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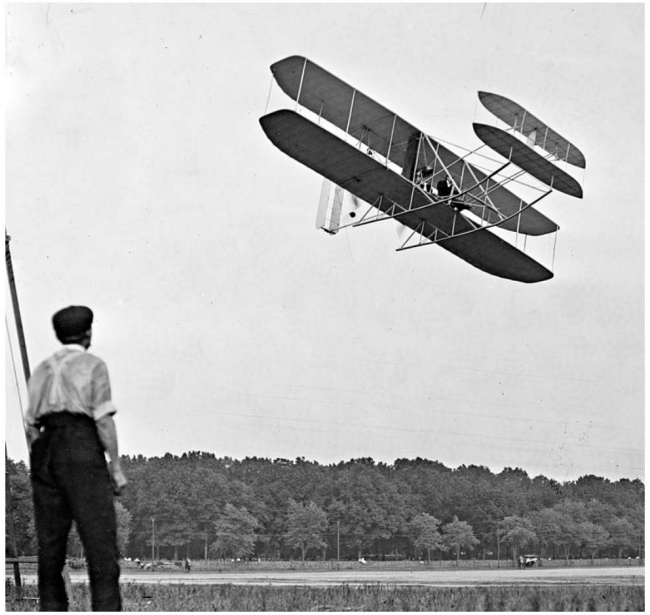

# Uncertainty and Robustness in Aerospace Structures

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Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

# In the aerospace industry…

”…a move towards **probabilistic design practices** has been recognized as a **potential game-changer**, as it is understood to reduce **costs**, **risks** and **lead times**, while increasing the **confidence** in analysis tools, and the **quality** and **reliability** of products“

Nasa report by Zang *et al.* (2002)

# A different simulation approach…

| **Deterministic design** | **Probabilistic design** |
| --- | --- |
| Nominal operation | Adds variation modeling |
| Worst-case scenarios | Uses probability distributions, etc. |
| Safety factors | Allows some probability of failure |
| Easy to implement in simulation | Difficult to implement in simulation |

**Probabilistic design → Robust design → Geometry assurance**

"**Robust design** is an engineering **methodology** that aims at **minimizing** the **effects** of **variation** without eliminating the variation **itself**. "

Phadke (1995)

## Probabilistic design → Robust design → **Geometry assurance**

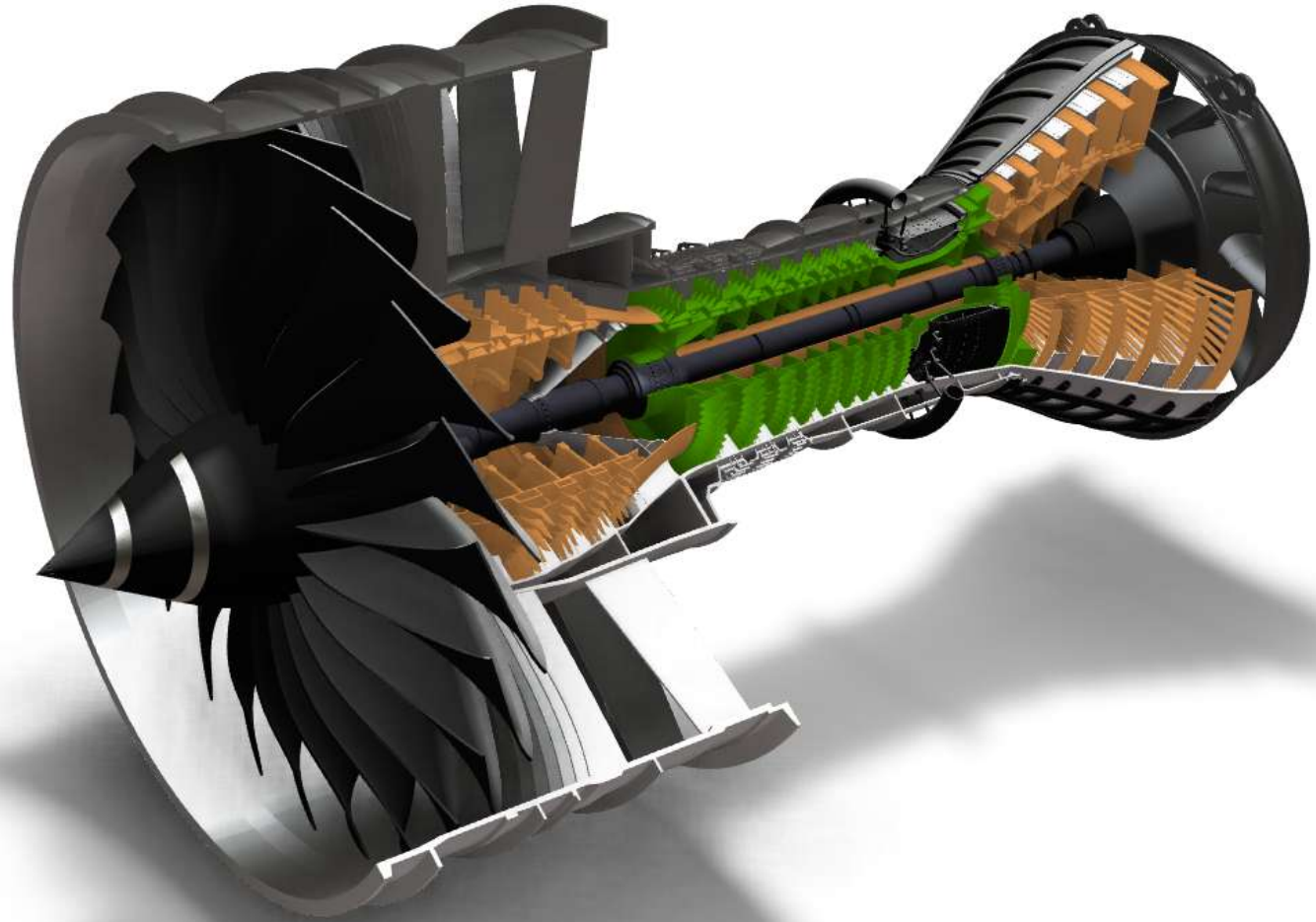
"***Geometry assurance*** is a set of activities aimed at **reducing** the **effects** of **geometric variation** and increasing the precision of **functional** attributes of products."

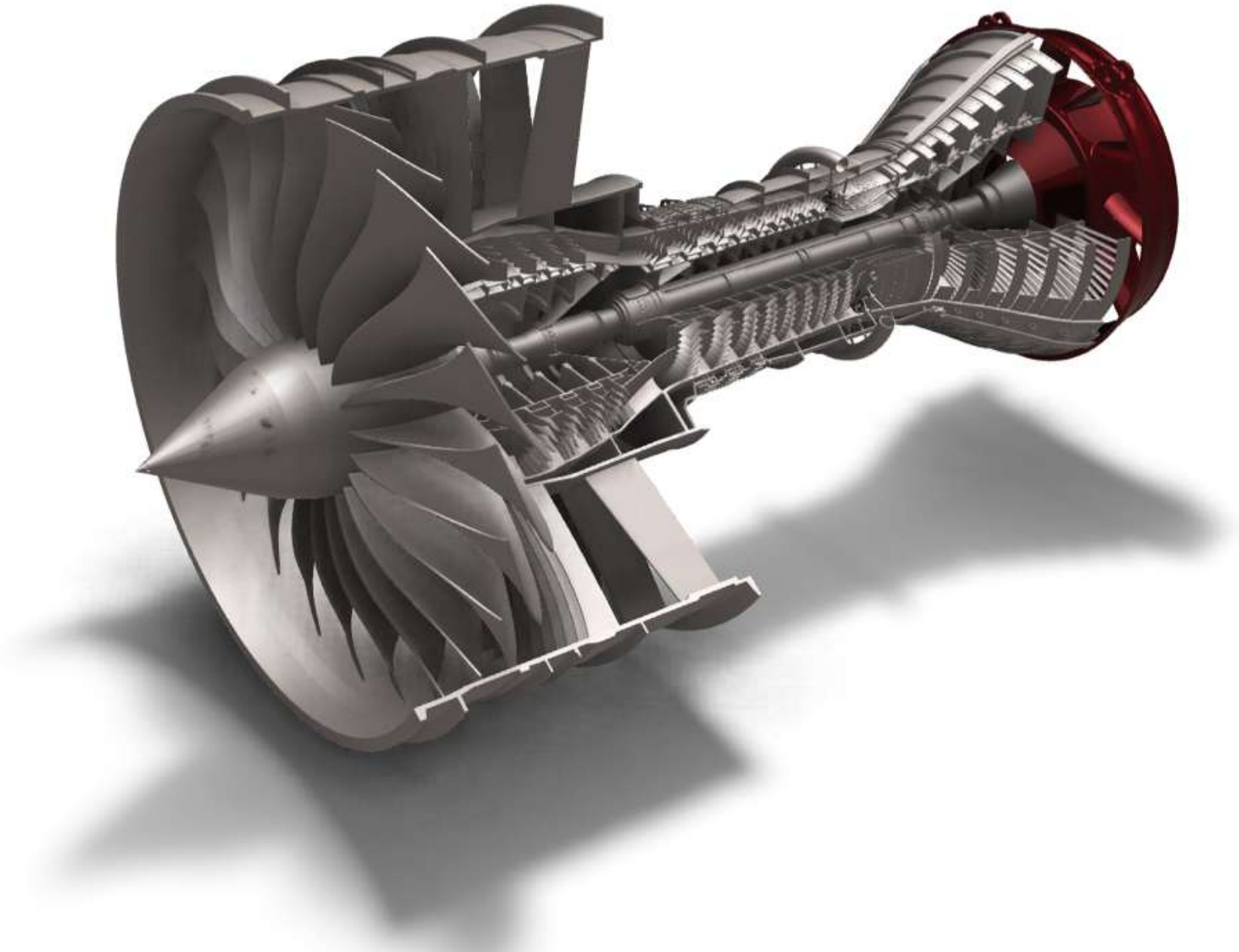
Söderberg *et al.* (2006)

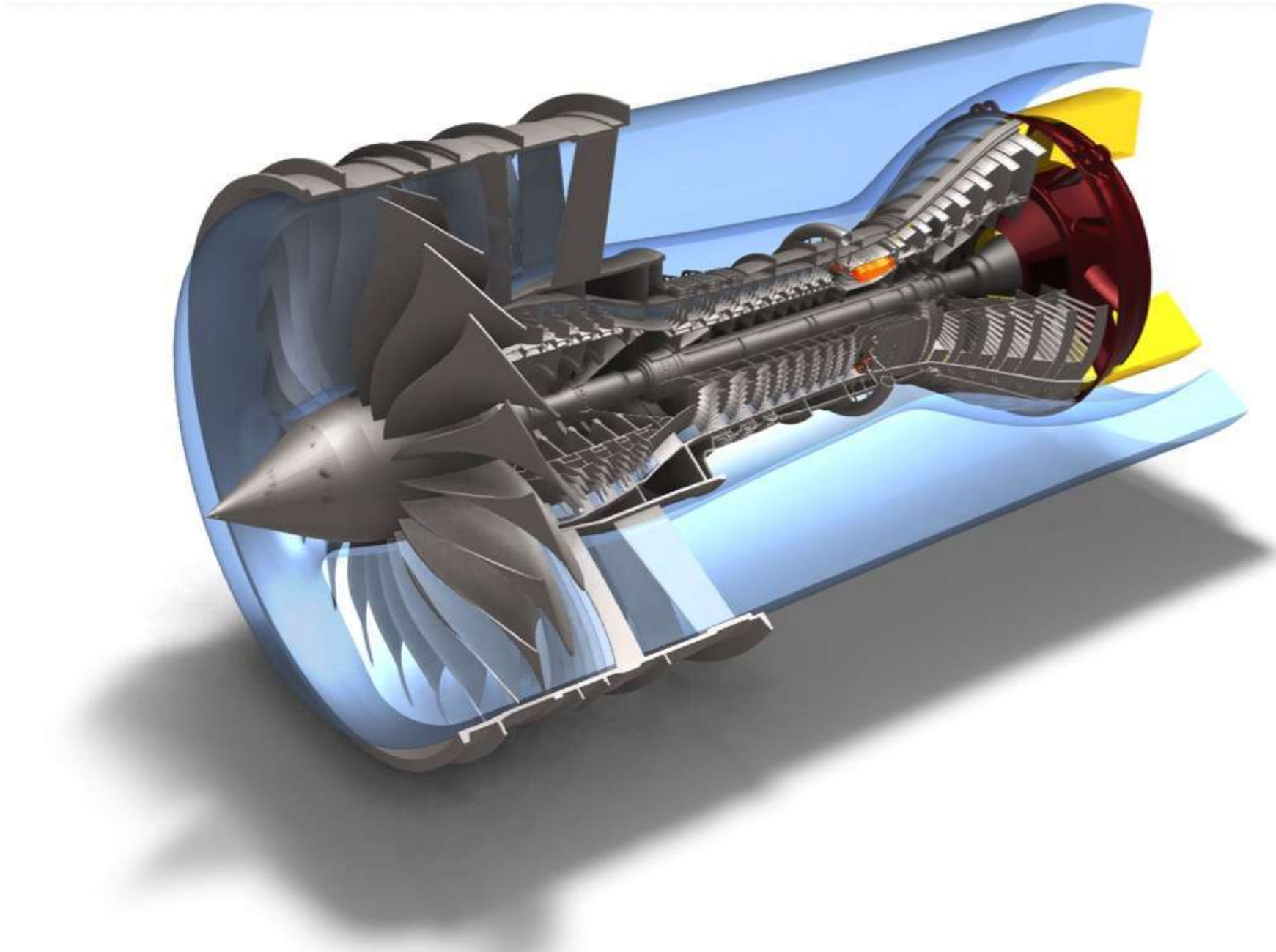
# Part variation

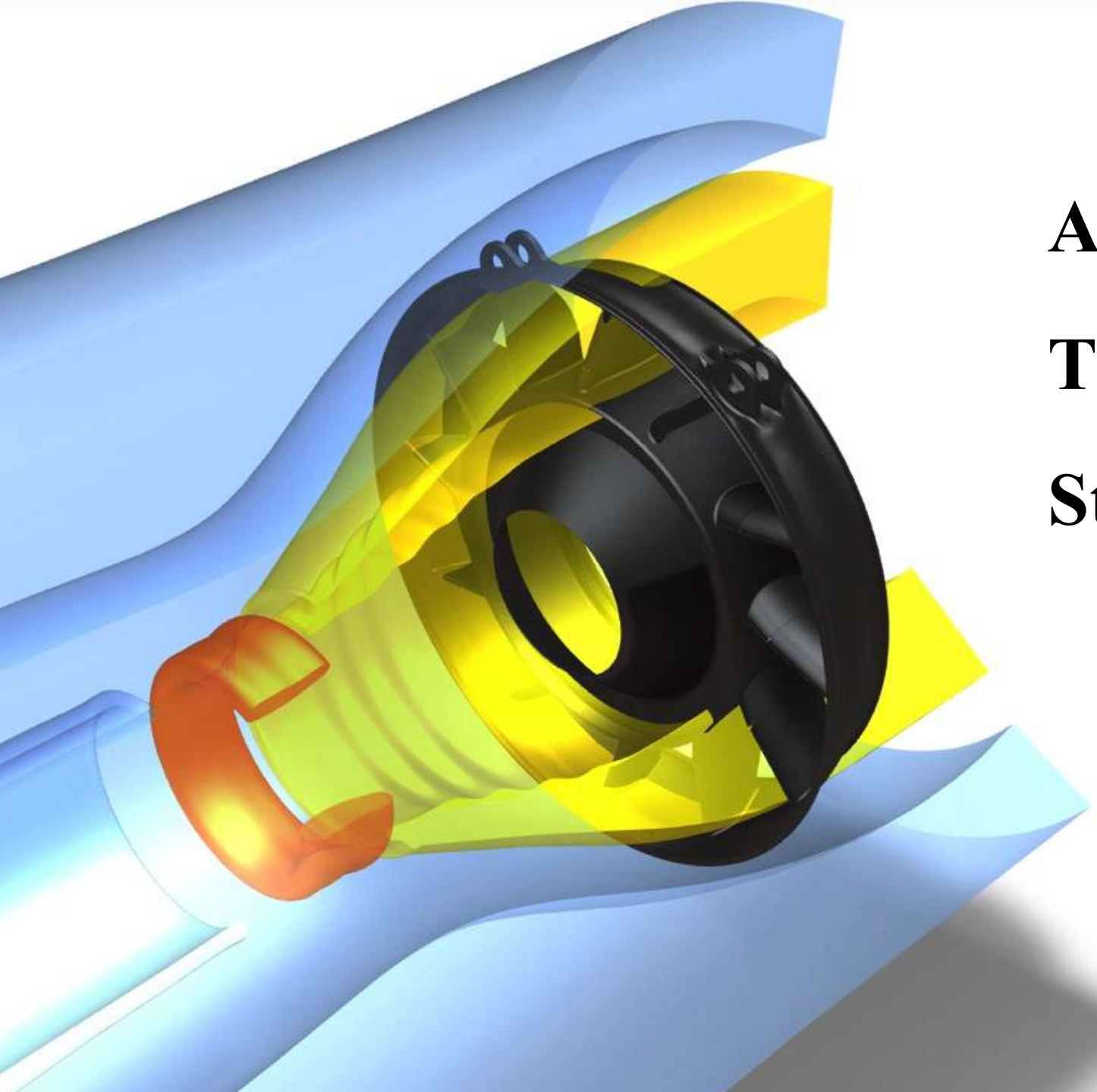
**Part variation** → **Assembly variation**

