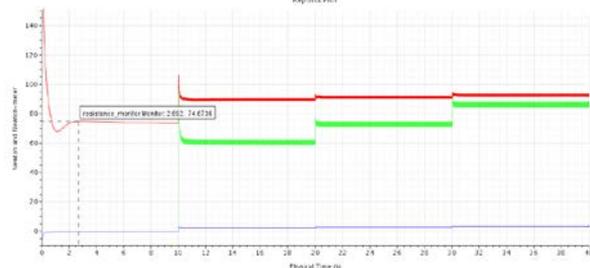
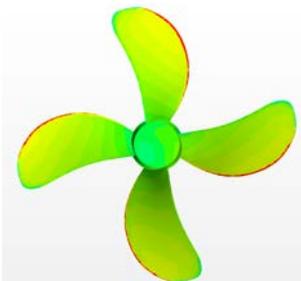
自动优化

几何前处理



数值评估及后处理

网格划分





螺旋桨型值转换



FGenericBlade

Type Documentation

Description

This is the major blade entity for maritime applications i.e. propellers.

For turbomachinery blades, see the [stream section](#) curve type. For more generalized axial blades like industrial fans etc, use the [cylindrical transformation](#) along with [image curves](#) and [meta surfaces](#) (see also the blade design tutorials). Centrifugal impellers can be modeled with customized feature definitions (there is also an impeller sample included).

Arbitrary user-defined radial functions for rake, skew and pitch can be combined with arbitrary profile definitions.

Common NACA
the CAD
blade at

Radial Information

Radial functions are defined in the global xy-plane in the range [0,1] x [0,1], where the x-coordinate corresponds to the normalized radius:

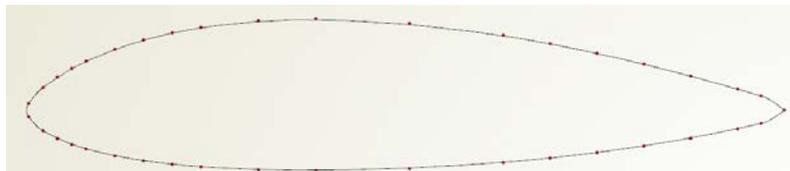
r/R	X	Y	Z	W	V	U
0.2	0.0000	2.6286	0.7703	3.5492	1.5405	4.2034
					2.3110	3.0812
					4.7629	5.2542

	弦长	导边基线的距离	厚度	纵倾	螺距	弦长中心到基线的距离
0.2	0.3172	0.1725	0.0322	0.0175	1.7289	-0.0139
0.25	0.3367	0.1904	0.0298	0.0219	1.7407	-0.0220
0.3	0.3560	0.2047	0.0274	0.0262	1.7532	-0.0267
0.4	0.3929	0.2261	0.0226	0.0350	1.7727	-0.0297
0.5	0.4336	0.2393	0.0182	0.0437	1.7868	-0.0225
0.6	0.4666	0.2339	0.0148	0.0525	1.7918	-0.0006
0.7	0.4842	0.2047	0.0118	0.0612	1.7873	0.0374
0.8	0.4781	0.1487	0.0087	0.0700	1.7694	0.0904
0.85	0.4593	0.1071	0.0072	0.0744	1.7536	0.1226

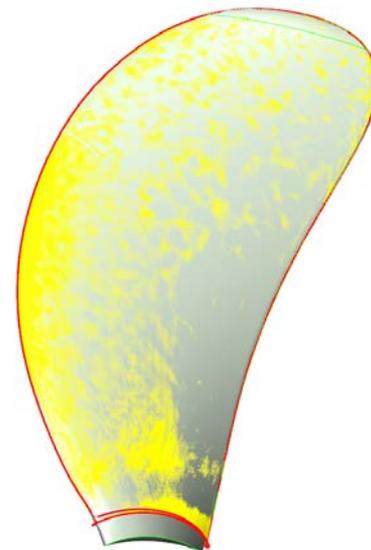
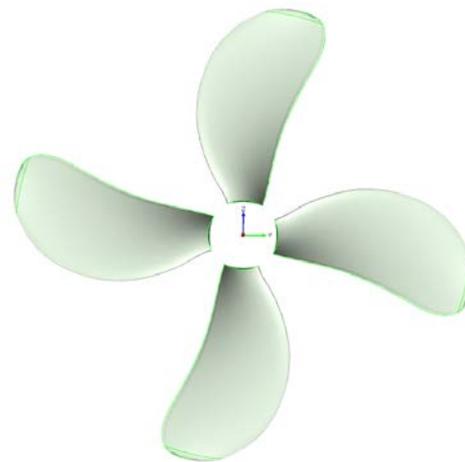
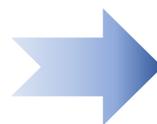


螺旋桨参数化建模

二维切面翼型



Generic Blade



Periodic BReps



螺旋桨几何处理

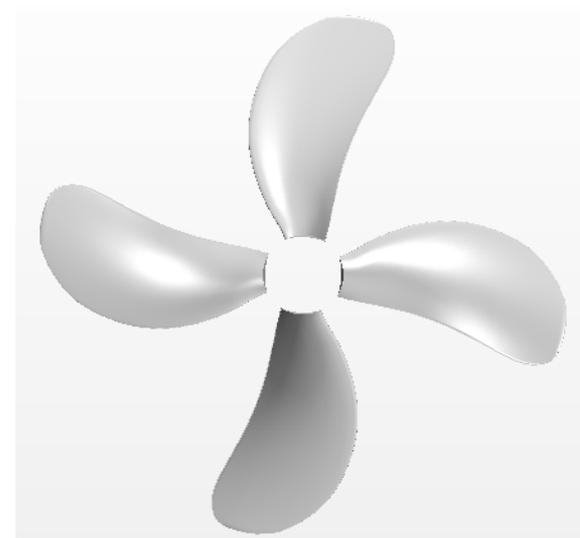
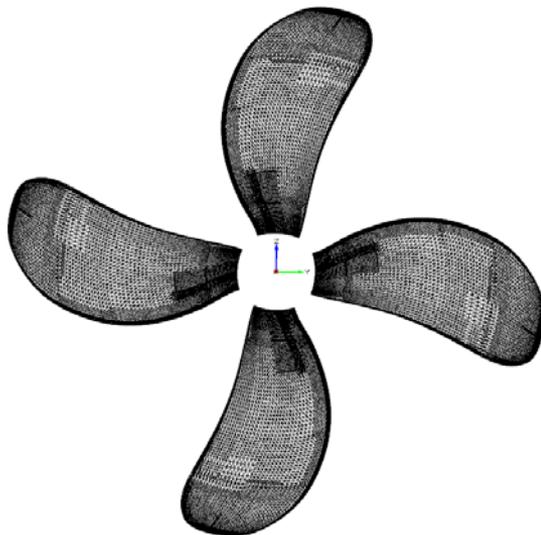
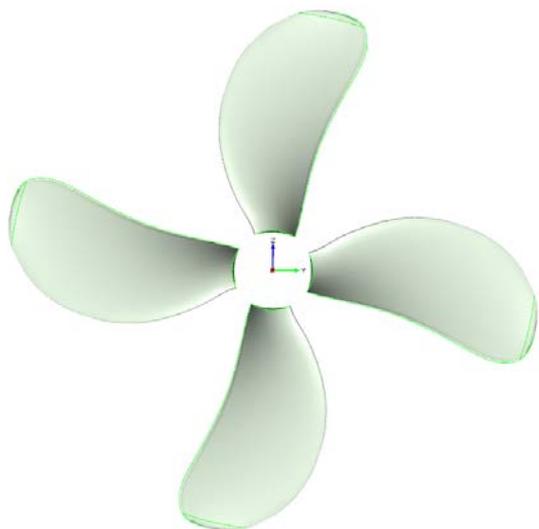
Breps 面



TriMesh 面



Solid 面





CAESES 与 STAR-CCM+的耦合

The screenshot shows the CAESES interface on the left and the STAR-CCM+ interface on the right. The CAESES window displays the export settings for 'blades.stl', with 'Export Type' set to 'STARCCMSTL' and 'Entry Value' set to 'Relative Path'. The STAR-CCM+ interface shows the 'Input Files' section with 'blades.stl' and 'propulsion.java' files. Below this, the 'Runner' section shows the execution of the simulation, resulting in 'Result Files' including 'suction_side.png', 'streamlines.png', 'pressure_side.png', and 'results.csv'. The 'Result Values' section shows the output of the simulation.

① 导出几何

② 宏命令（前处理、网格、求解器、后处理）

③ 后处理图片

④ 监测物理量



单个算例情况

基本情况

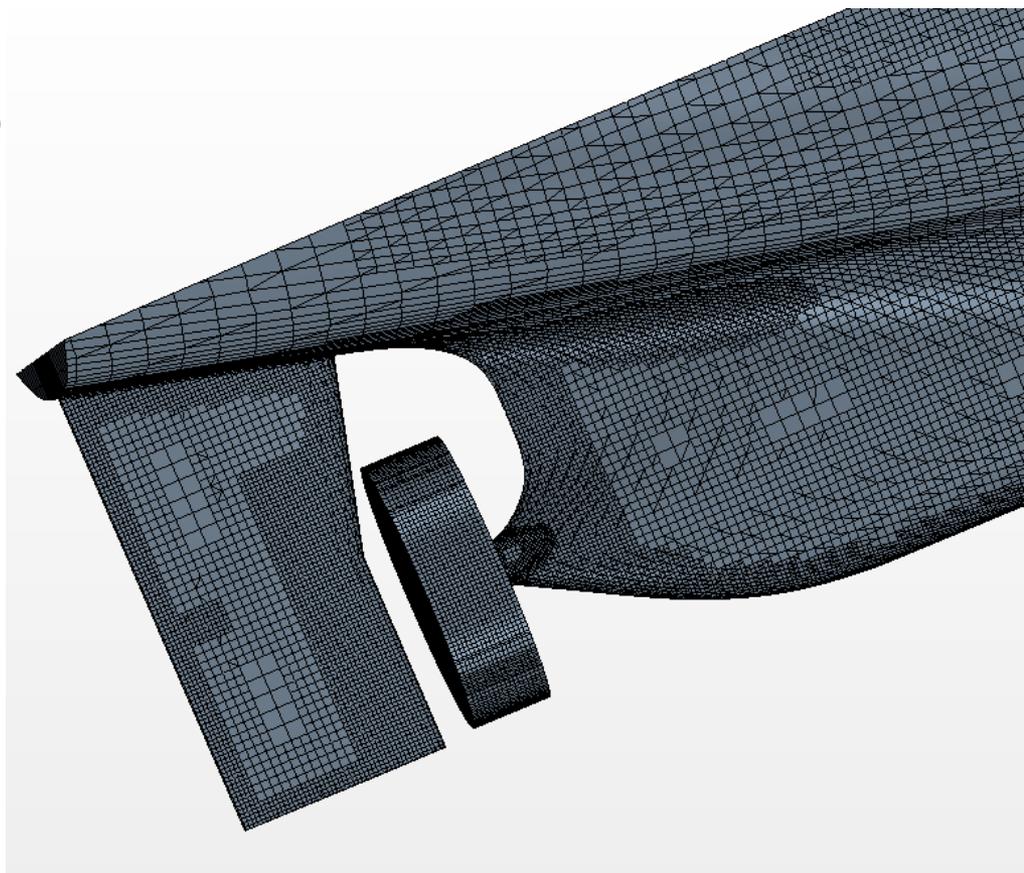
- 实船航速 15kn（模型下 1.577m/s）
- 螺旋桨直径 6.12m（模型下 0.256m）
- 4 叶螺旋桨