**Part variation** → **Assembly variation** → **Functional variation**









**Aerodynamic** loads

**Thermal** loads

**Structural** loads

**Fabricated** assembly

**Cast**, **forged** and **sheet metal** parts

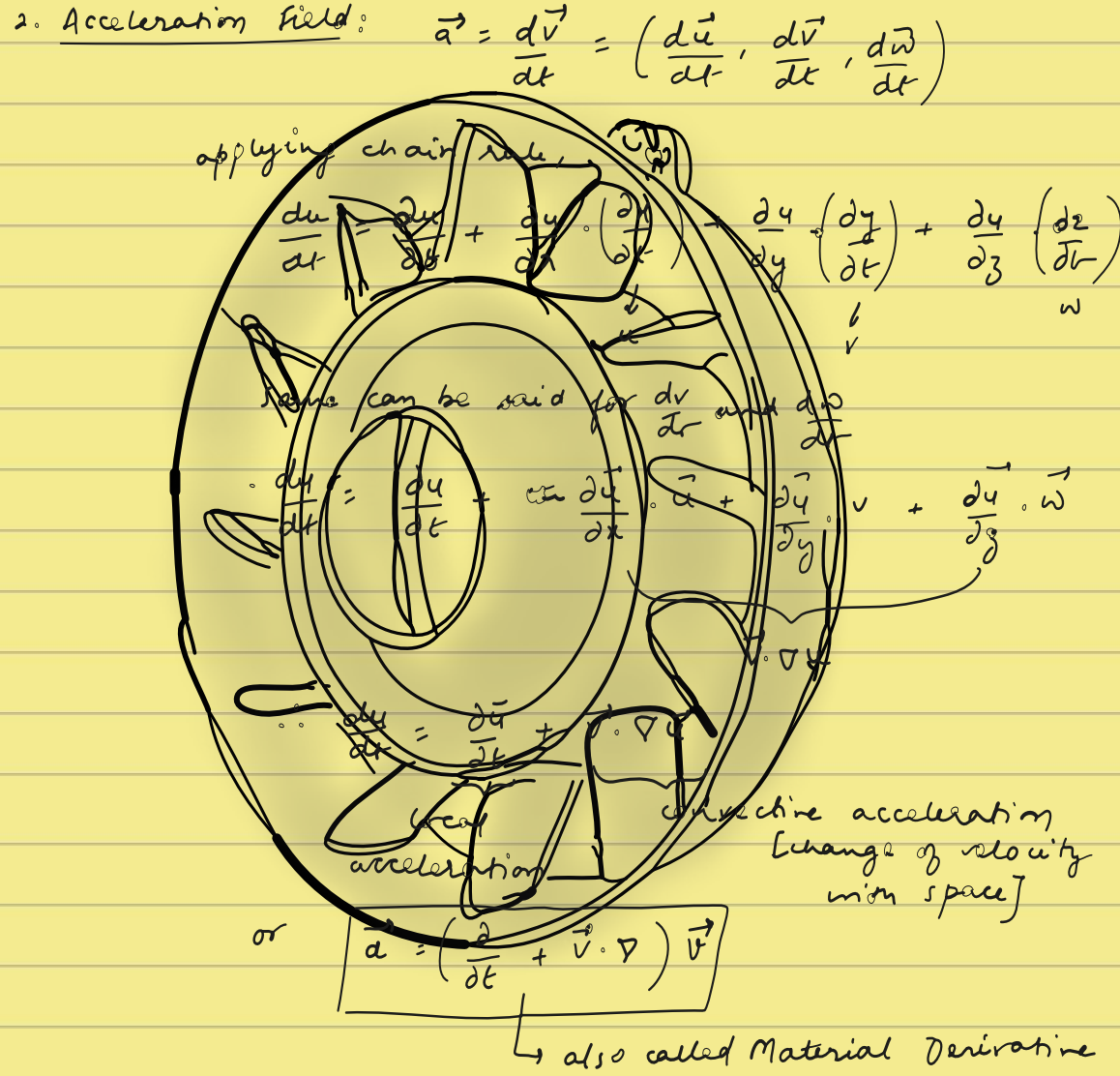
**Welded** together

Conceptual Modeling

*(Adapted from: Oberkampf, 2002)*

Mathematical Modeling

Conceptual Modeling



Computer Programming

Mathematical Modeling

Conceptual Modeling

Discretization & Algorithm Selection

Computer Programming

Mathematical Modeling

Conceptual Modeling

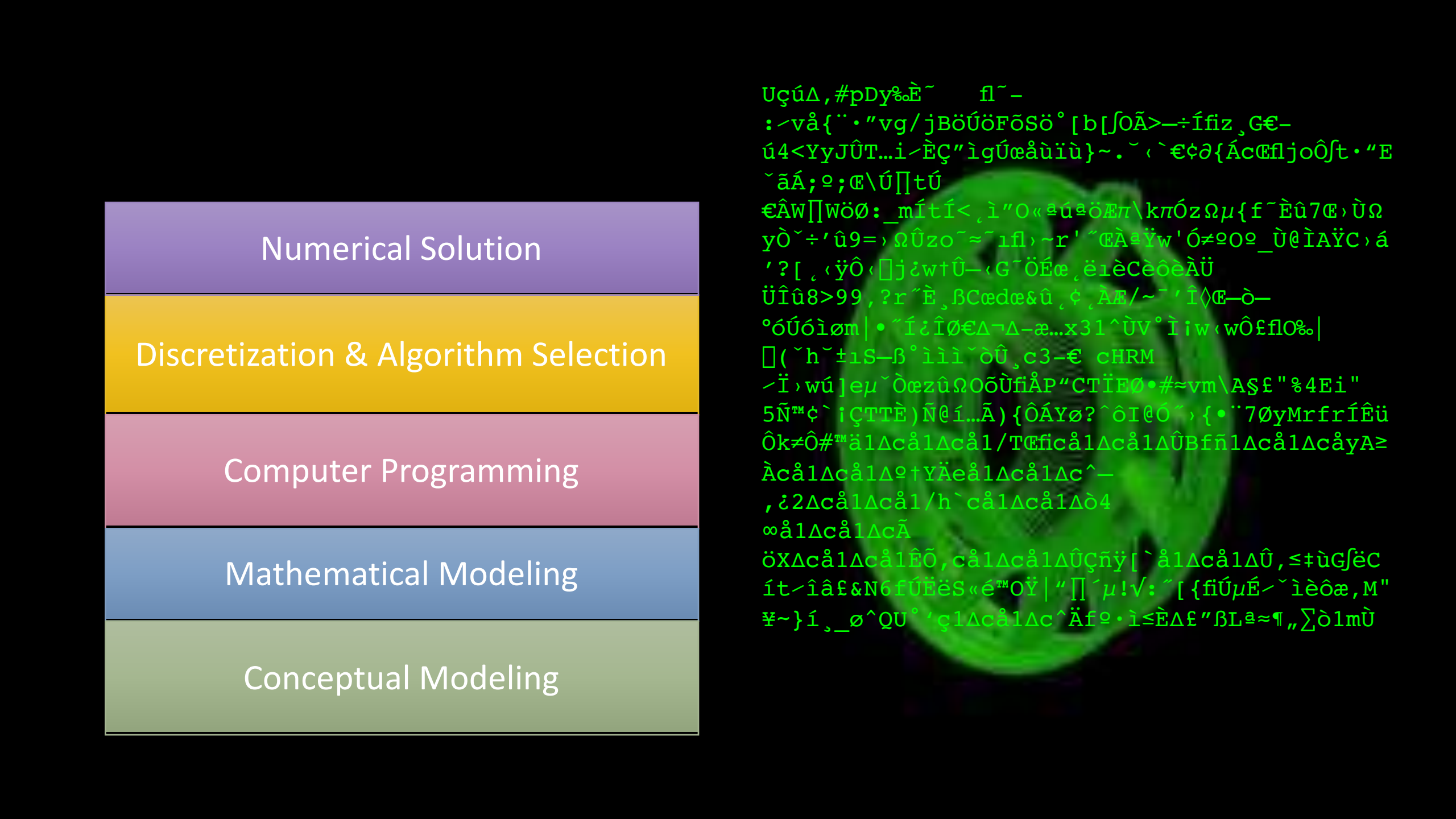
Numerical Solution

Discretization & Algorithm Selection

Computer Programming

Mathematical Modeling

Conceptual Modeling



Solution Representation

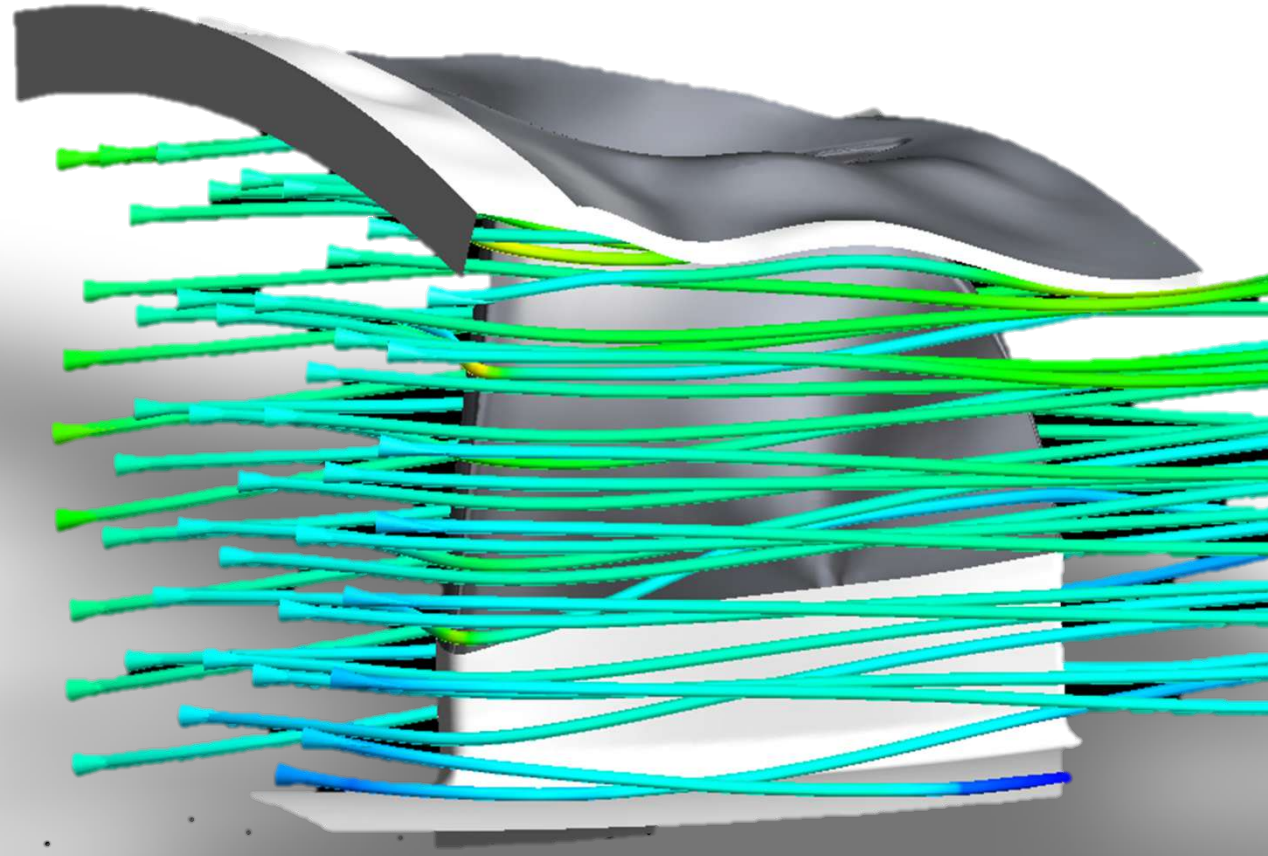
Numerical Solution

Discretization & Algorithm Selection

Computer Programming

Mathematical Modeling

Conceptual Modeling



**Research Question I:**

*What barriers to implementing geometry assurance practices can be identified in the aero engine industry?*

**Research Question II:**

*How can geometry assurance methods be implemented in multidisciplinary simulations in industrial settings?*

**Research Question III:**

*What role should geometry assurance play in the early phases of aerospace component design?*

**Research Question I:**

*What barriers to implementing geometry assurance practices can be identified in the aero engine industry?*

# Barrier #1:

# **Barrier #1:**
# *Model Form Error*

# *Model Form Error*

# Barrier #2:

# **Barrier #2:**
*Discretisation Error*

*Discretisation Error*

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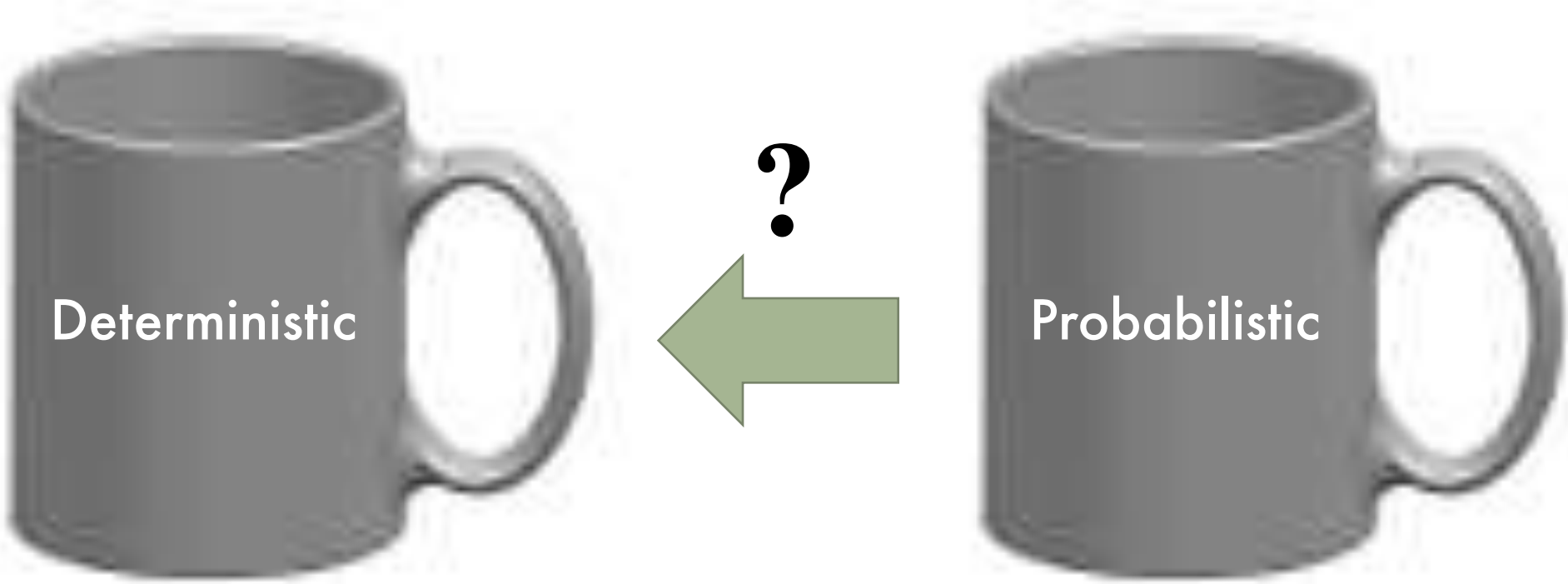
*Discretisation Error*

*Discretisation Error*

# Barrier #3:

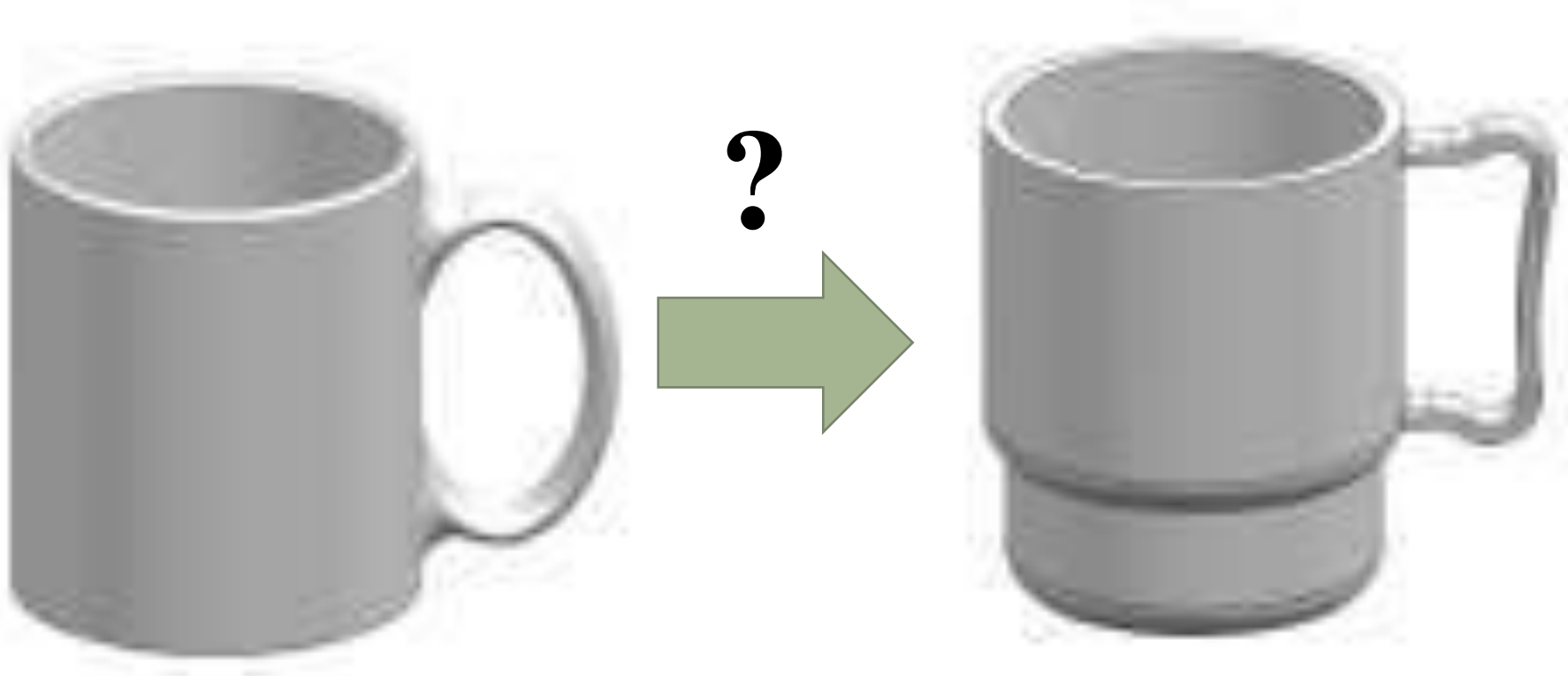
# **Barrier #3:**
*Backwards Incompatibility*




*Backwards Incompatibility*

# Barrier #4:

# **Barrier #4:**
*Forward Applicability*

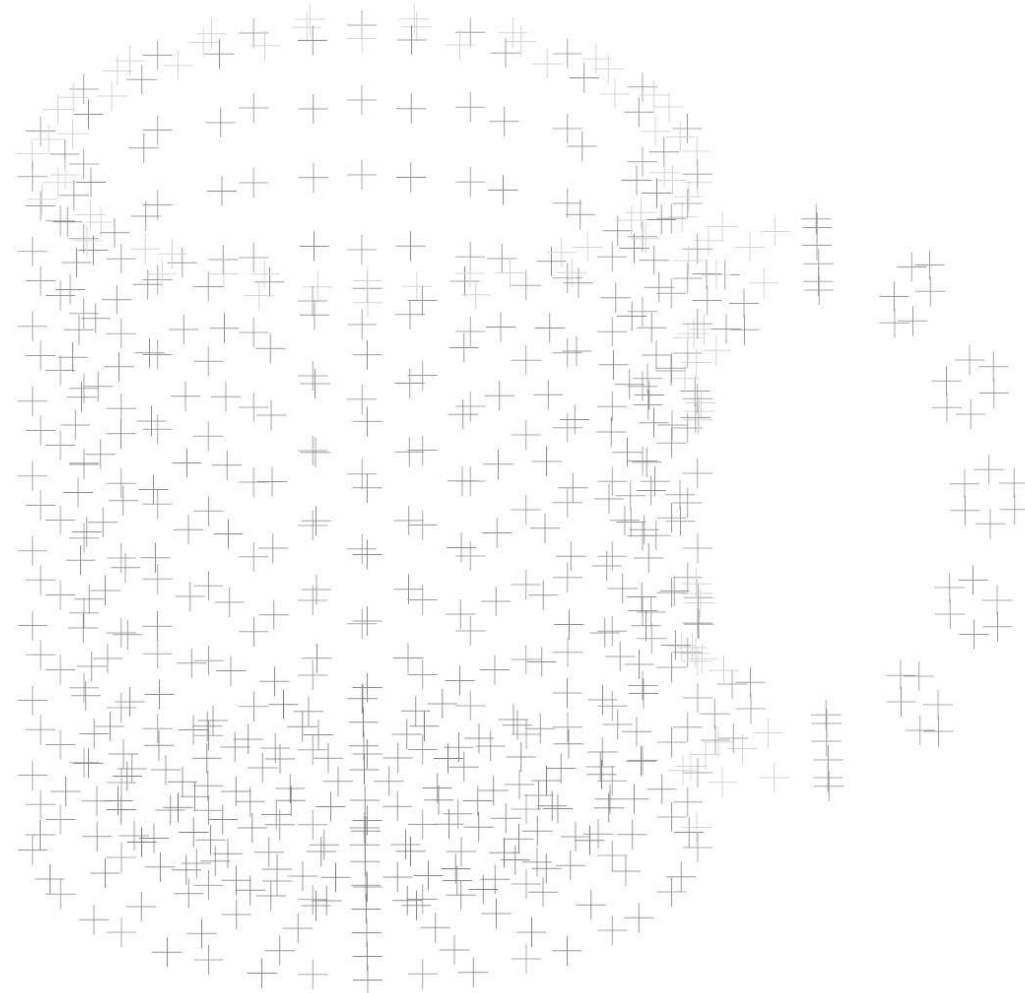


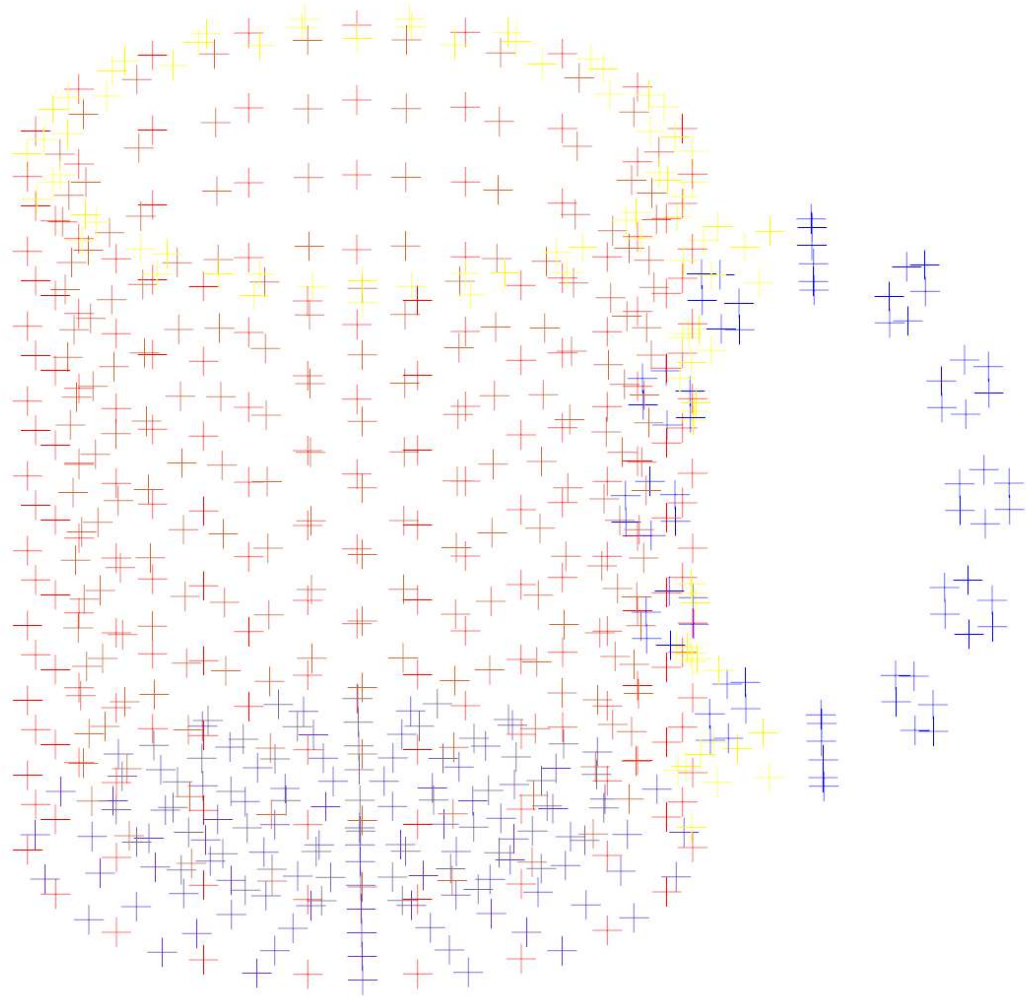

*Forward Applicability*

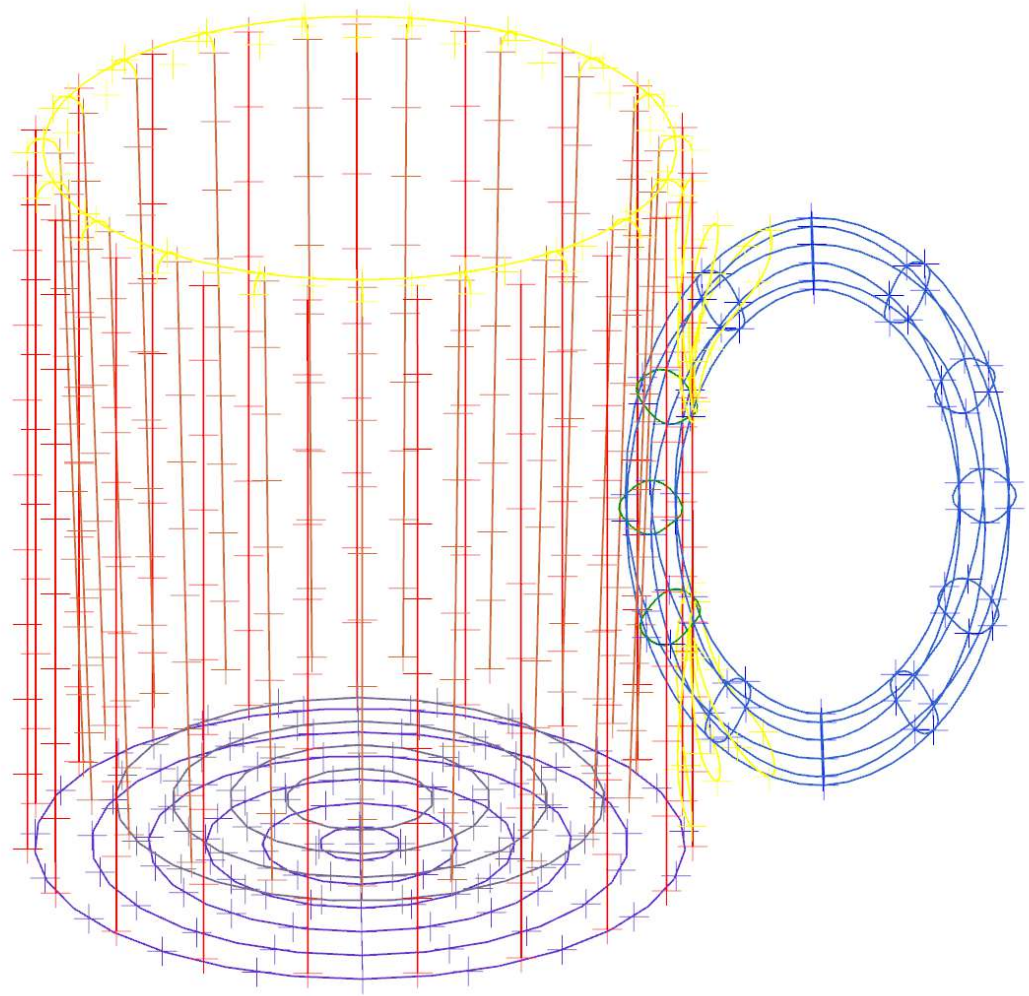
**Research Question II:**

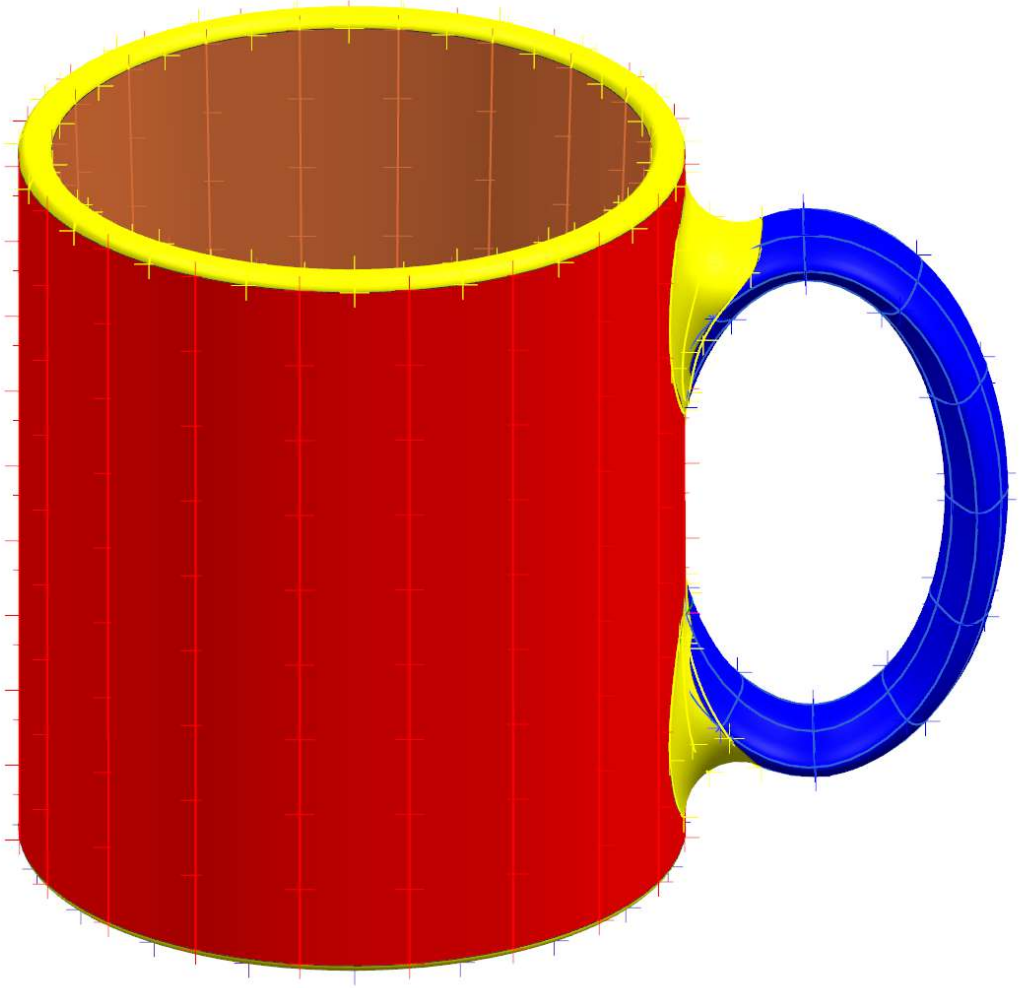
*How can geometry assurance methods be implemented in multidisciplinary simulations in industrial settings?*