计算方法

- 叠模法，不考虑空泡及强度
- SST k- ω 湍流模型
- 模型尺度（可与试验数据对比）

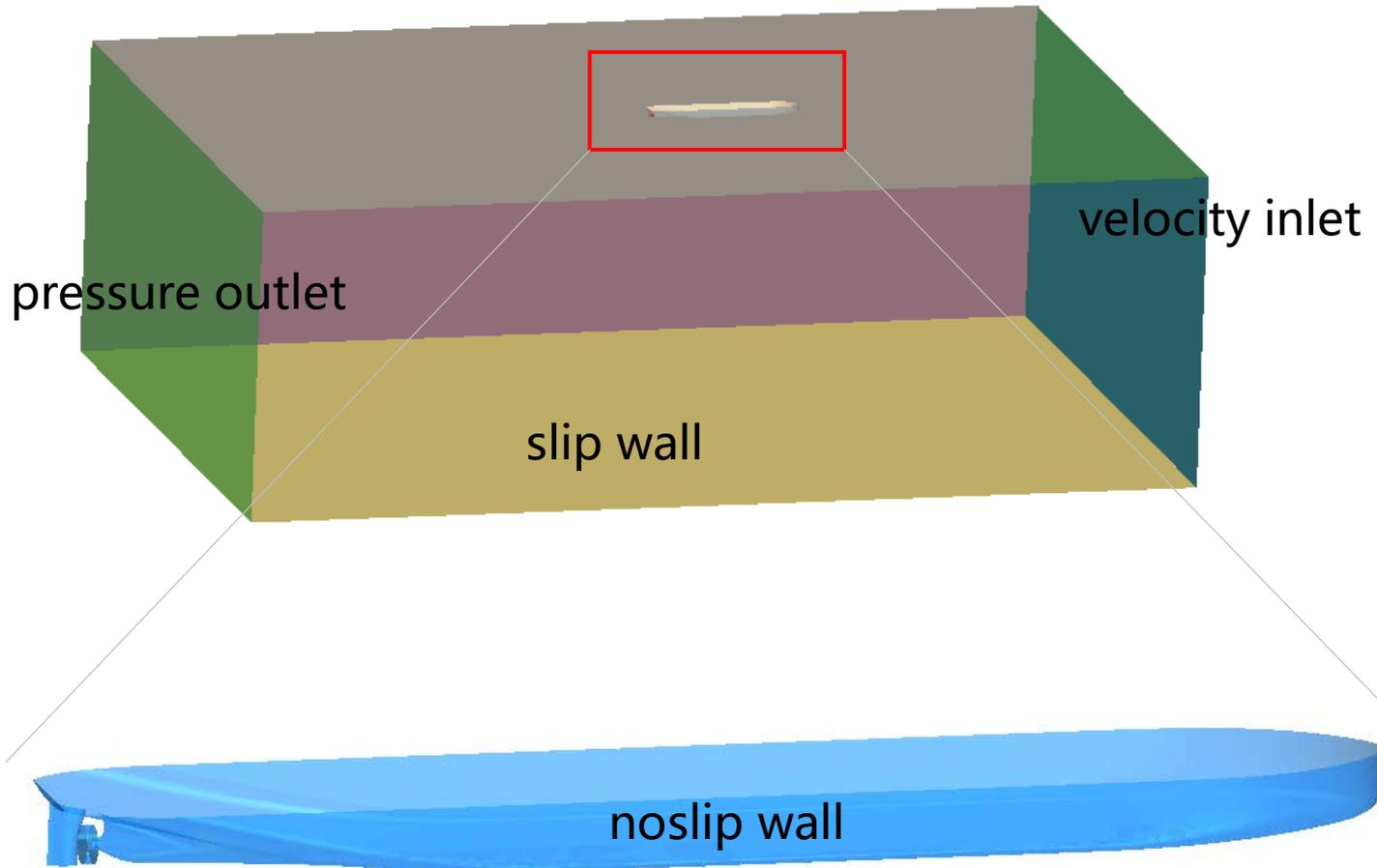
自航条件下的优化计算

- 600+ 万网格，TriMesh
- 旋转区域（MRF）
- 自动变换转速以满足插值需求
- 2个算例/小时（7个节点，168核）





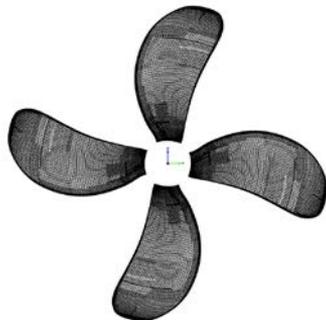
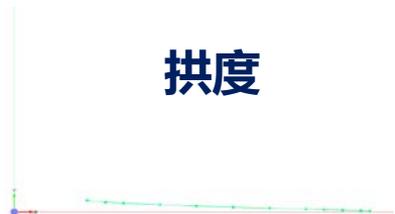
边界条件设定



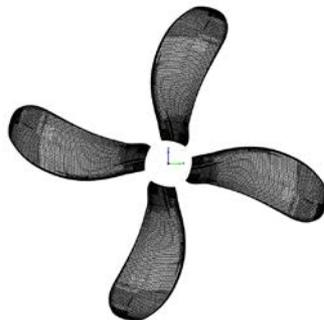
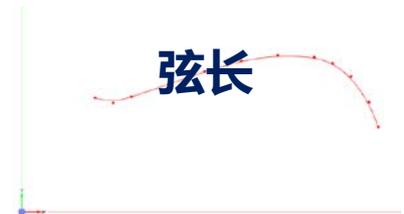