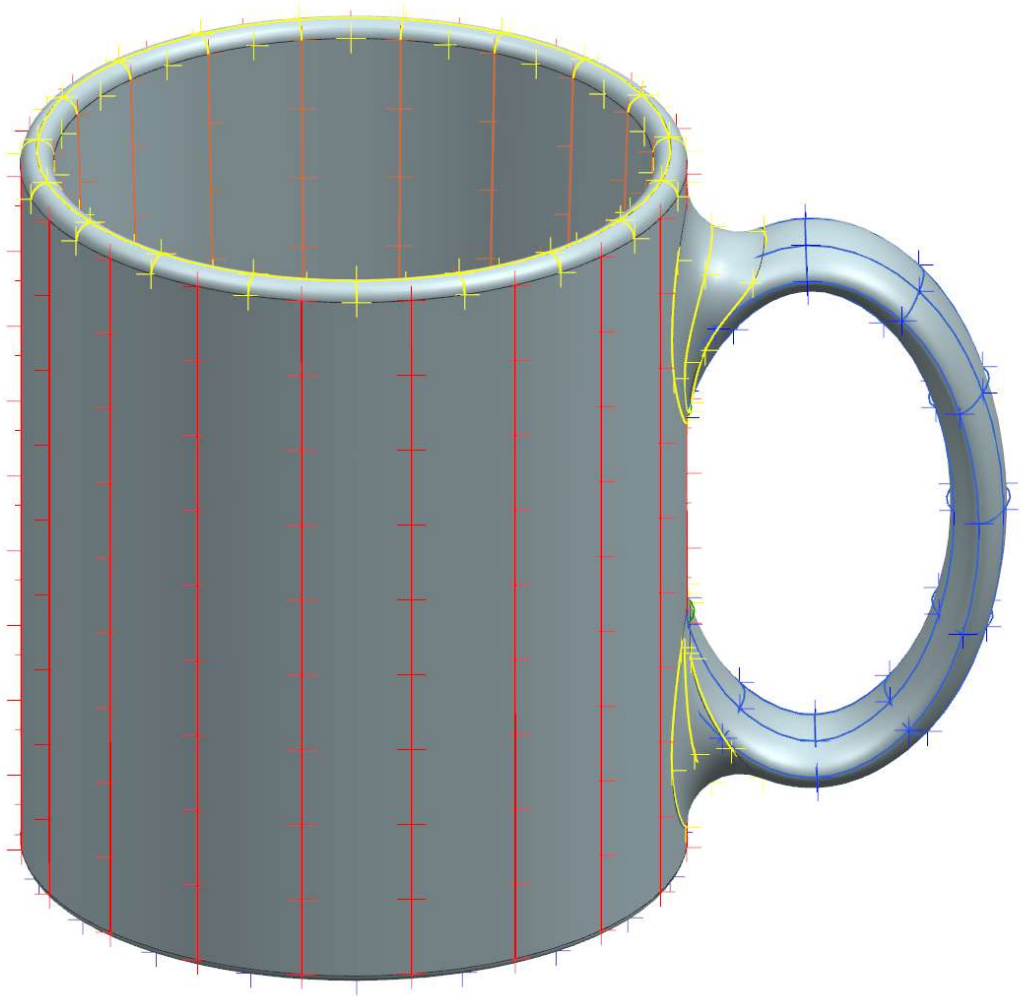
# #1:
# The parametric point method

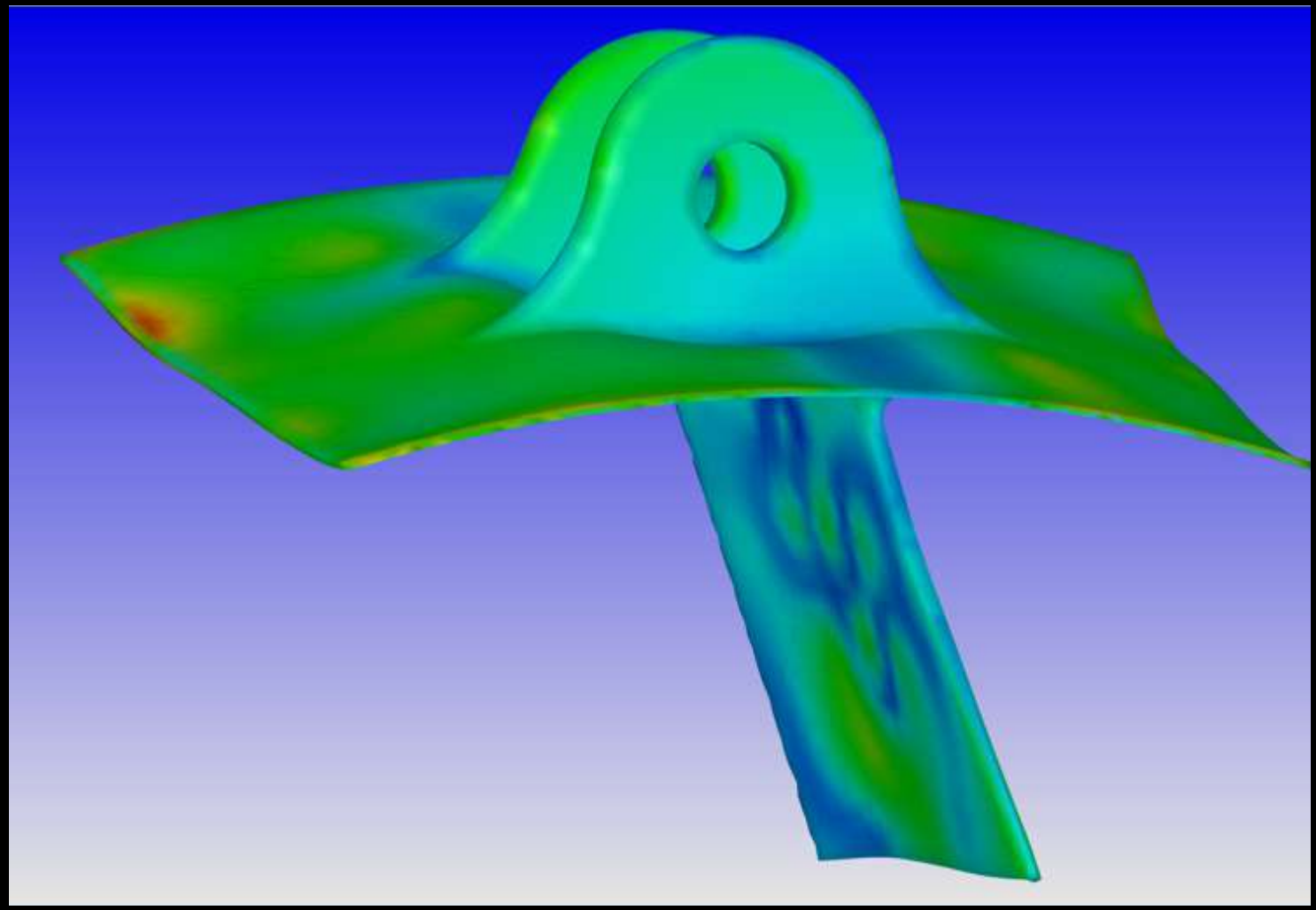




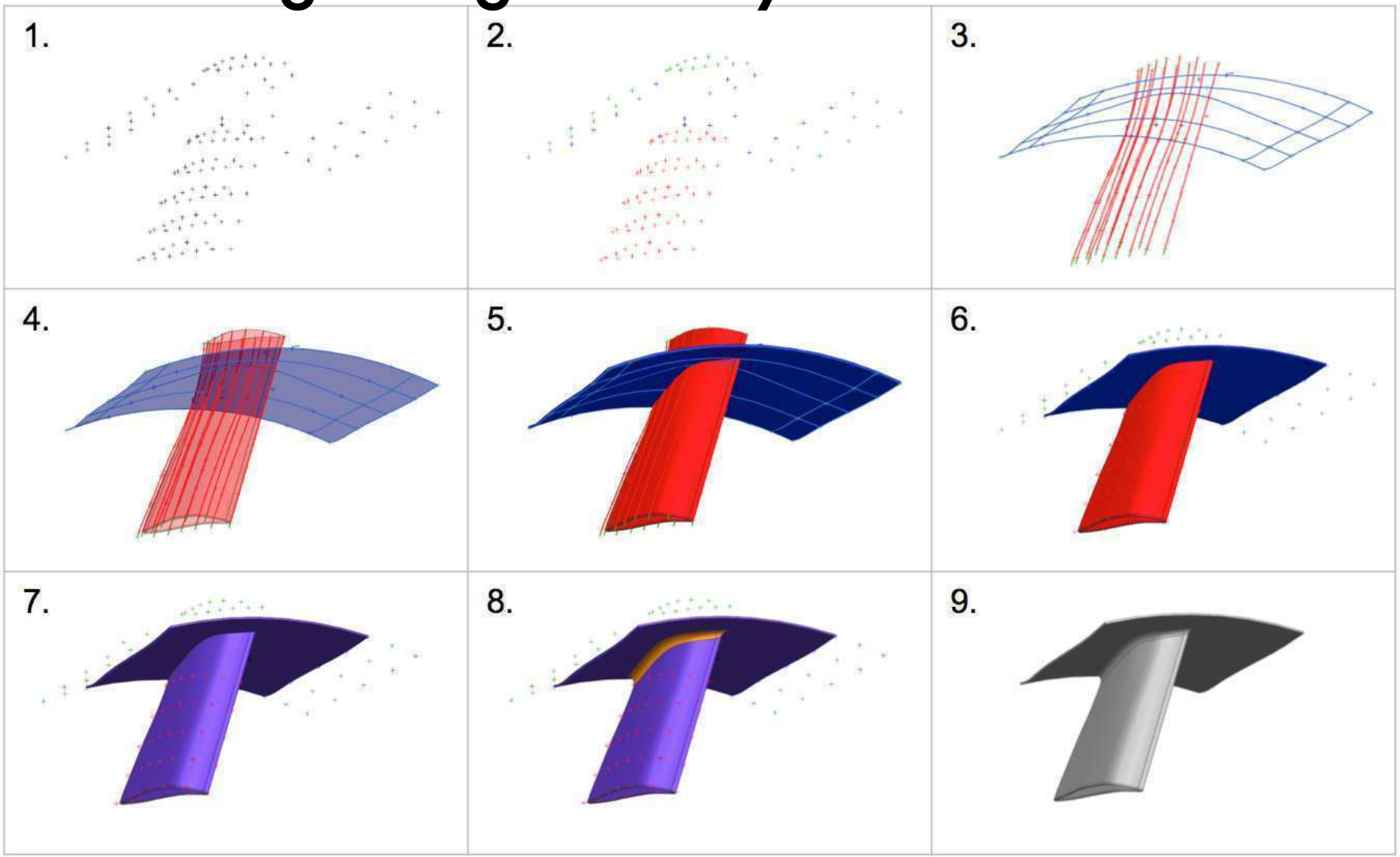






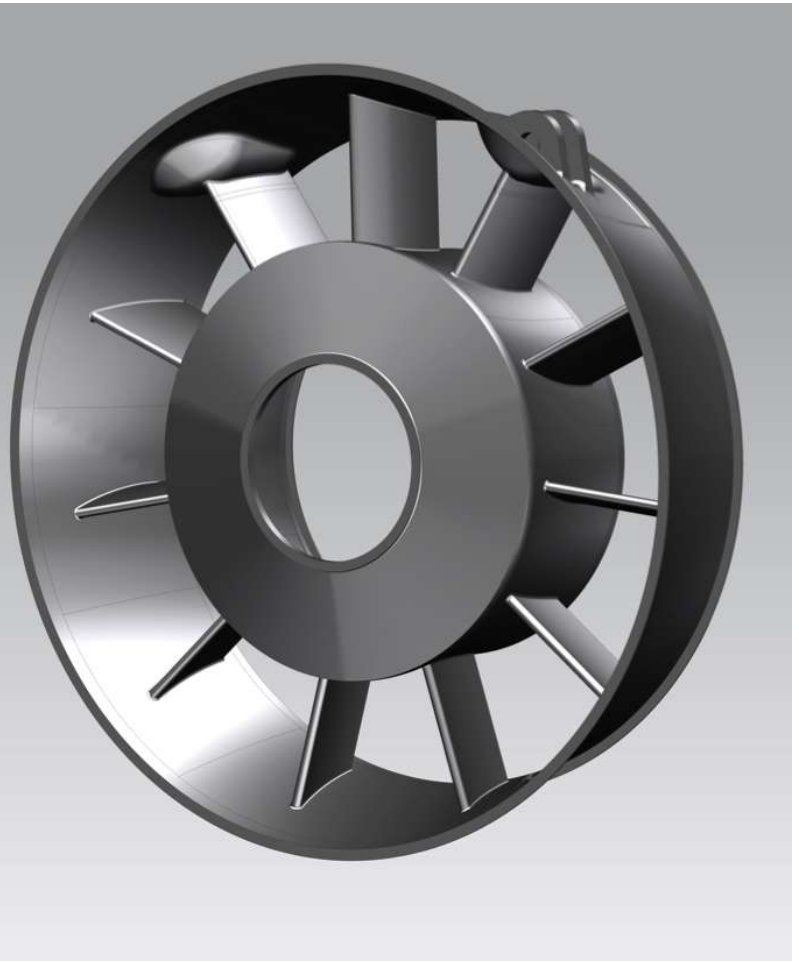


# Reconstructing the geometry…



# Models

1st gen *-Papers A and B*

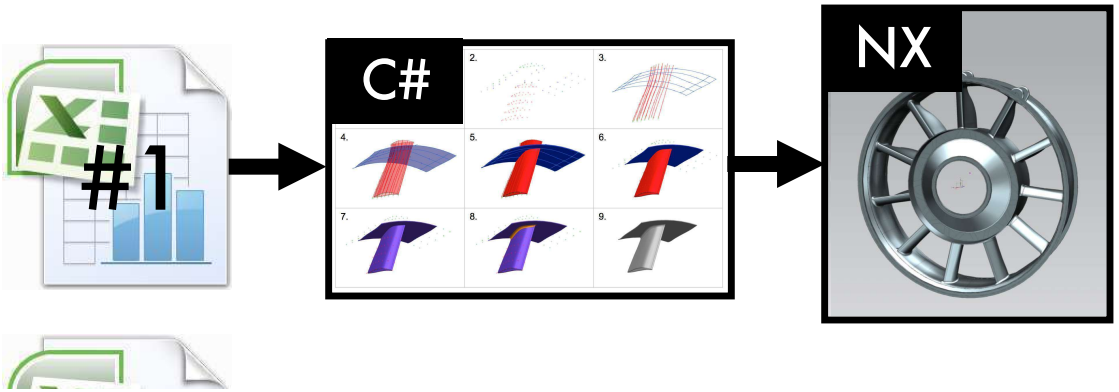


2nd gen *-Paper C*

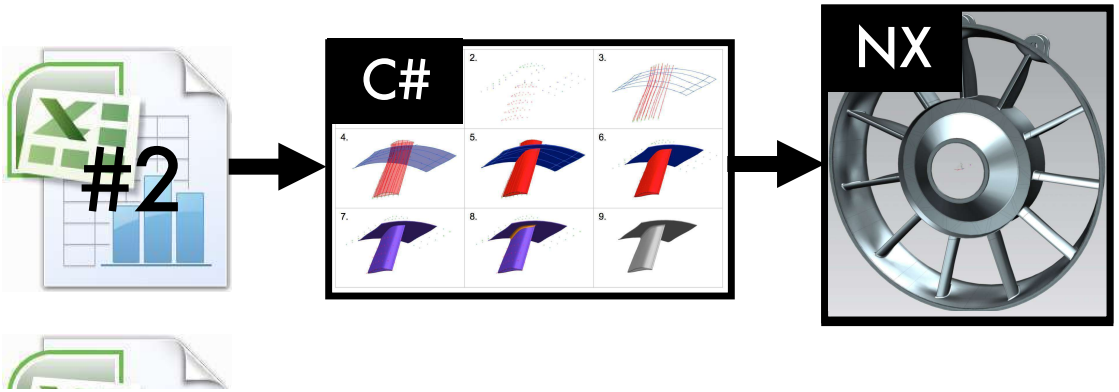
3rd gen *- Papers D-G*

# #2:
# Integrated simulation environment

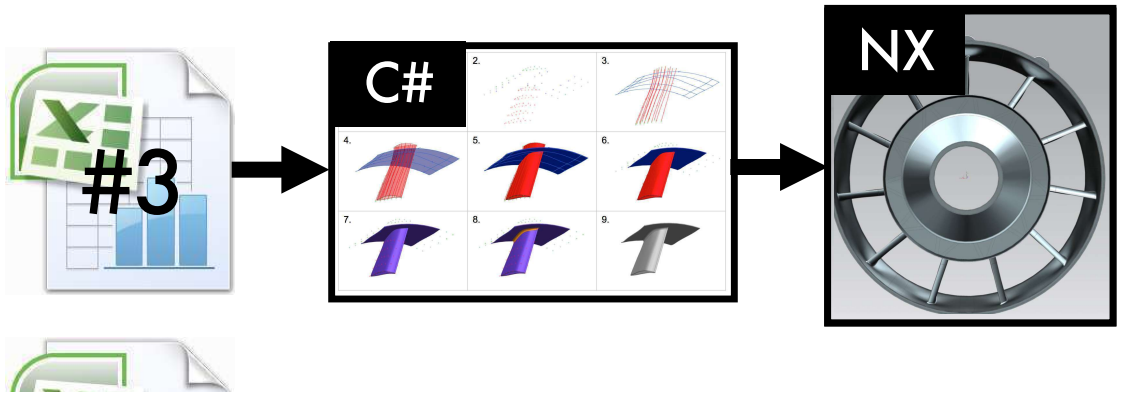
# Simulation workflow



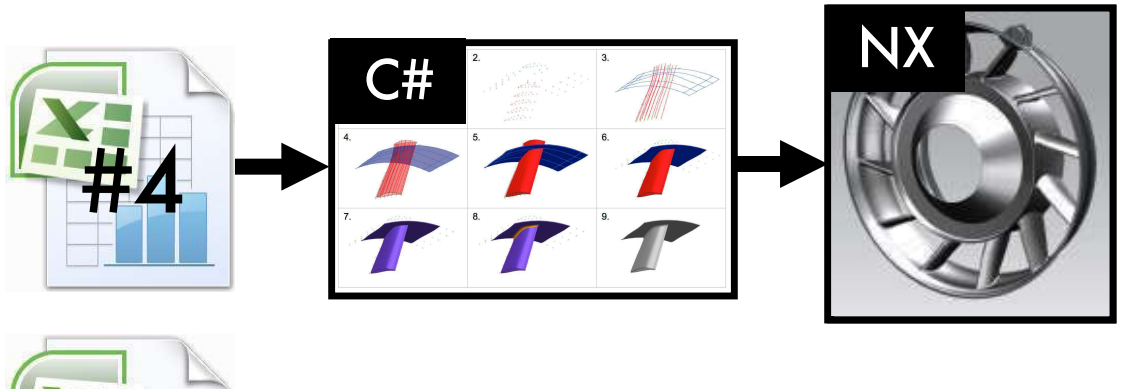
# Simulation workflow



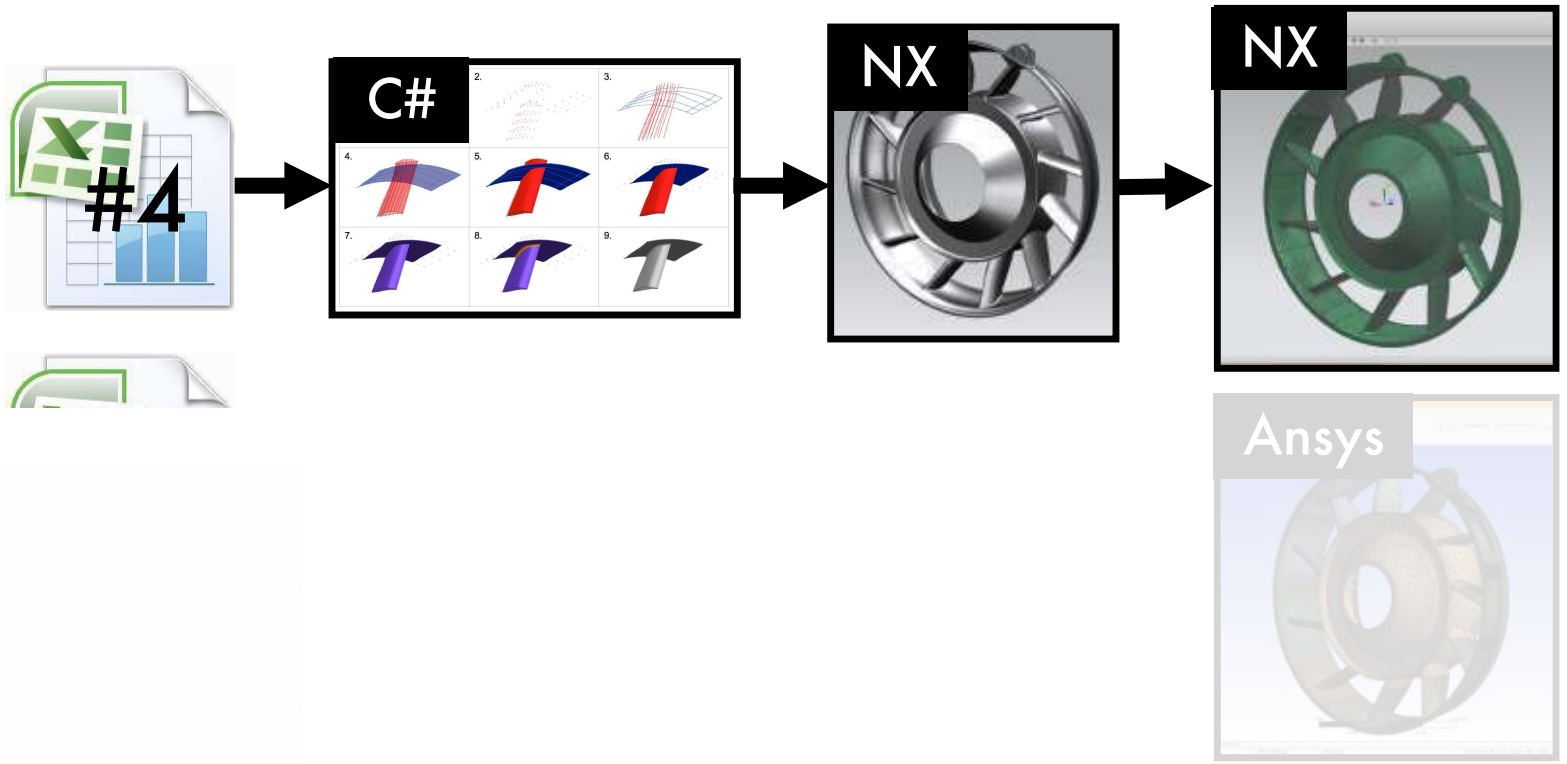
# Simulation workflow



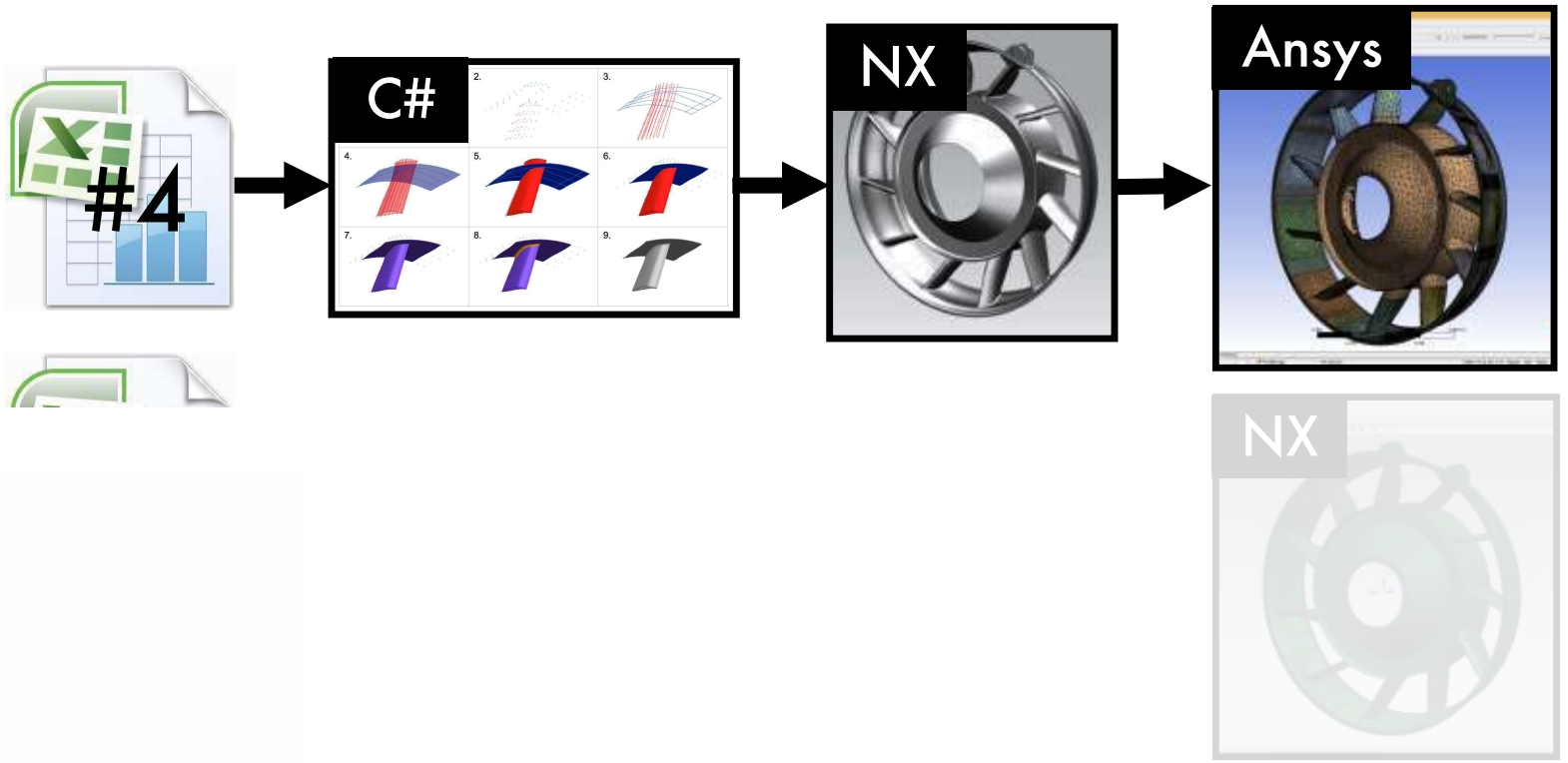
# Simulation workflow



# Simulation workflow



# Simulation workflow



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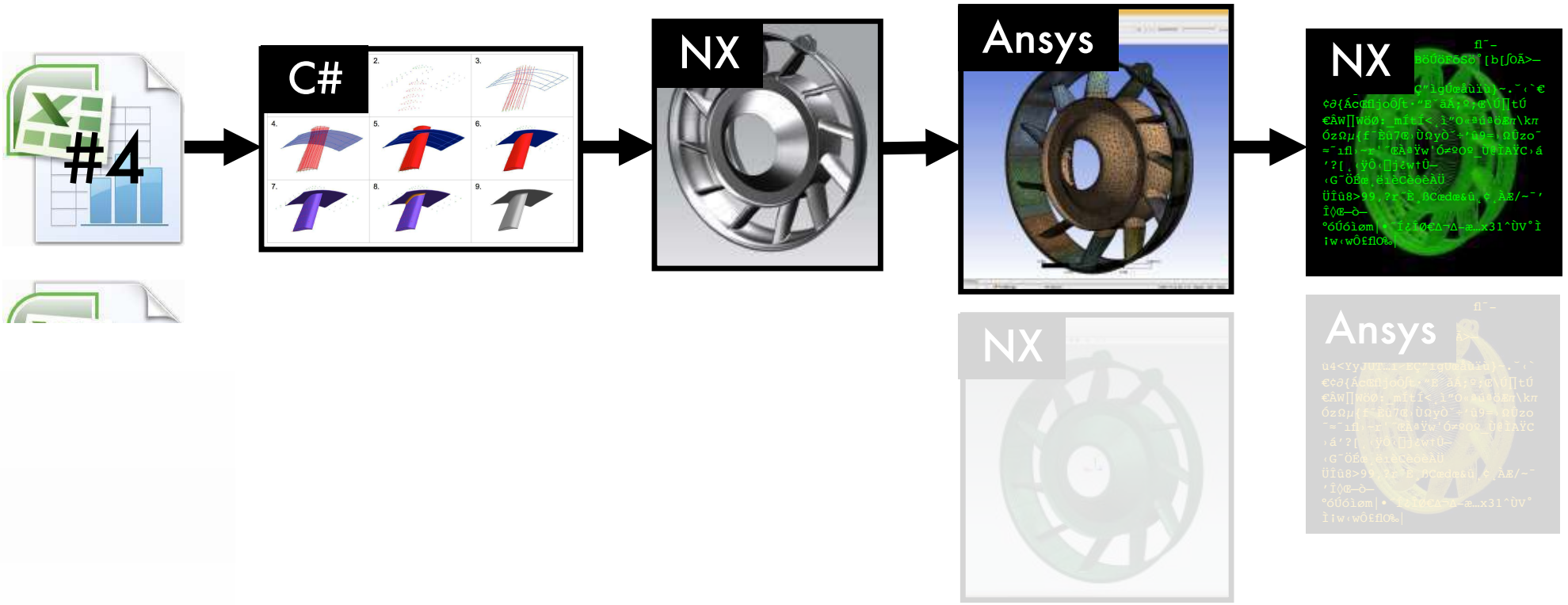
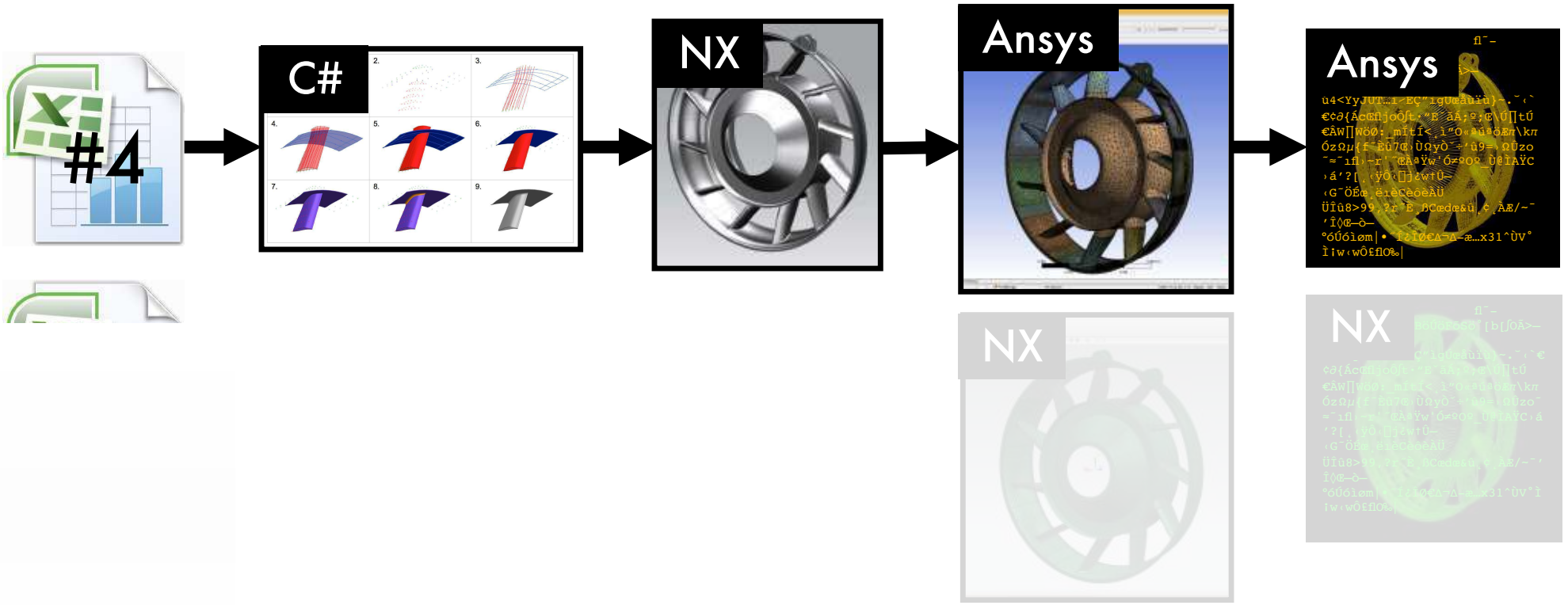
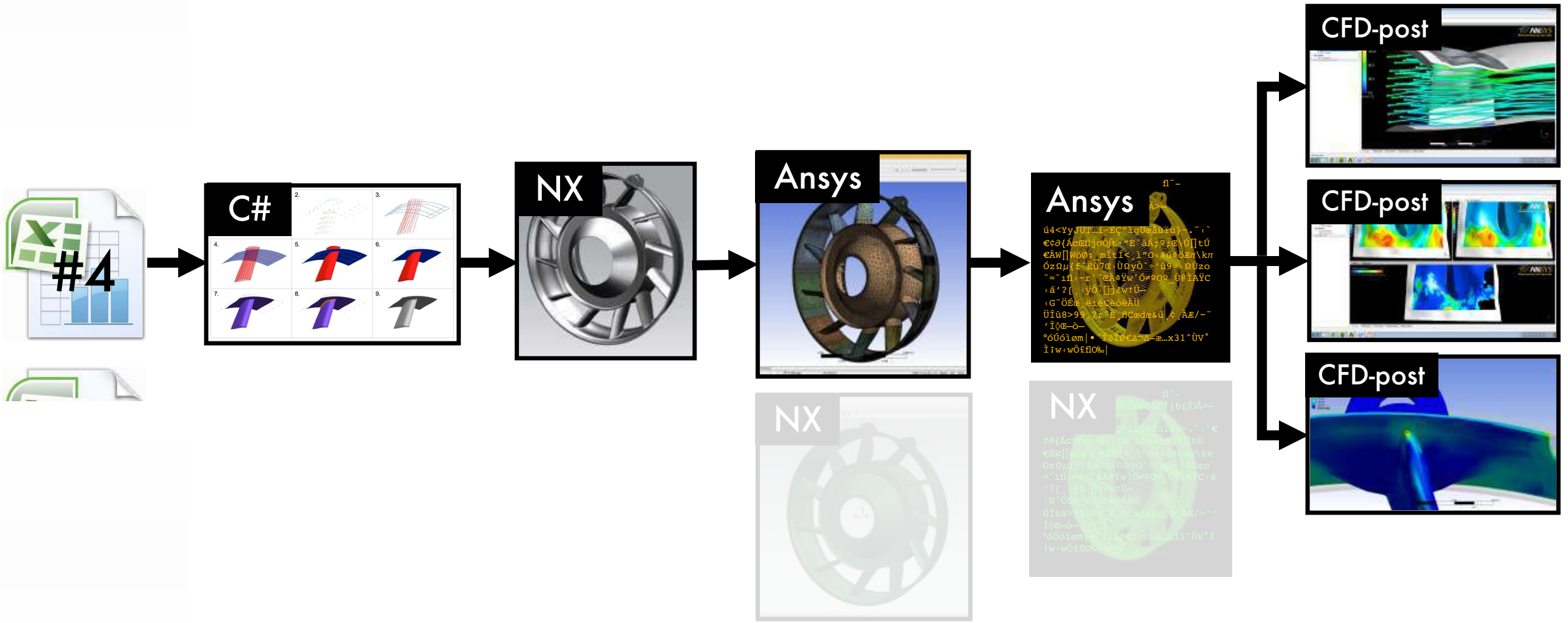
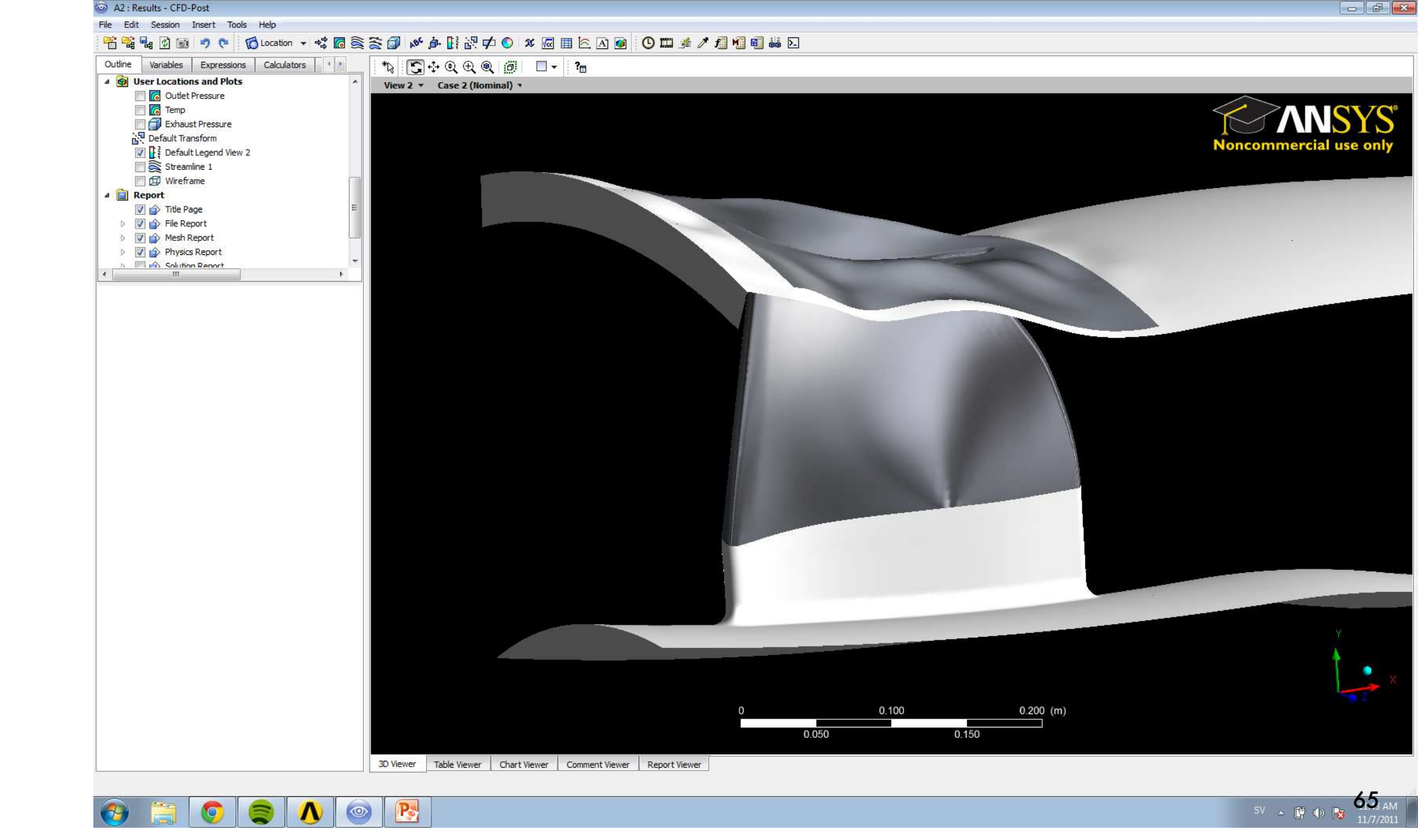


# Simulation workflow



# Simulation workflow

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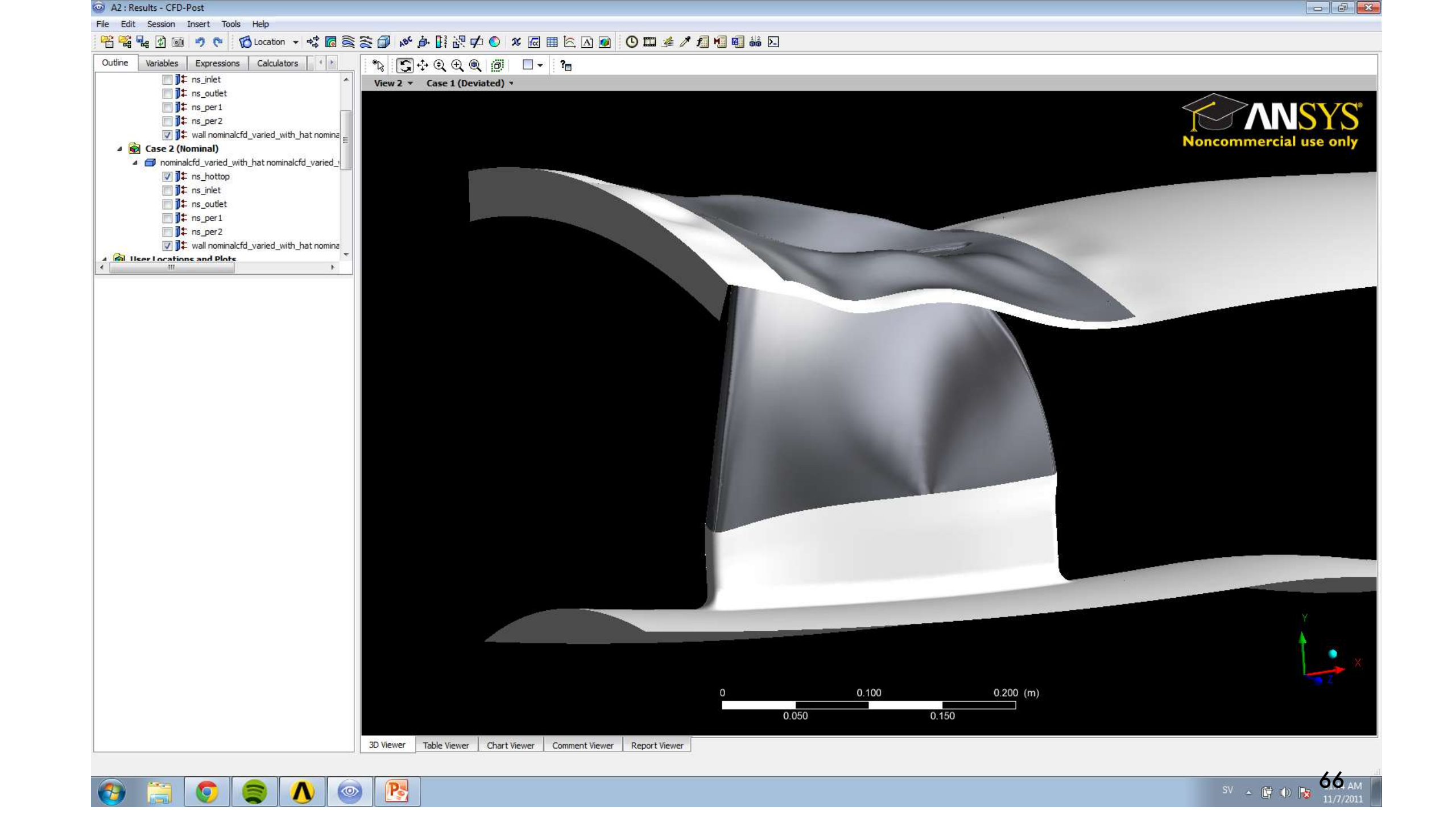
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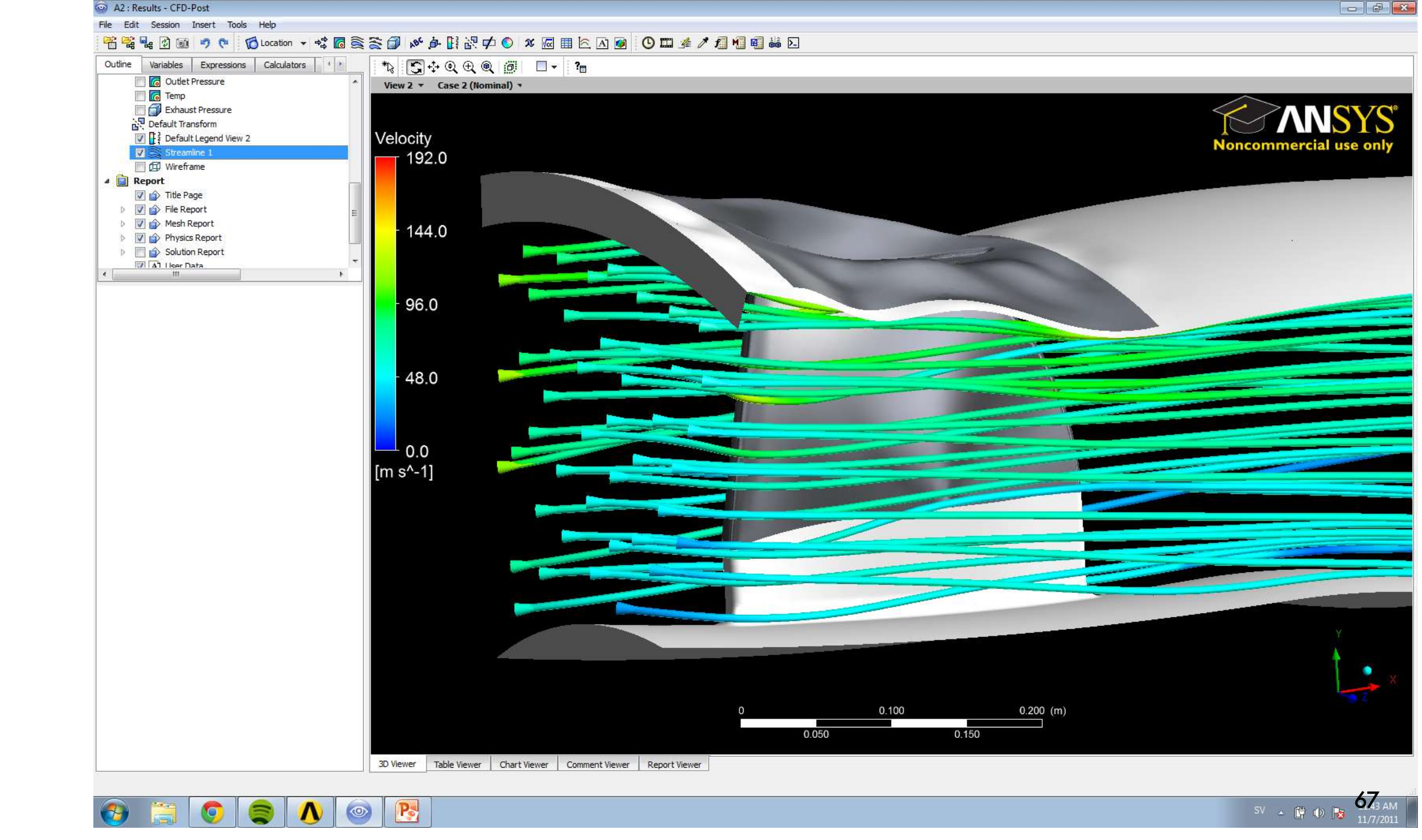
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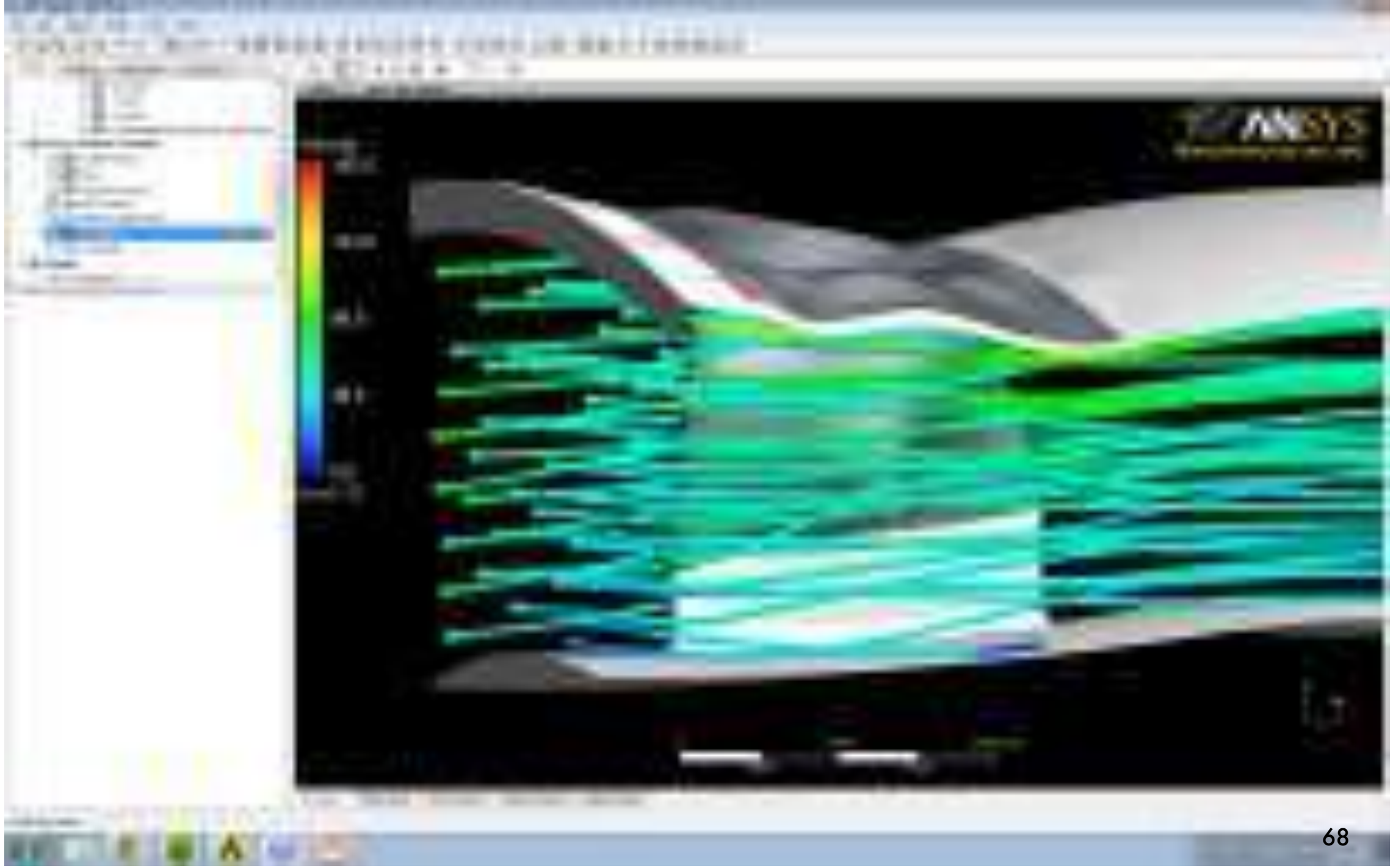
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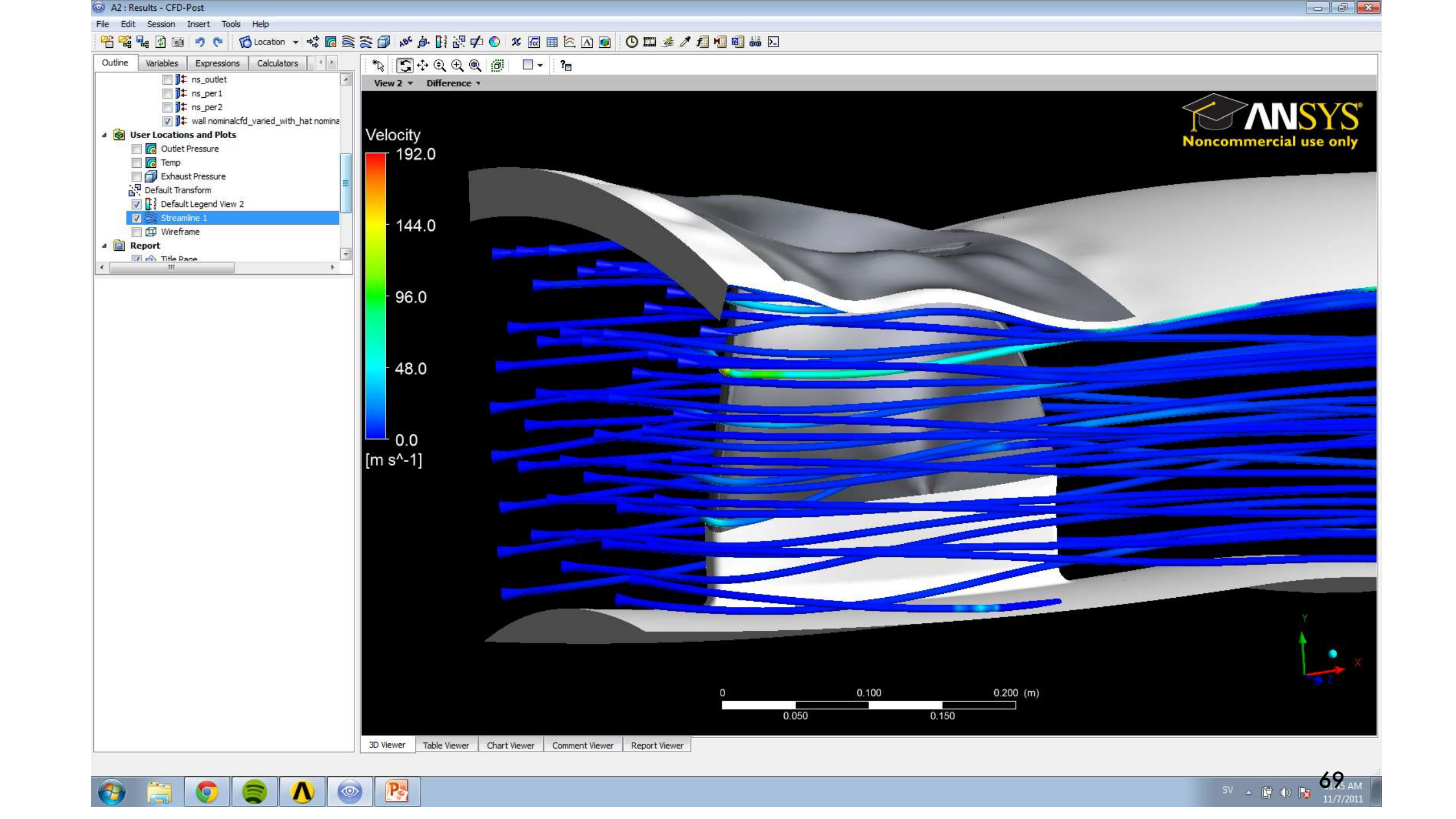
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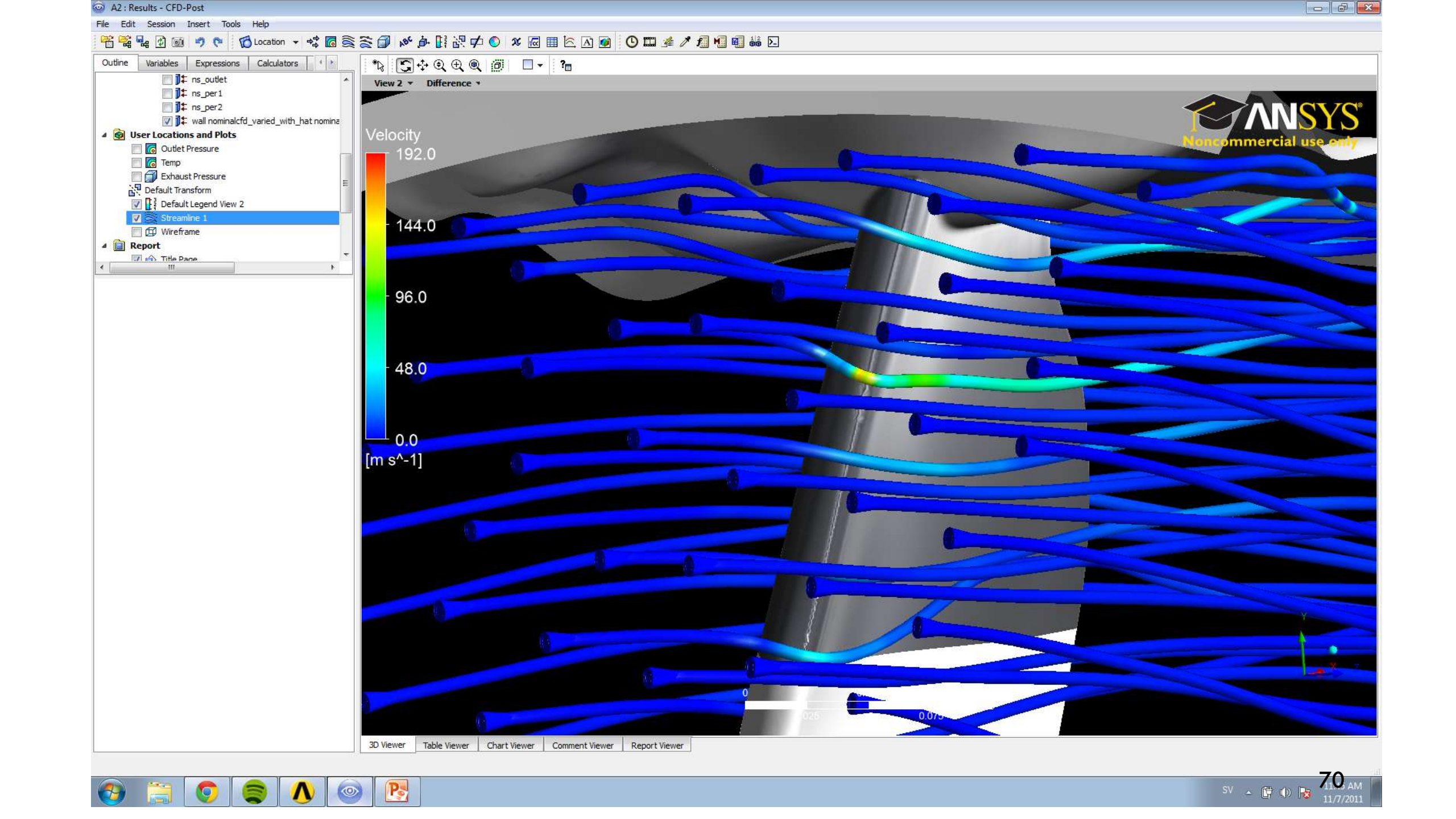
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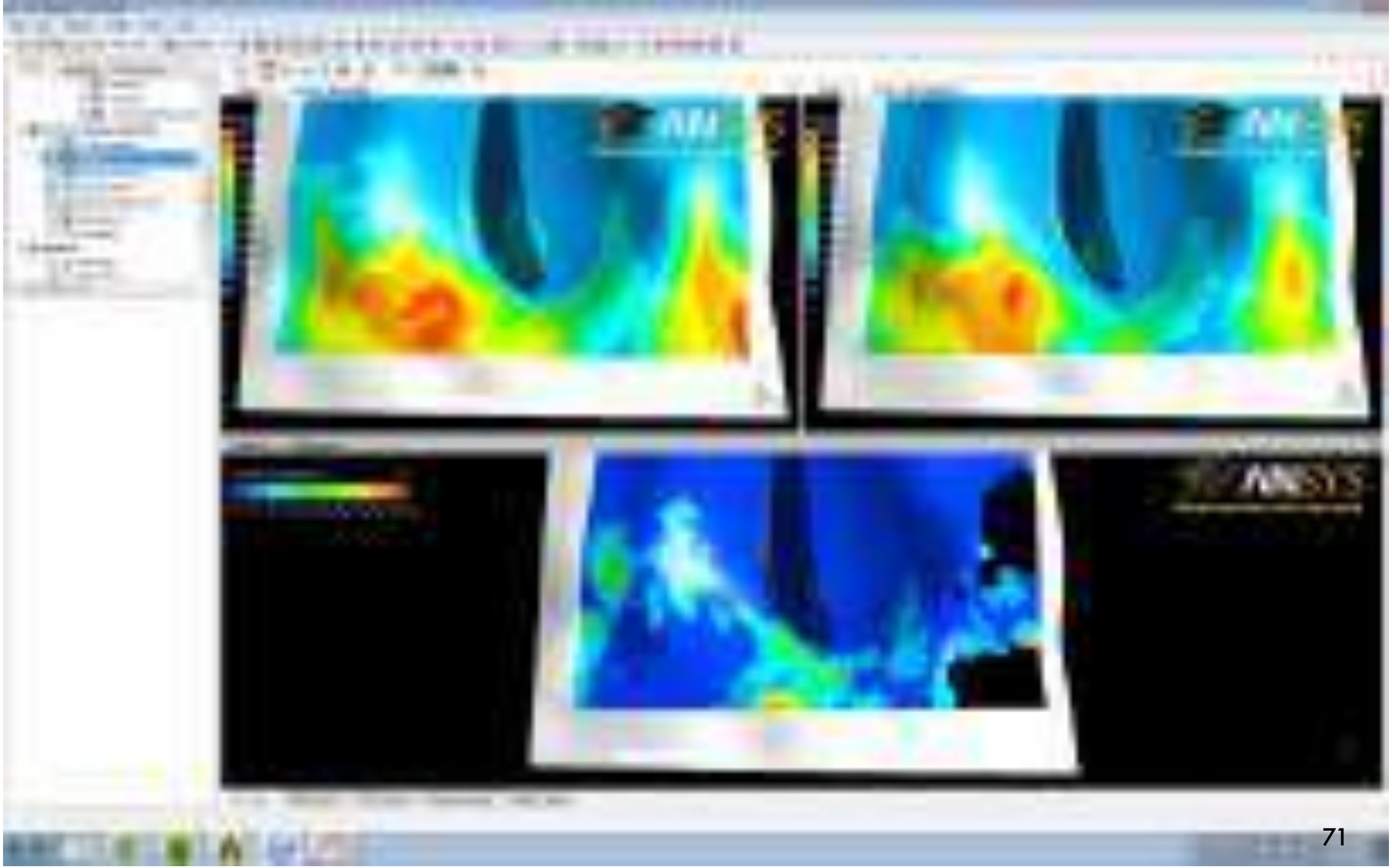
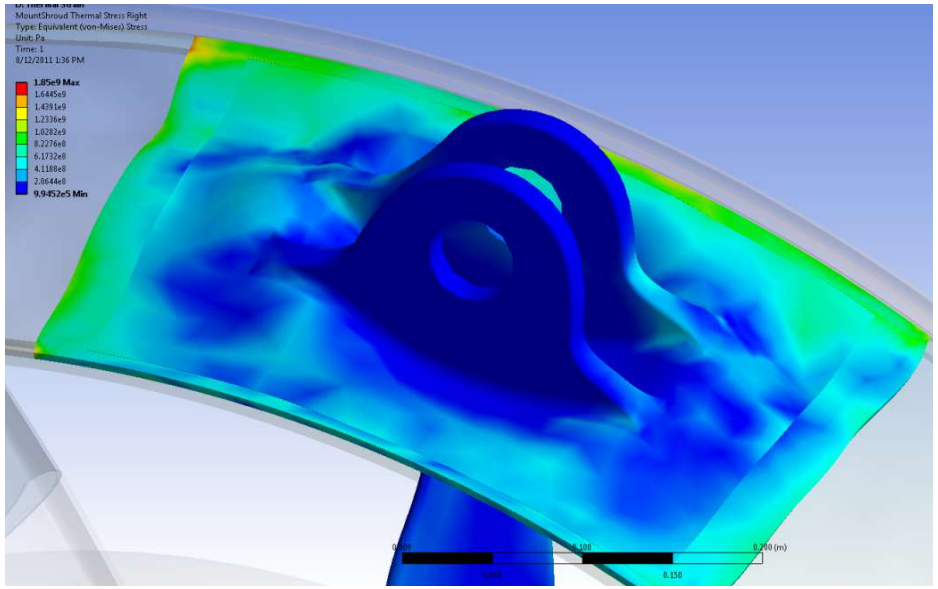
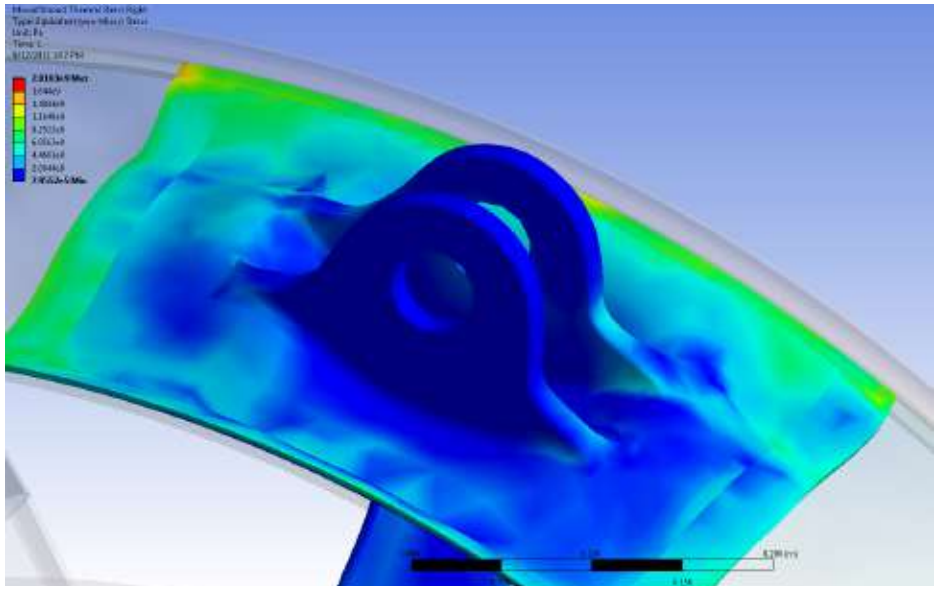