设计变量及约束

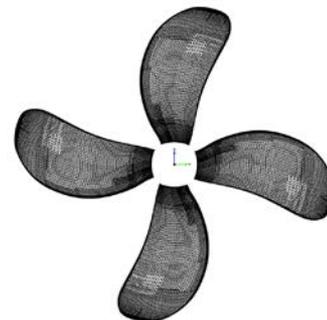
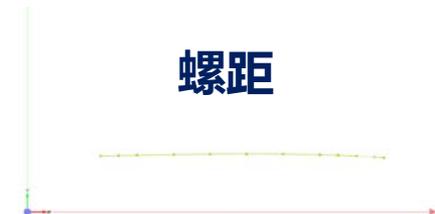
拱度



弦长



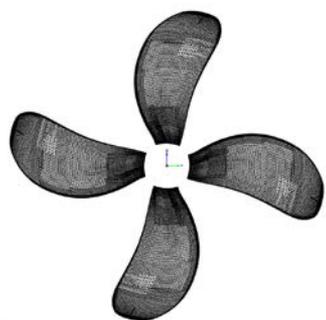
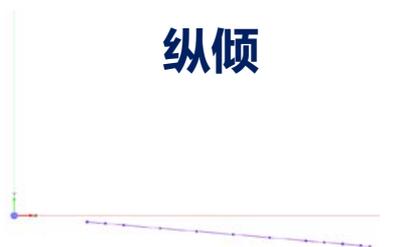
螺距



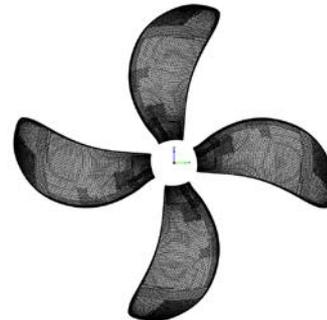
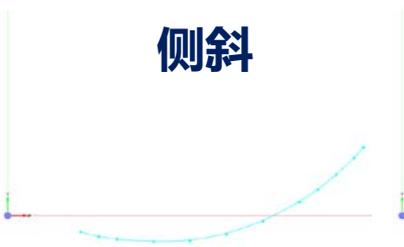
设计变量

- 拱度
- 弦长
- 螺距
- 纵倾
- 侧斜
- 厚度

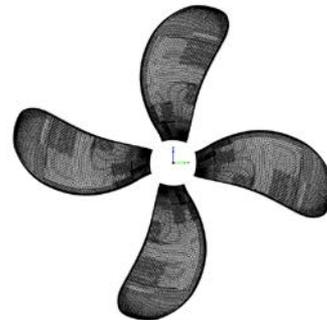
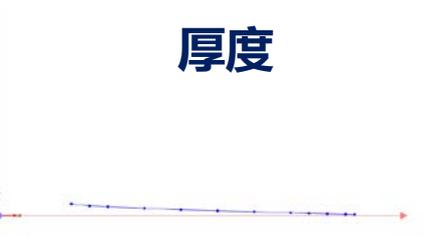
纵倾



侧斜



厚度



约束条件

- 转速 (7.688 ~8.385 rps)



优化目标及优化策略

阻力	推力	扭矩	转速
Rt1	T1	Q1	n1
Rt2	T2	Q2	n2
Rt3	T3	Q3	n3

优化目标

- 螺旋桨收到功率 P_D

$$P_D = 2\pi Qn$$

$$Q = \frac{(Q_1 - Q_2)(r_1 - r_3) = (Q_1 - Q_3)(r_1 - r_2)}{(r_1^2 - r_2^2)(r_1 - r_3) = (r_1^2 - r_3^2)(r_1 - r_2)} r^2$$

$$+ \frac{(Q_1 - Q_2)(r_1^2 - r_3^2) = (Q_1 - Q_3)(r_1^2 - r_2^2)}{(r_1 - r_2)(r_1^2 - r_3^2) - (r_1 - r_3)(r_1^2 - r_2^2)} r$$

优化策略

- 灵敏度分析

(Dakota-sensitivity analysis)

- 基于灵敏度分析，再次进行优化

(Dakota-global optimization on response surface)

$$+ Q_1 - \frac{(Q_1 - Q_2)(r_1 - r_3) - (Q_1 - Q_3)(r_1 - r_2)}{(r_1^2 - r_2^2)(r_1 - r_3) = (r_1^2 - r_3^2)(r_1 - r_2)} r_1^2 - \frac{(Q_1 - Q_2)(r_1^2 - r_3^2) - (Q_1 - Q_3)(r_1^2 - r_2^2)}{(r_1 - r_2)(r_1^2 - r_3^2) - (r_1 - r_3)(r_1^2 - r_2^2)} r_1$$