# *Thermal Stress*

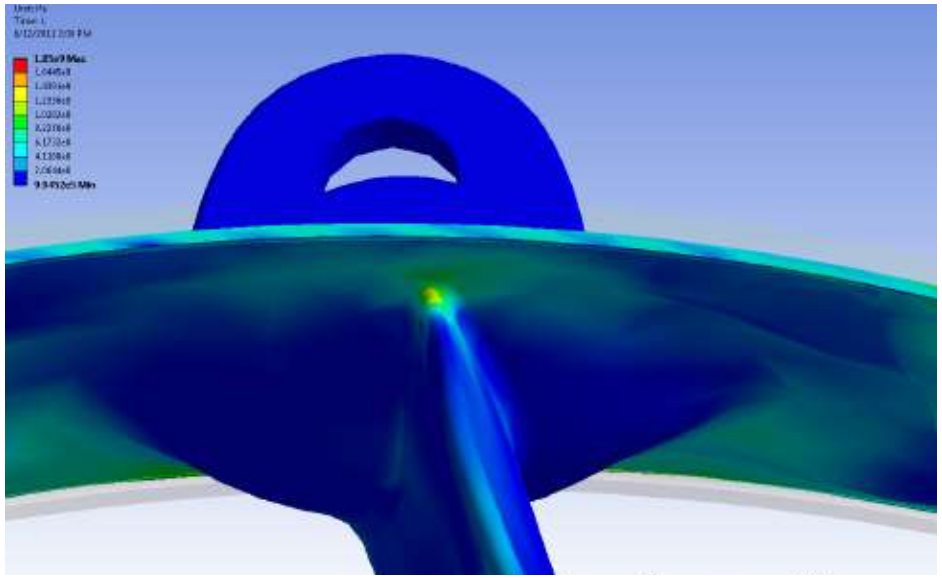
**Nominal** **Max**

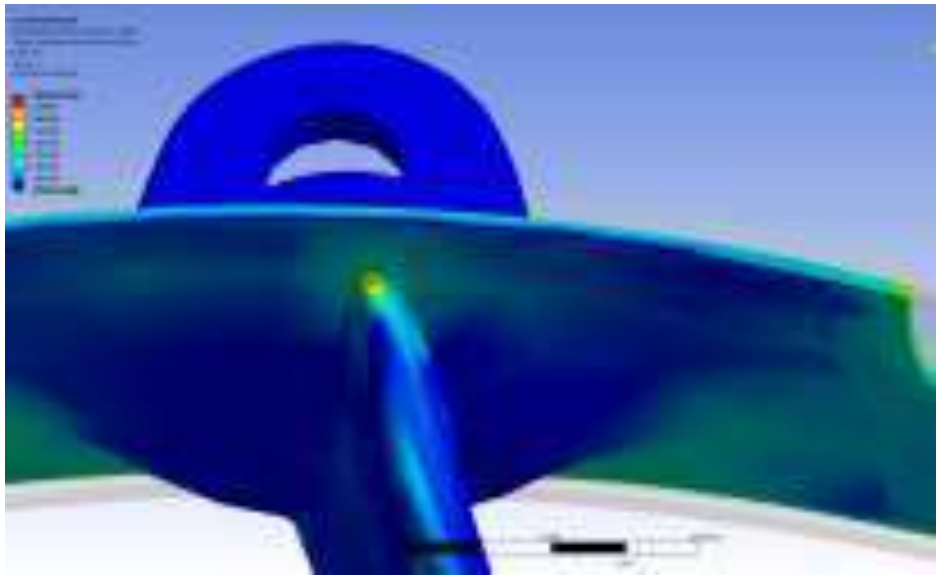
**Left**



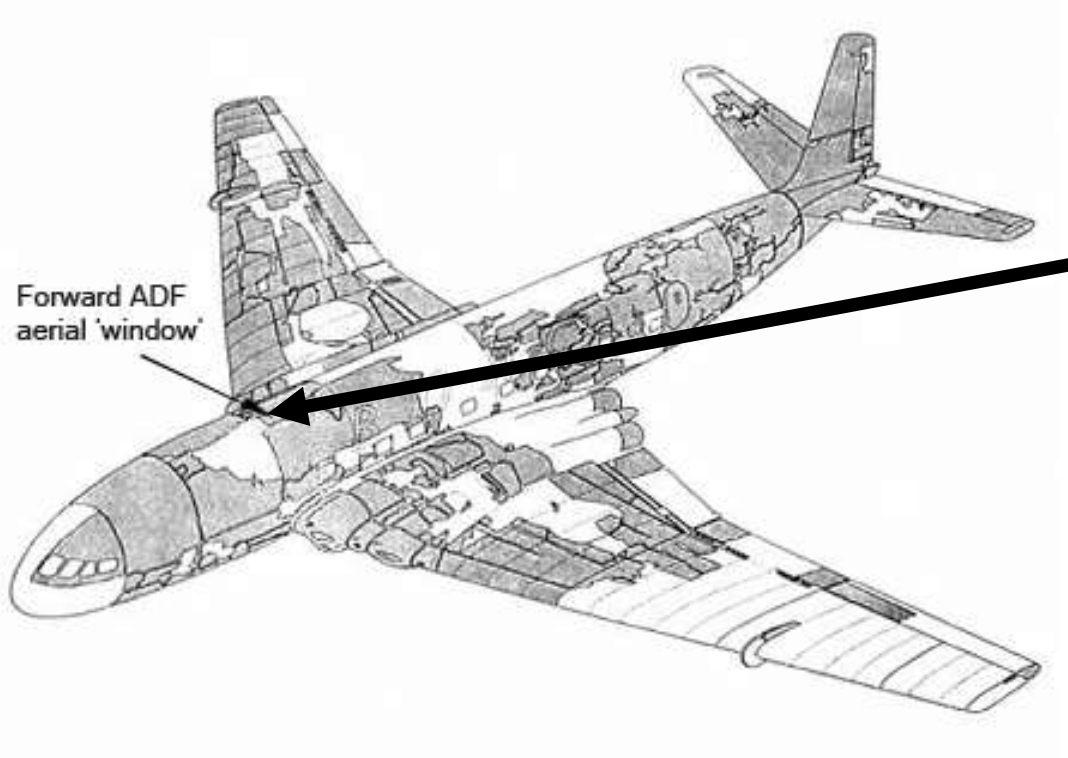



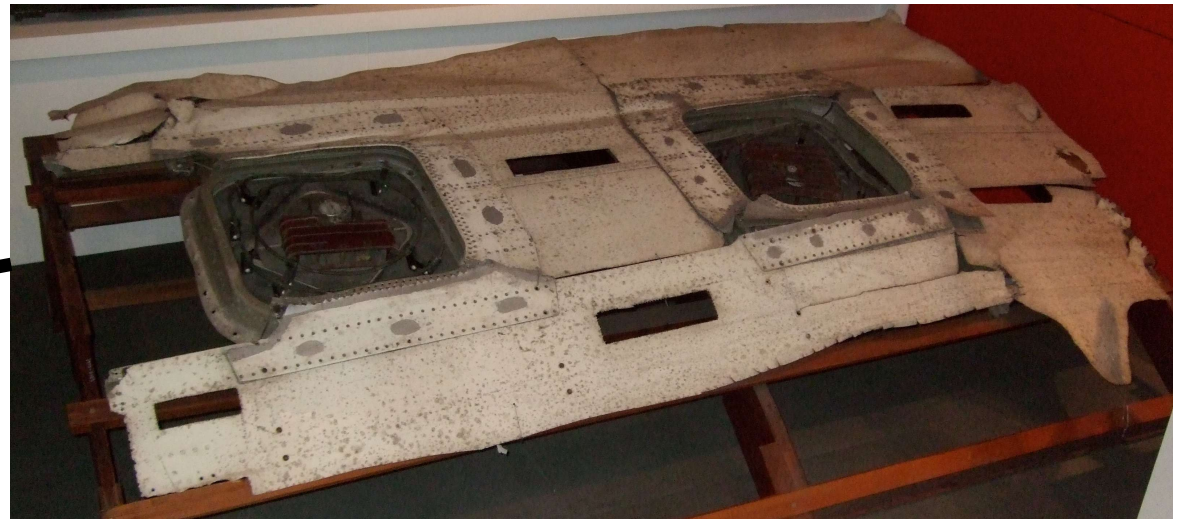
**Right**





# Material fatigue

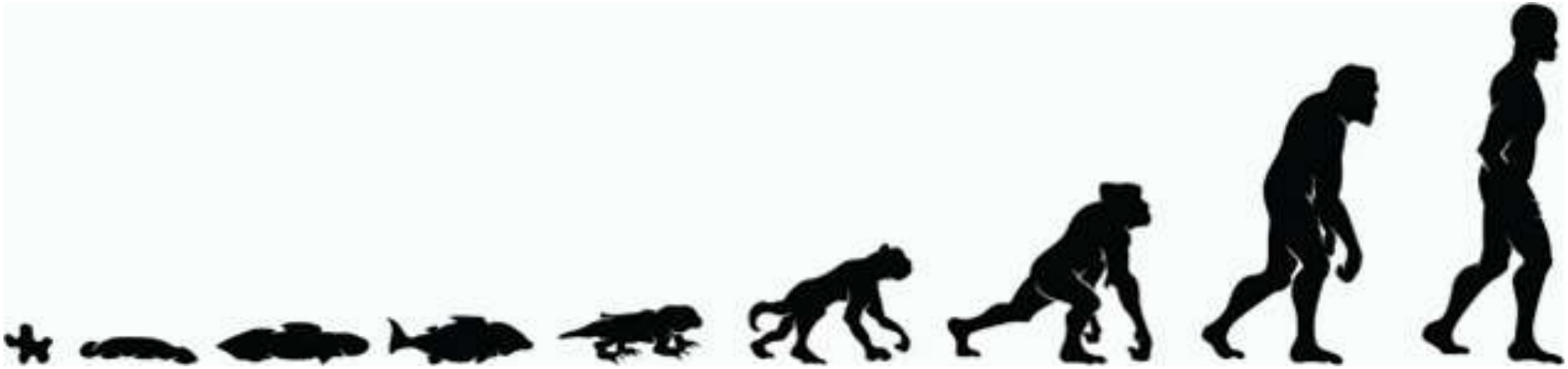


de Havilland Comet 1 crash, Jan 10th 1954

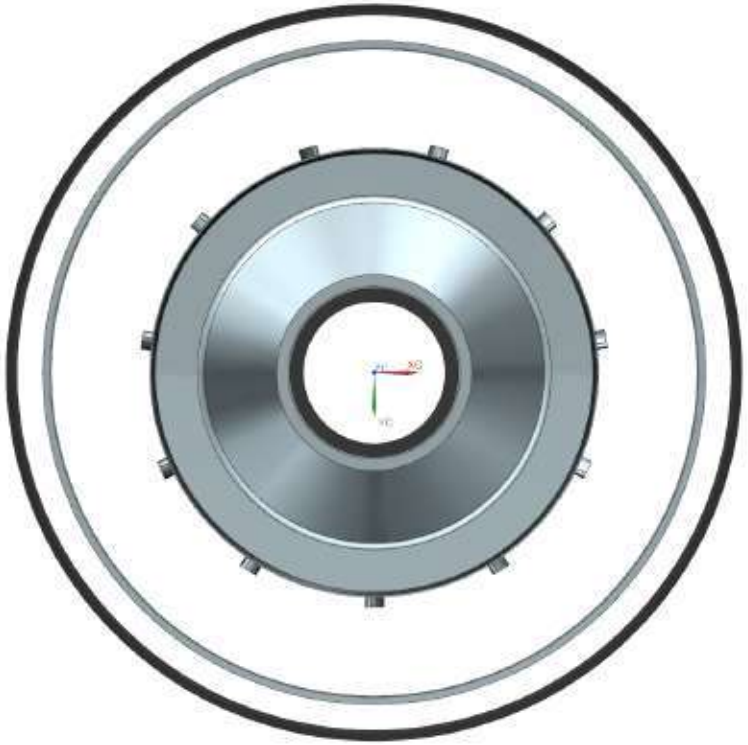
# Genetic algorithms (Papers D, E and G)

*Genetic algorithms* (GA) are search procedures that mimic the mechanics of natural selection and genetics (Goldberg 2013).