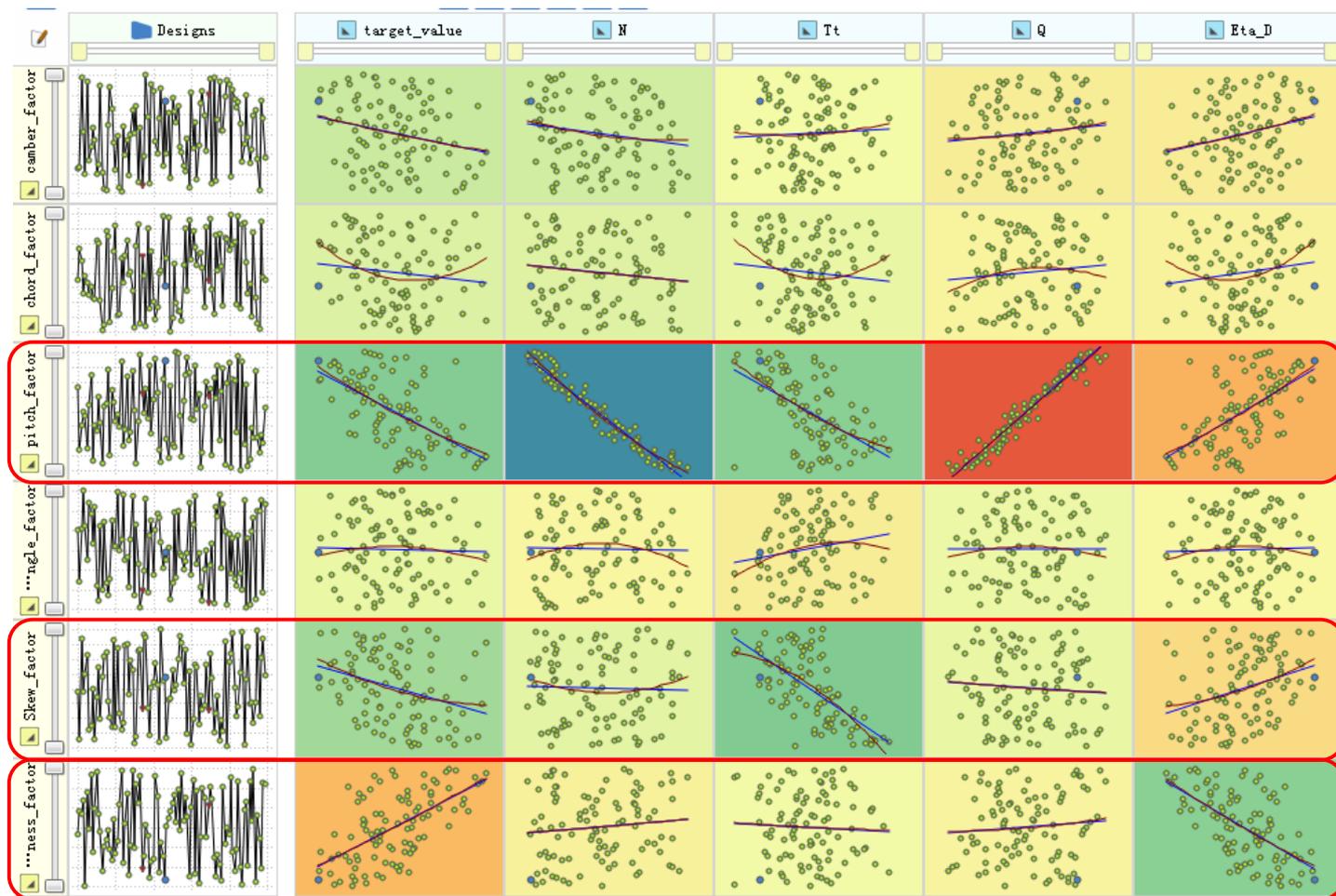
灵敏度分析

灵敏度分析

- Dakota
- 100 样本数
- 设计变量
 - 拱度
 - 弦长
 - 螺距
 - 纵倾
 - 侧斜
 - 厚度

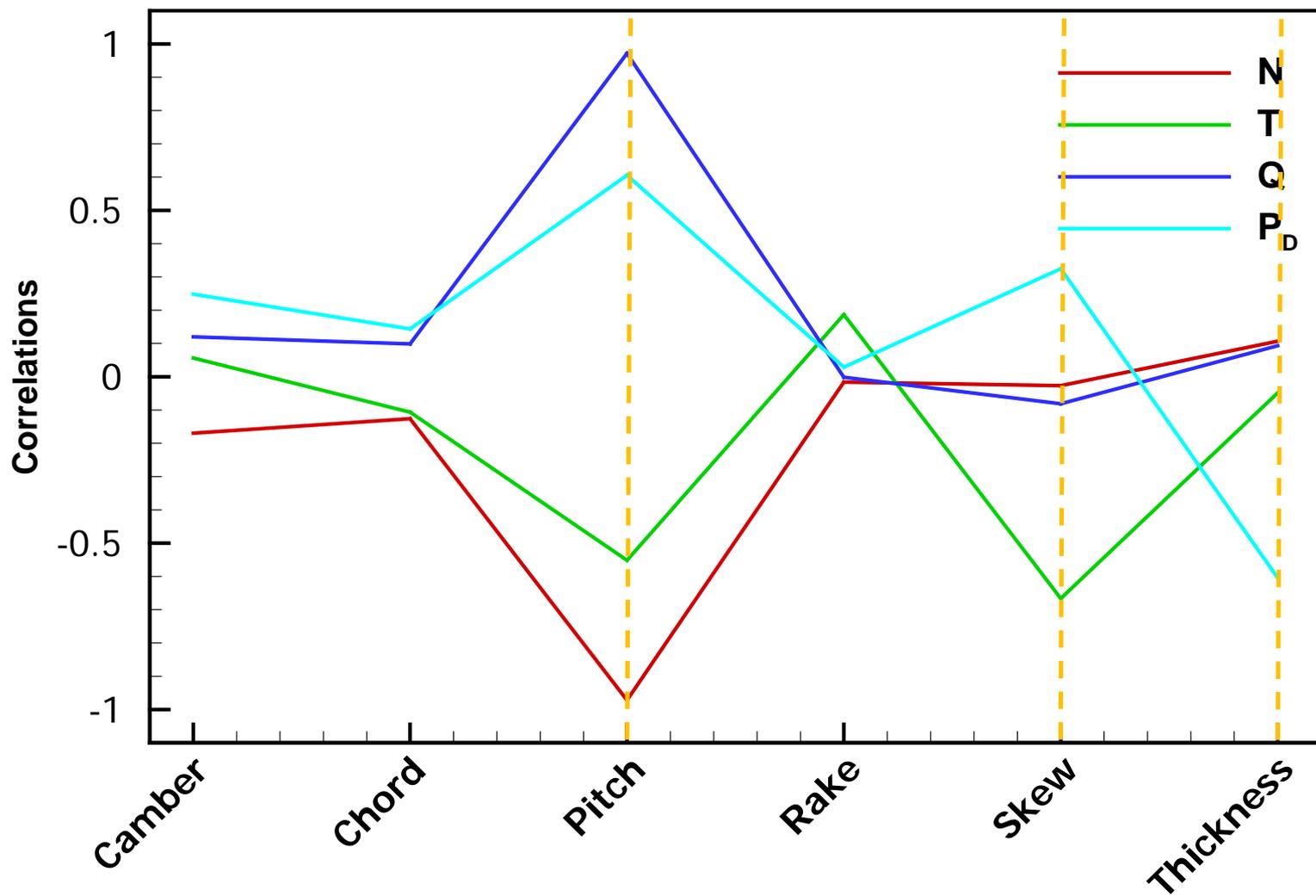
优化目标

- 螺旋桨收到功率 P_D





灵敏度分析





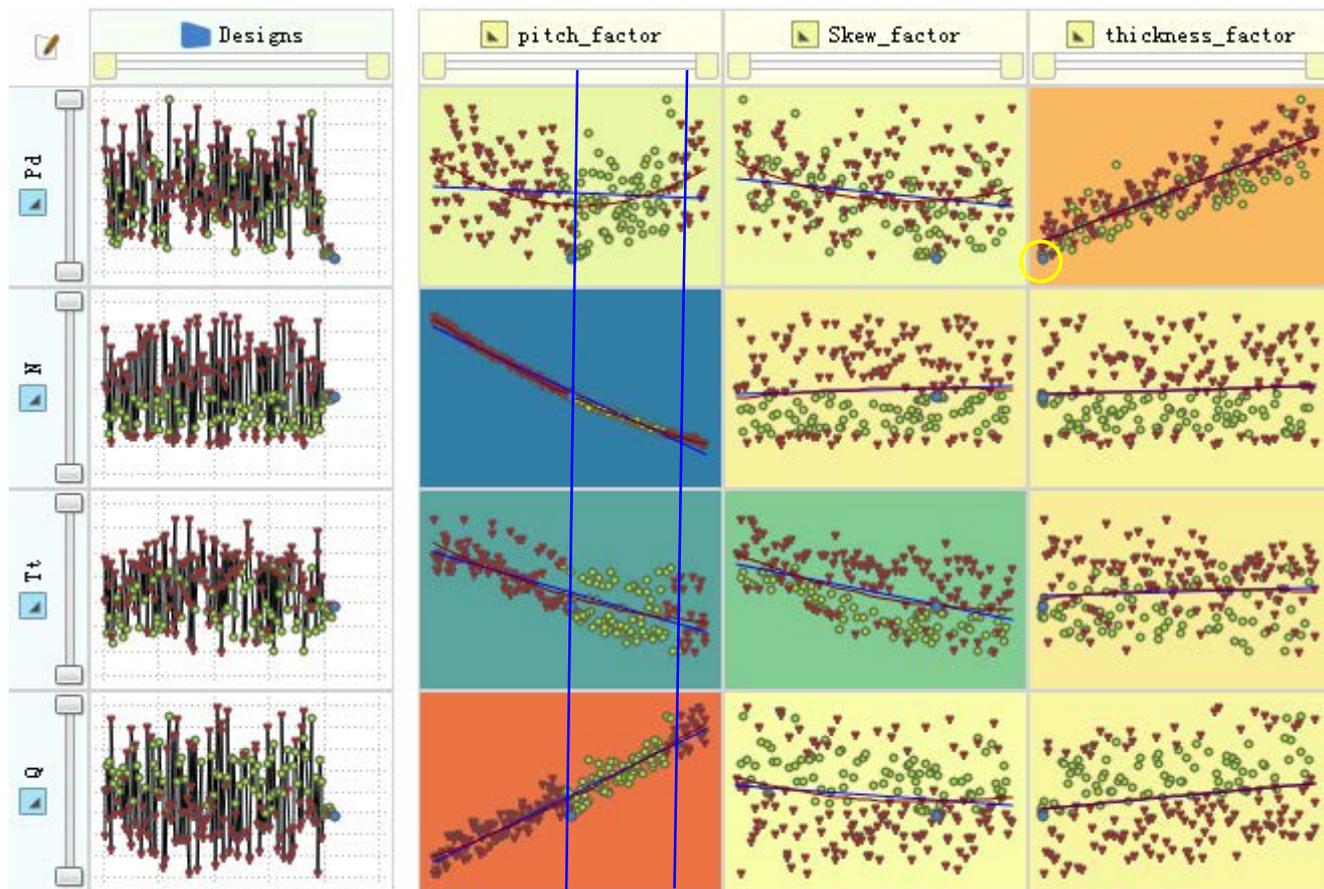
螺旋桨优化

再次优化

- Dakota
响应面上的全局优化
- 200样本数
- 设计变量
 - 螺距
 - 侧斜
 - 厚度

优化目标

- 螺旋桨收到功率 P_D





结果分析

opt_02_des0210

FDesign

opt_02_des0210

Fri May 24 17:23:43 2019 | created
Fri May 24 17:51:10 2019 | finalized

Design Variables

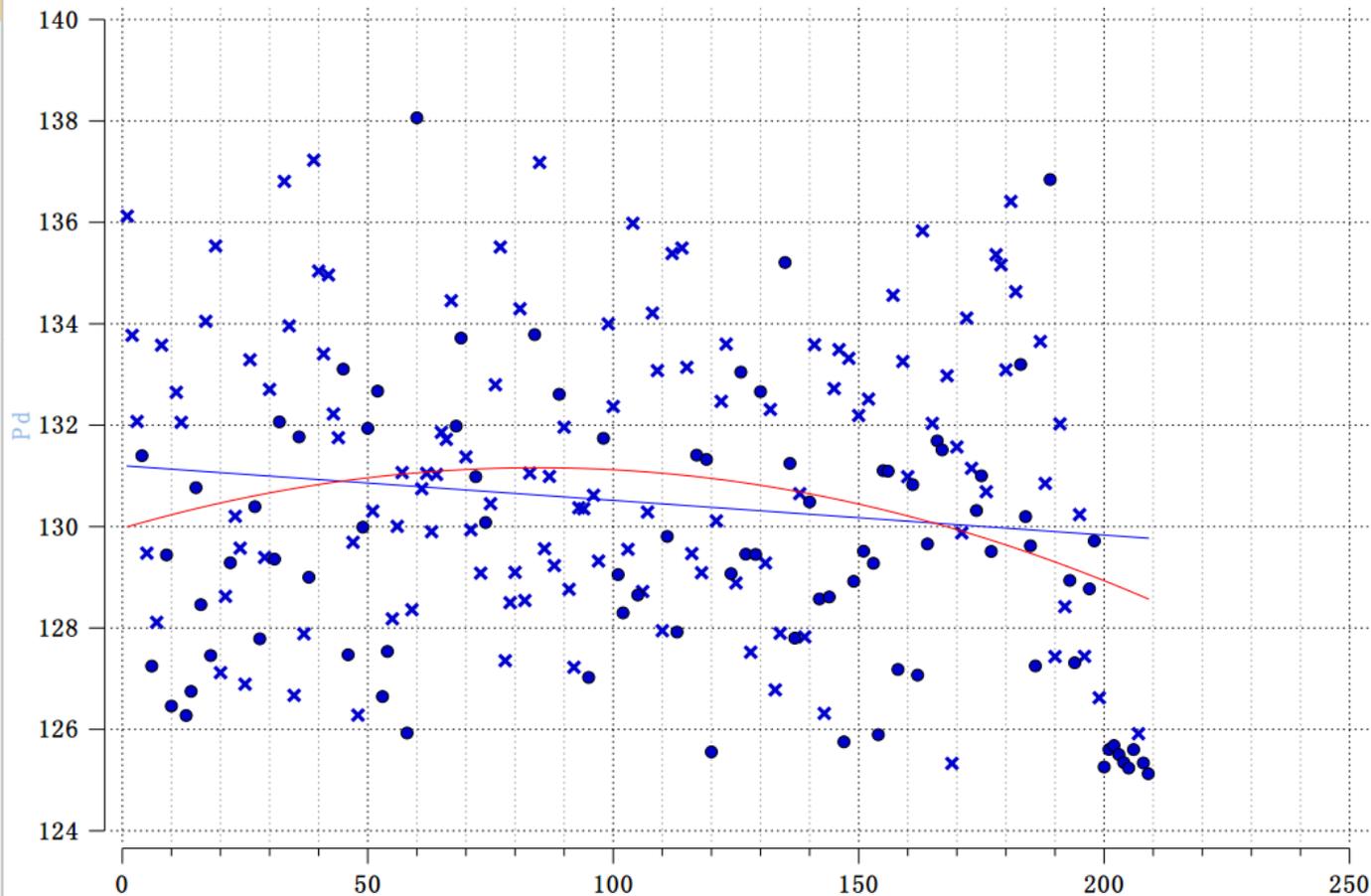
Name	Lower Bound	Value	Upper Bound
opt_values pitch_factor	-200	12	200
opt_values Skew_factor	-200	90	200

Evaluations

Name	Value	Is Objective
result_value Pd	125.126	Yes
result_value Eta_D	0.69856	No
result_value N	8.3436	No
result_value Tt	66.9187	No
result_value Q	2.38678	No

Constraints

Name	State	Value	Comparator	Limit	Is Considered
<input checked="" type="checkbox"/> N_lower	Valid	8.3436	>=	7.688	Yes
<input checked="" type="checkbox"/> N_upper	Valid	8.3436	<=	8.385	Yes