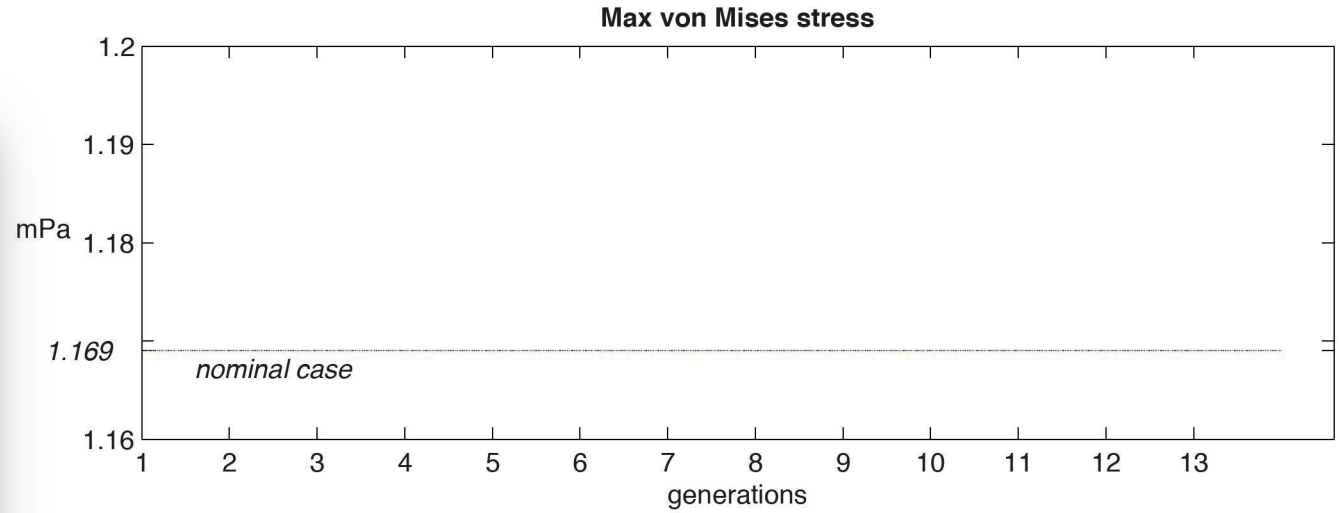
# A combinatory problem

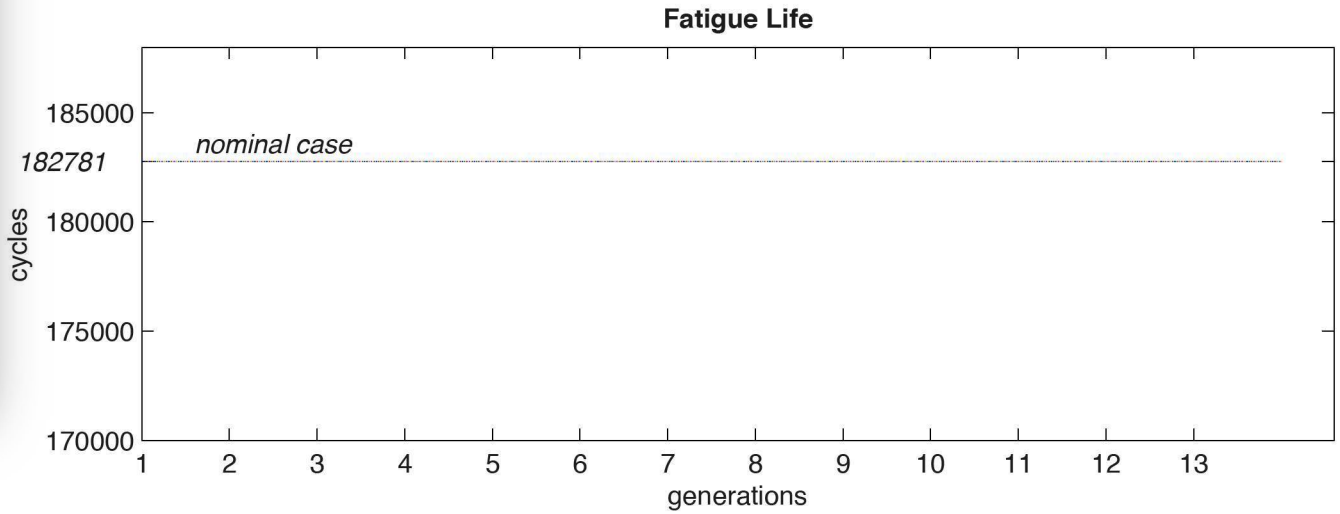
?



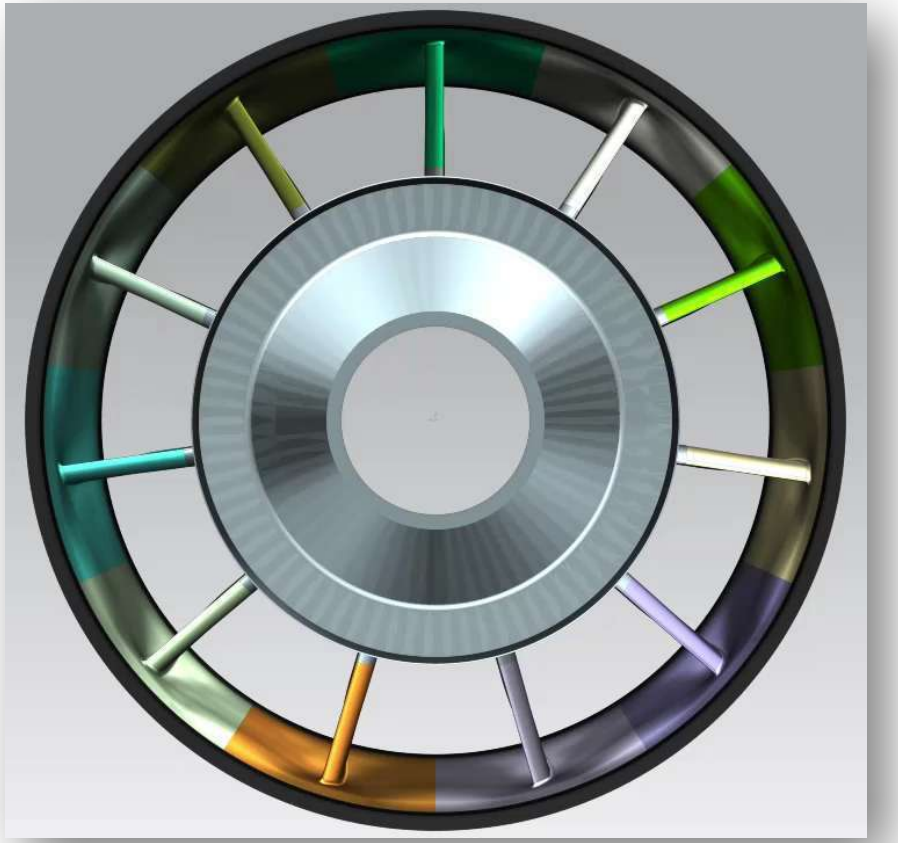
- 11 vanes
- 10! = *3,628,800* different combinations!
- 10 minutes per fatigue life simulation ≈ **70 years** of simulations

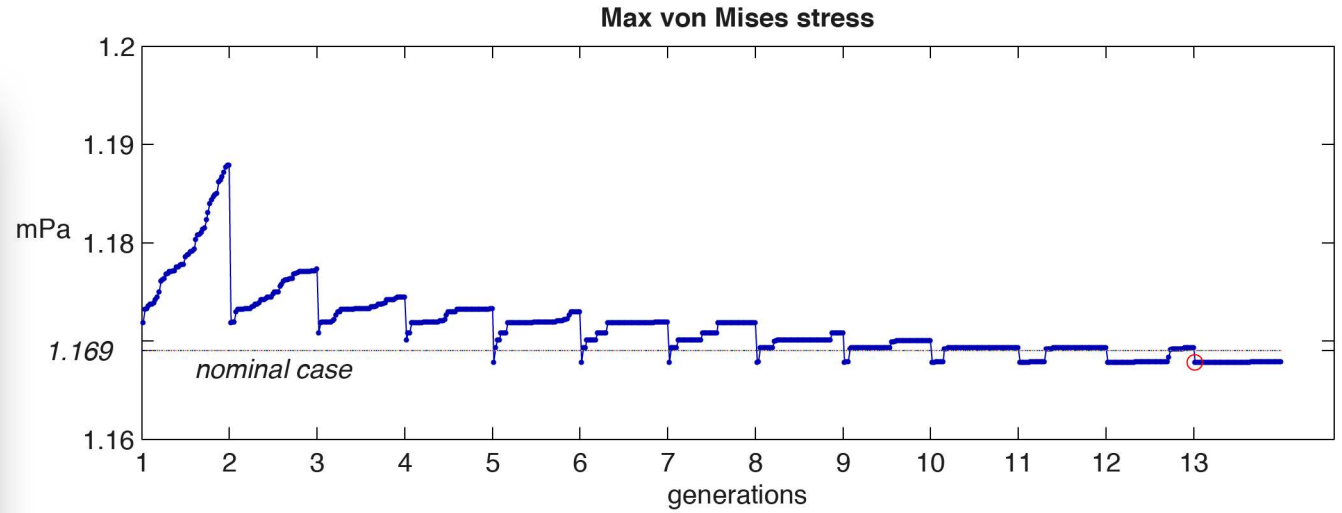
# Paper D


Max von Mises stress
1.2
1.19
1.18
mPa
1.169
nominal case
1.16
1
2
3
4
5
6
7
8
9
10
11
12
13
generations


Fatigue Life
185000
nominal case
182781
180000
cycles
175000
170000
1
2
3
4
5
6
7
8
9
10
11
12
13
generations

# Results




Max von Mises stress
1.2
1.19
1.18
mPa
1.169
nominal case
1.16
1
2
3
4
5
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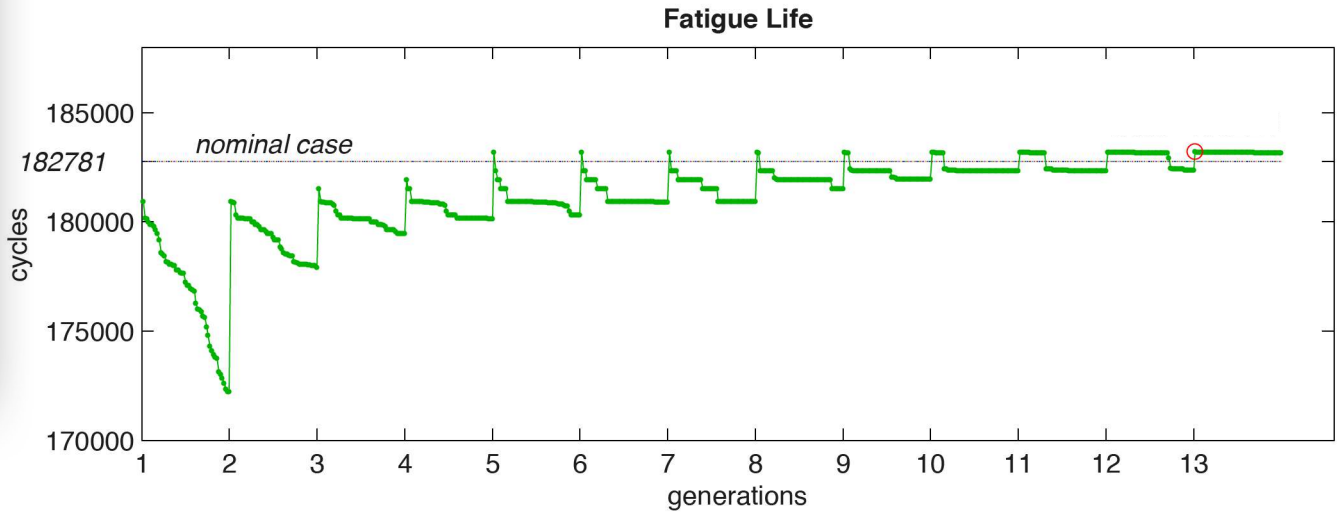
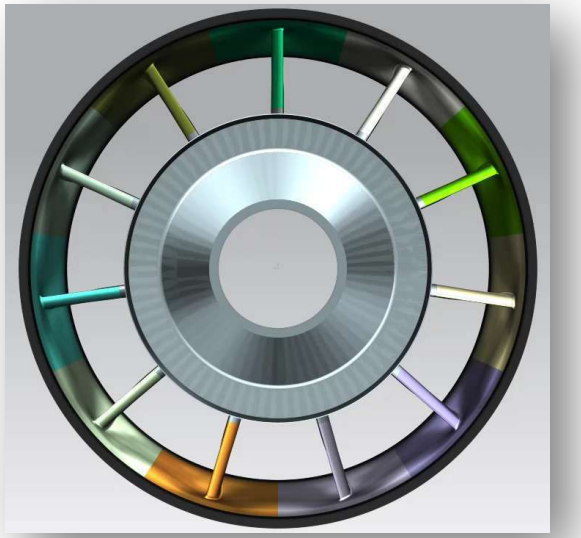
7
8
9
10
11
12
13
generations

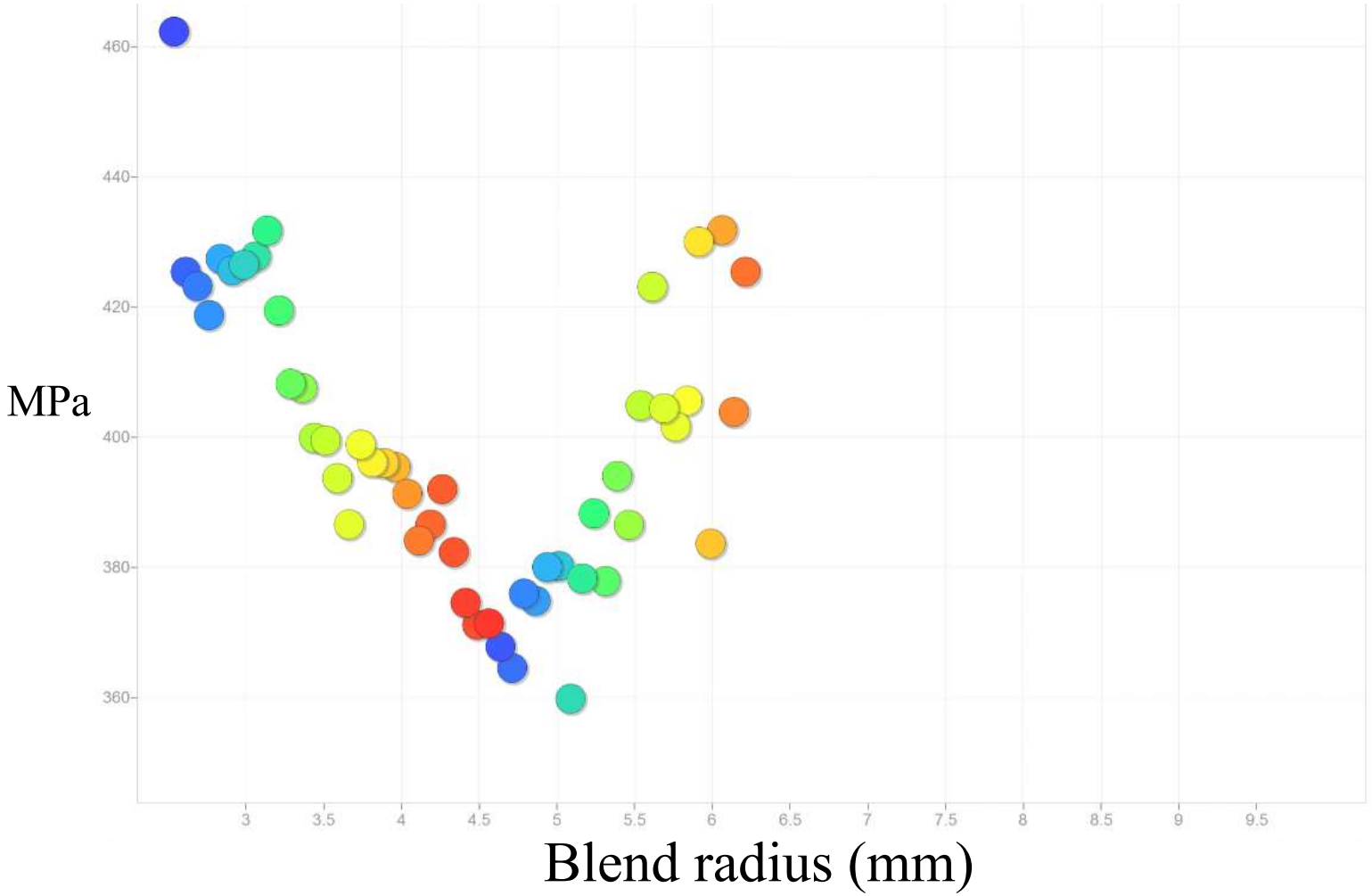

Fatigue Life
185000
nominal case
182781
180000
cycles
175000
170000
1
2
3
4
5
6
7
8
9
10
11
12
13
generations

# Paper E

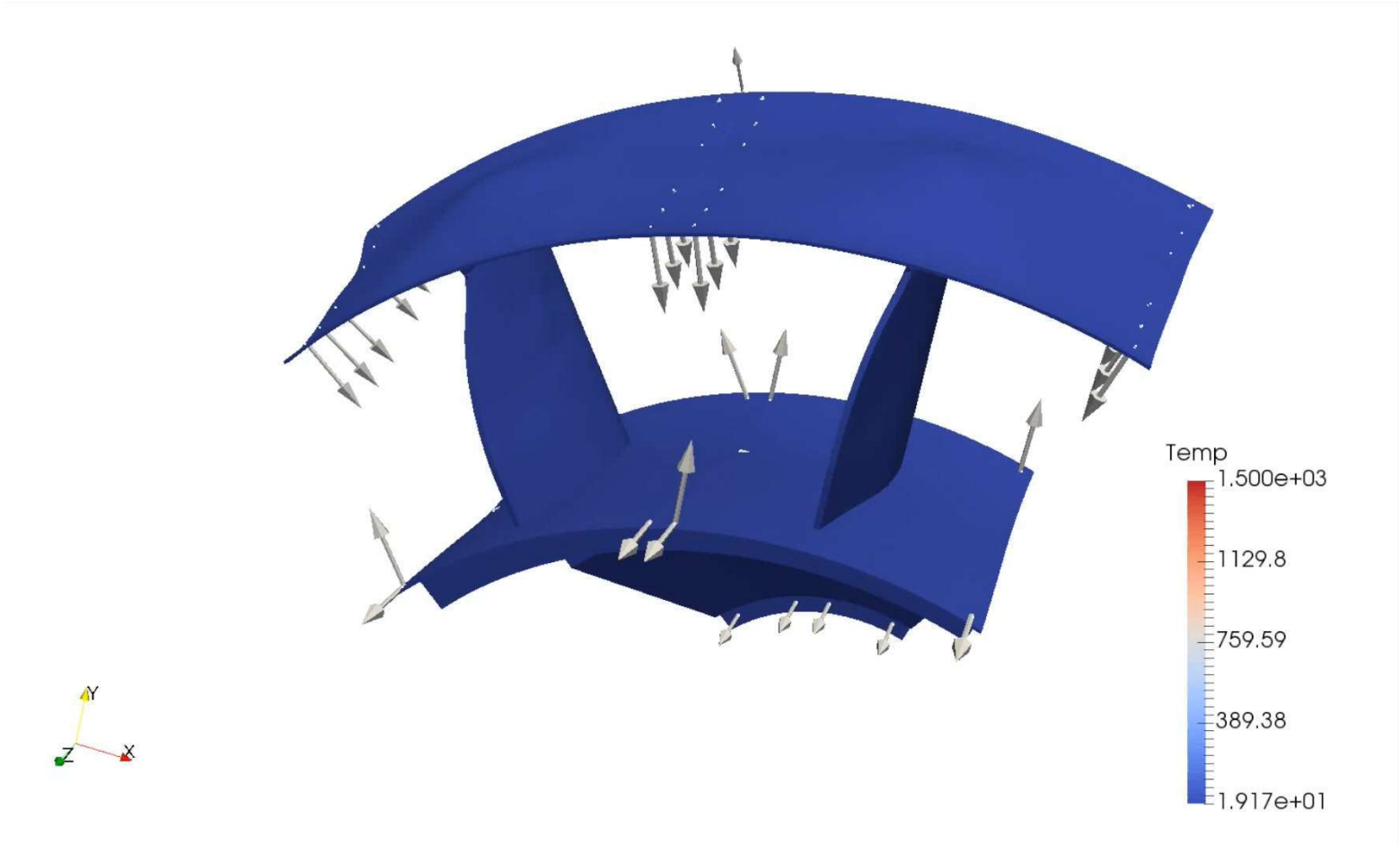
Let’s change a design parameter!



## Max von Mises stress



# Paper G

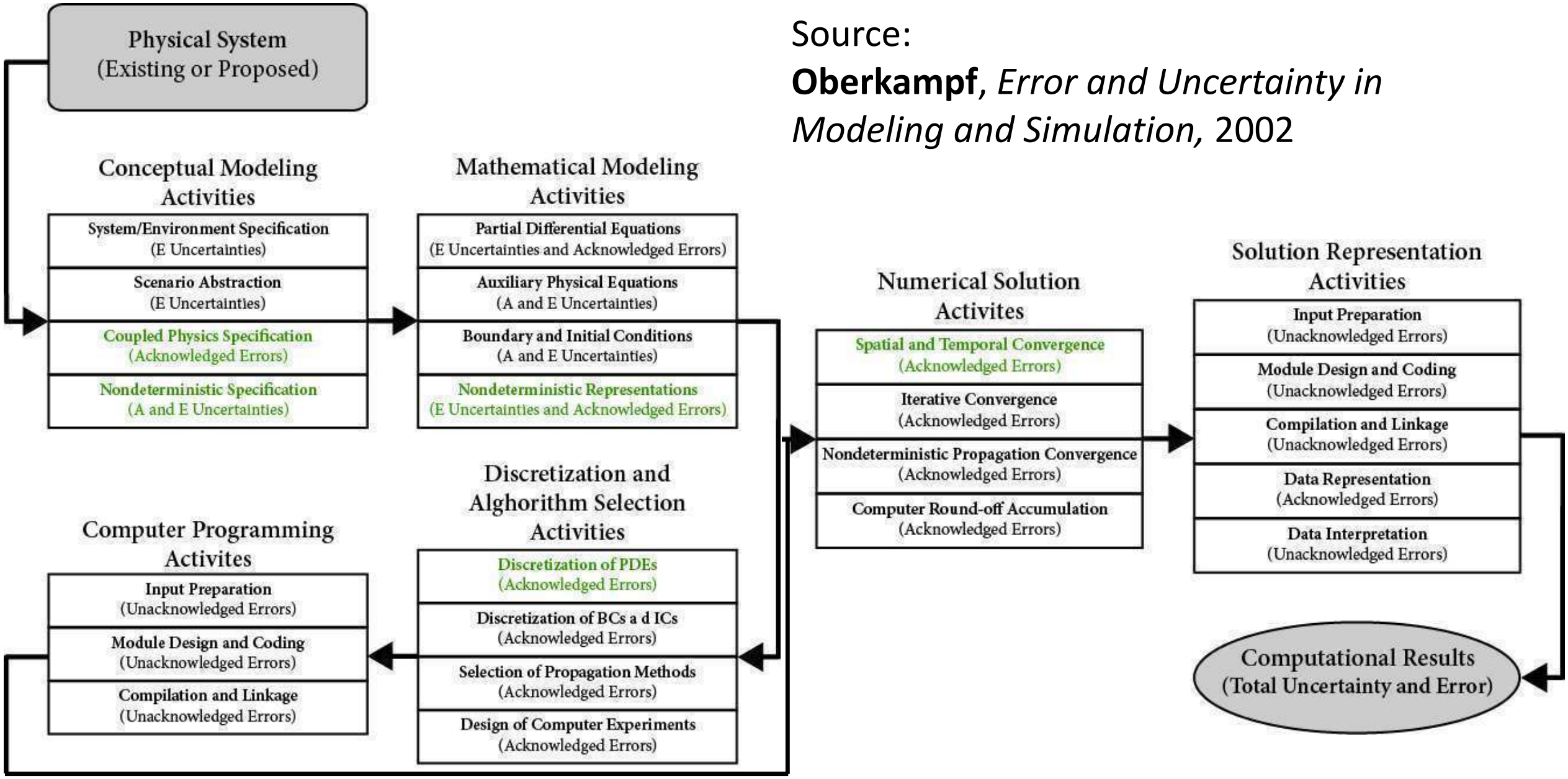


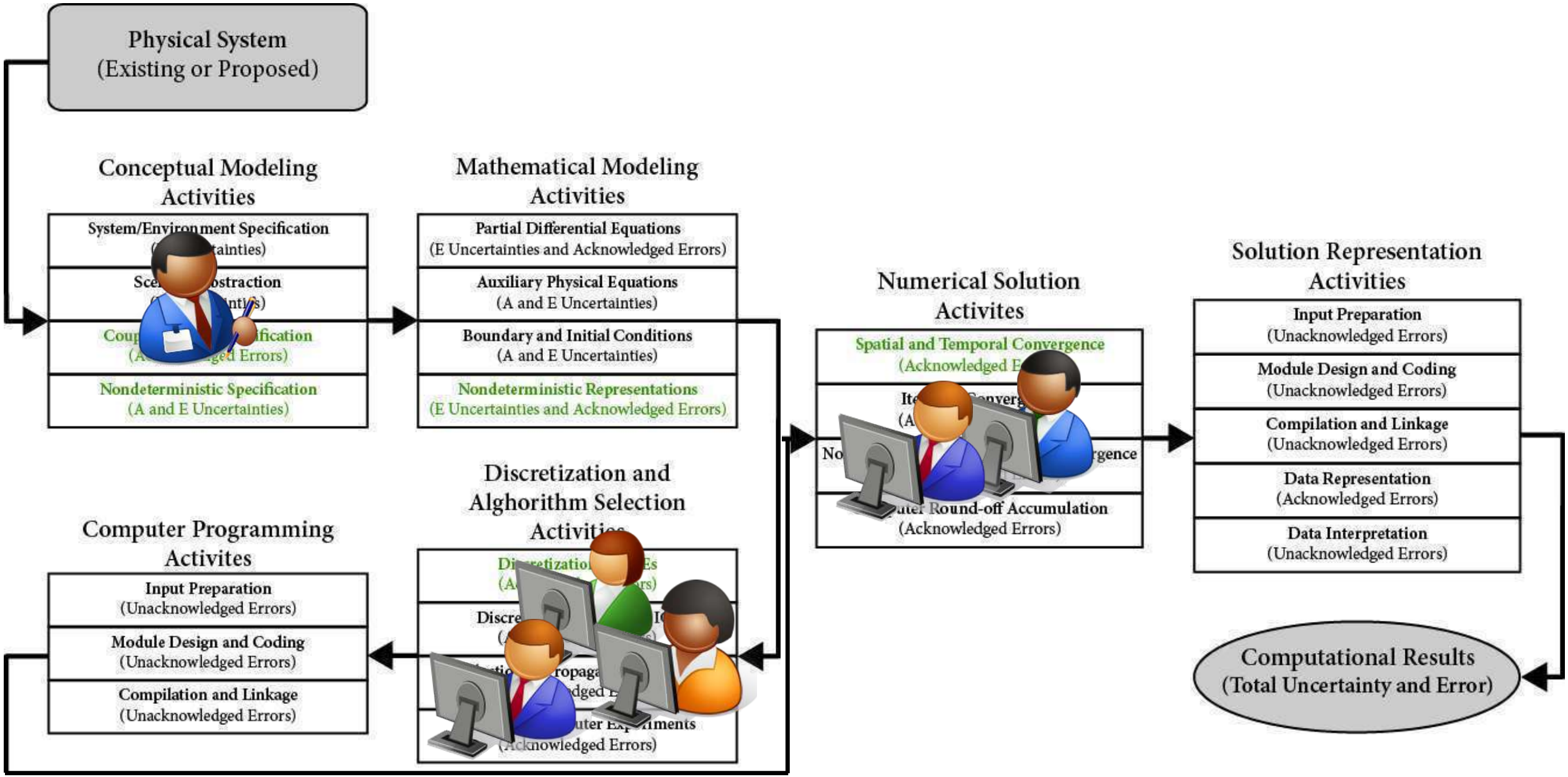
**Research Question III:**

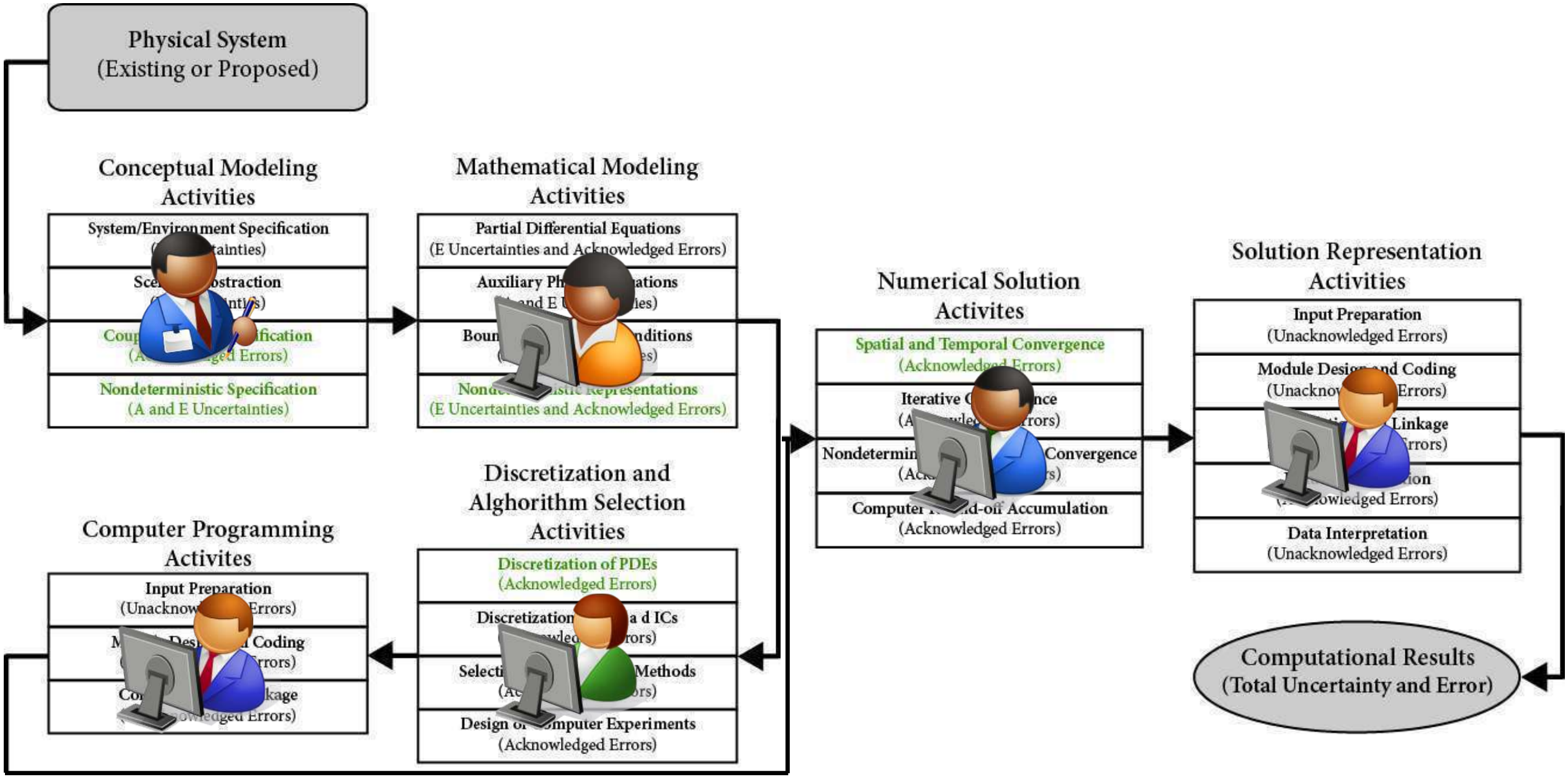
*What role should geometry assurance play in the early phases of aerospace component design?*

Source:

**Oberkampf**, *Error and Uncertainty in Modeling and Simulation*, 2002




Physical System
(Existing or Proposed)
Conceptual Modeling Activities
System/Environment Specification
Nondeterministic Specification
(A and E Uncertainties)
Mathematical Modeling Activities
Partial Differential Equations
(E Uncertainties and Acknowledged Errors)
Auxiliary Physical Equations
(A and E Uncertainties)
Boundary and Initial Conditions
(A and E Uncertainties)
Nondeterministic Representations
(E Uncertainties and Acknowledged Errors)
Numerical Solution Activites
Spatial and Temporal Convergence
(Acknowledged E
(Acknowledged Errors)
Solution Representation Activities
Input Preparation
(Unacknowledged Errors)
Module Design and Coding
(Unacknowledged Errors)
Compilation and Linkage
(Unacknowledged Errors)
Data Representation
(Acknowledged Errors)
Data Interpretation
(Unacknowledged Errors)
Computational Results
(Total Uncertainty and Error)
Discretization and Alghorithm Selection Activities
(Acknowledged Errors)
Computer Programming Activites
Input Preparation
(Unacknowledged Errors)
Module Design and Coding
(Unacknowledged Errors)
Compilation and Linkage
(Unacknowledged Errors)


Physical System
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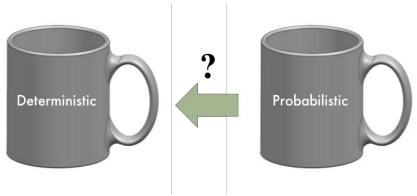
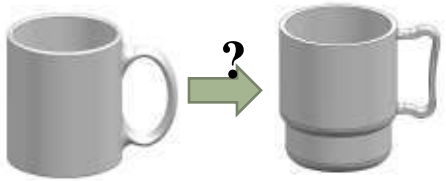
Discretization of PDEs
(Acknowledged Errors)
Computer Programming Activites
Input Preparation
Numerical Solution Activites
Spatial and Temporal Convergence
(Acknowledged Errors)
Solution Representation Activities
Input Preparation
(Unacknowledged Errors)
Data Interpretation
(Unacknowledged Errors)
Computational Results
(Total Uncertainty and Error)

# Conclusions

# Conclusions –Research Questions I & II




*Identified barriers*

Model form error

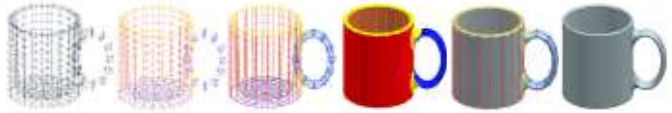
Discretisation error

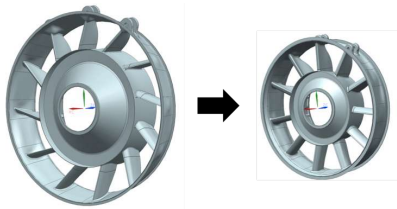
Backwards incompatibility

Forward applicability

*Proposed solutions*

Parametric point method (PPM)

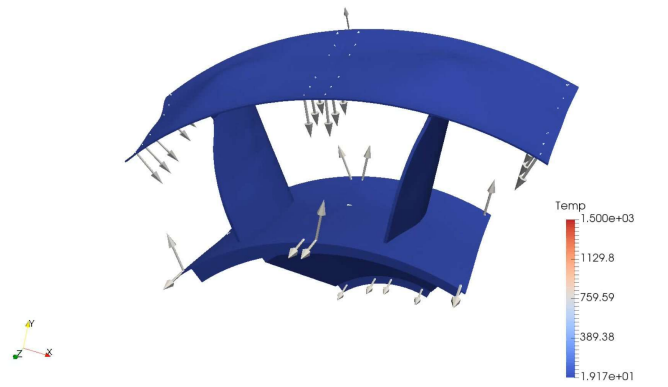


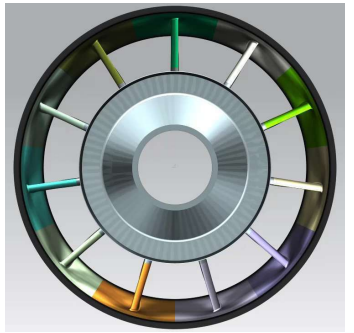


COTS Software independence and redundancy

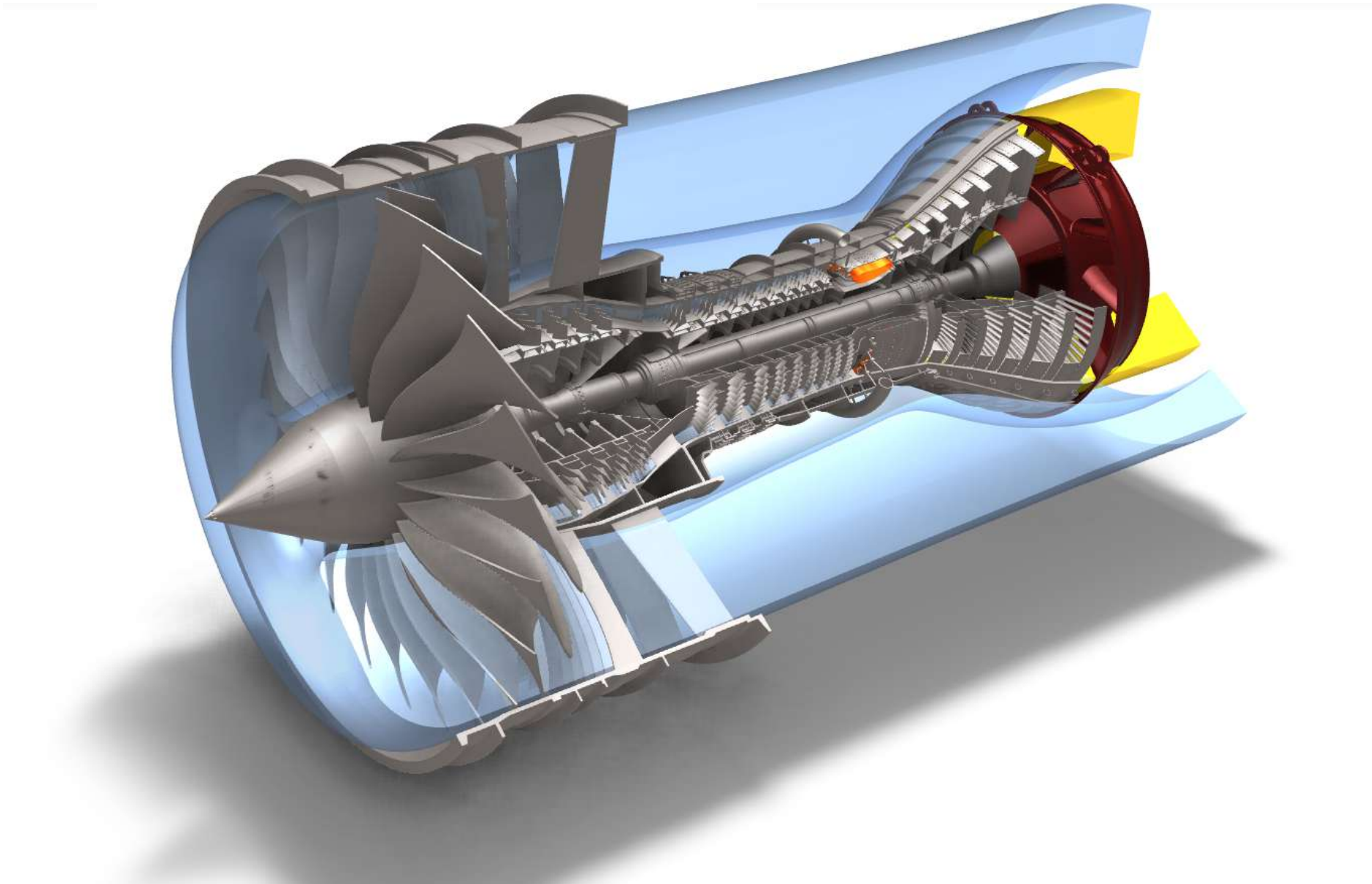
# Conclusions – Research Question III

- Geometric variation has the most major impact within thermal fatigue analysis.
- The case studies showed that simulation results were heavily affected by geometric variation in parts and assemblies.
- Welding exacerbates the effects of geometric variation.
- Genetic algorithms can be used to mitigate these effects.



# Future work

- We should improve the quality and technological maturity of the multidisciplinary simulation environment, including its breadth as well its depth.
- To make this research more comprehensive, more researchers should be invited to contribute within their respective fields of expertise.
- The weakest links of the simulation chain are currently those activities that stray from the established and validated industrial design practices. Currently, these tools and methods lie within TRL 3-6. They need to be further matured.

# Thank you!