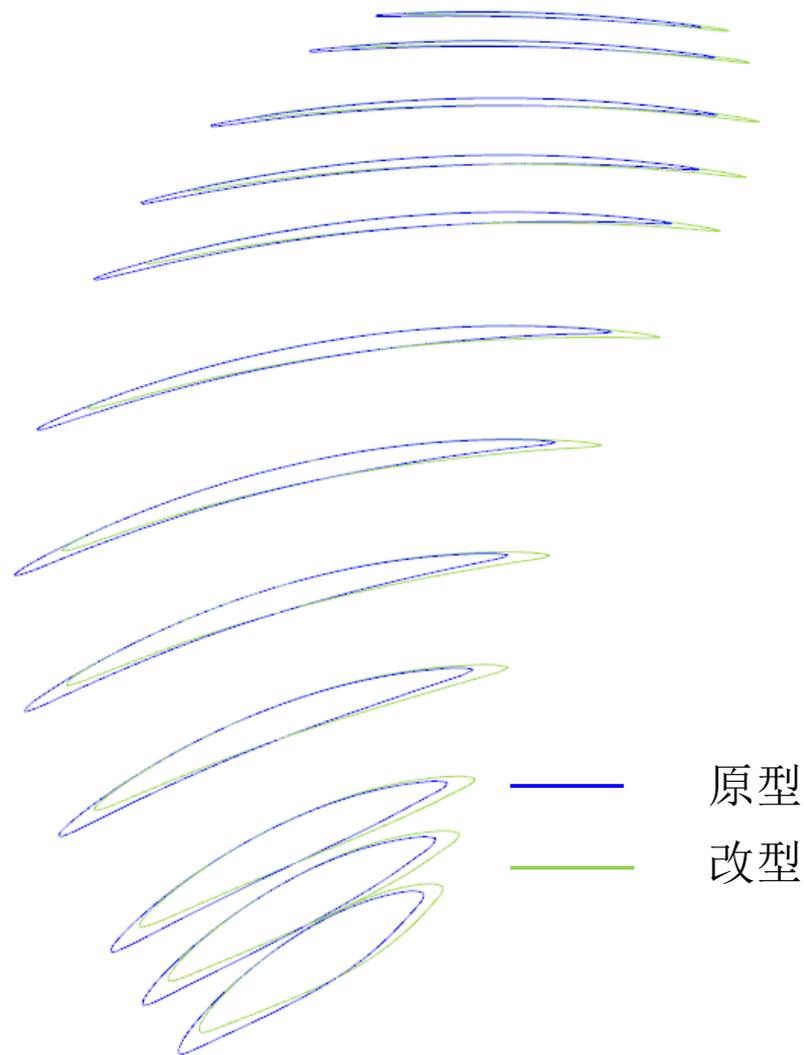




几何改进

	原型	改型	变化量 (最大值)
螺距因子	0	12	3.0244 mm
侧斜因子	0	90	5.5701 mm

- 螺距增加;
- 桨叶侧斜增加;

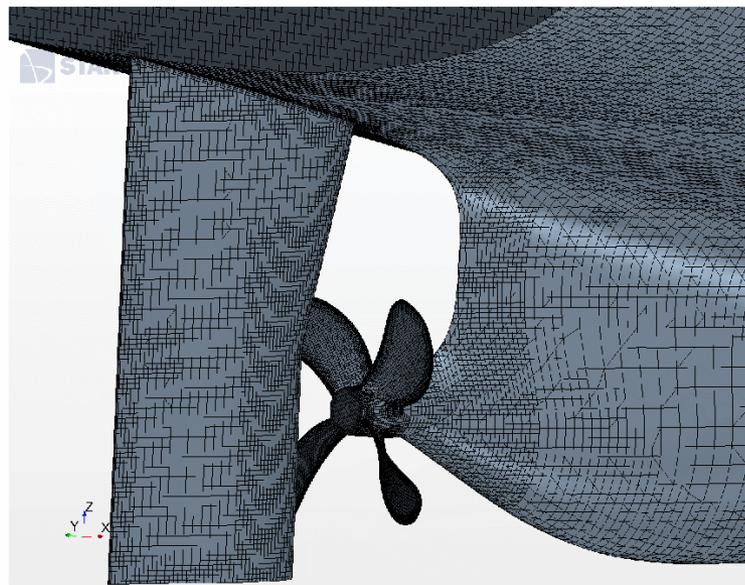




数值验证

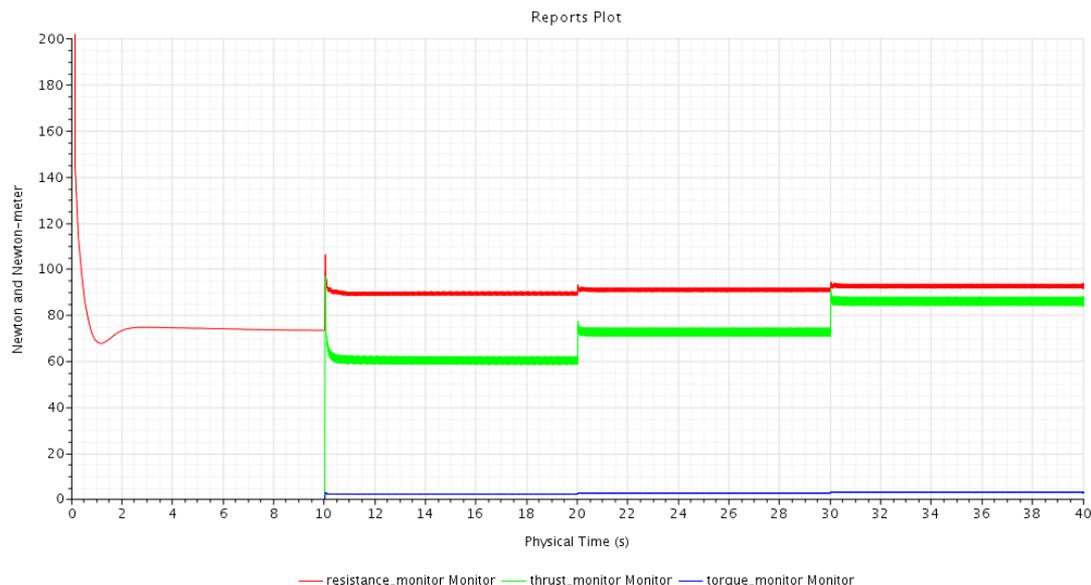
计算方法

- 叠模法，不考虑空泡及强度
- SST k- ω 湍流模型
- 模型尺度



自航条件下的优化计算

- 600+ 万网格，TriMesh
- 旋转区域（滑移动网格）
- 自动变换转速以满足插值需求
- 39小时（7个节点，168核）





优化效果

螺旋桨模型尺度	原型	改型	试验值
转速 (rps)	8.0782	8.0940	8.189
推力 (N)	64.3584	61.0824	62.739
扭矩 (N·m)	2.3267	2.2083	2.222
P_D (W)	118.0959	112.3055 (-4.90%)	114.3285 (-3.20%)



结论与展望

结论

- CAESES 是强大的优化工具，可快速实现多种几何设计及变形
- 基于 CAESES 工具，自航条件下的螺旋桨优化取得较好的结果

展望

- 考虑尺度效应在优化中的影响？
- 结合强度就按进行螺旋桨的优化？
- 螺旋桨空泡进行螺旋桨的优化？
- 结合节能装置一起优化？



Thank you for your attention!