
## On the determination of an:

# Efficient Geometrical Description of Perturbations to Designed Shape

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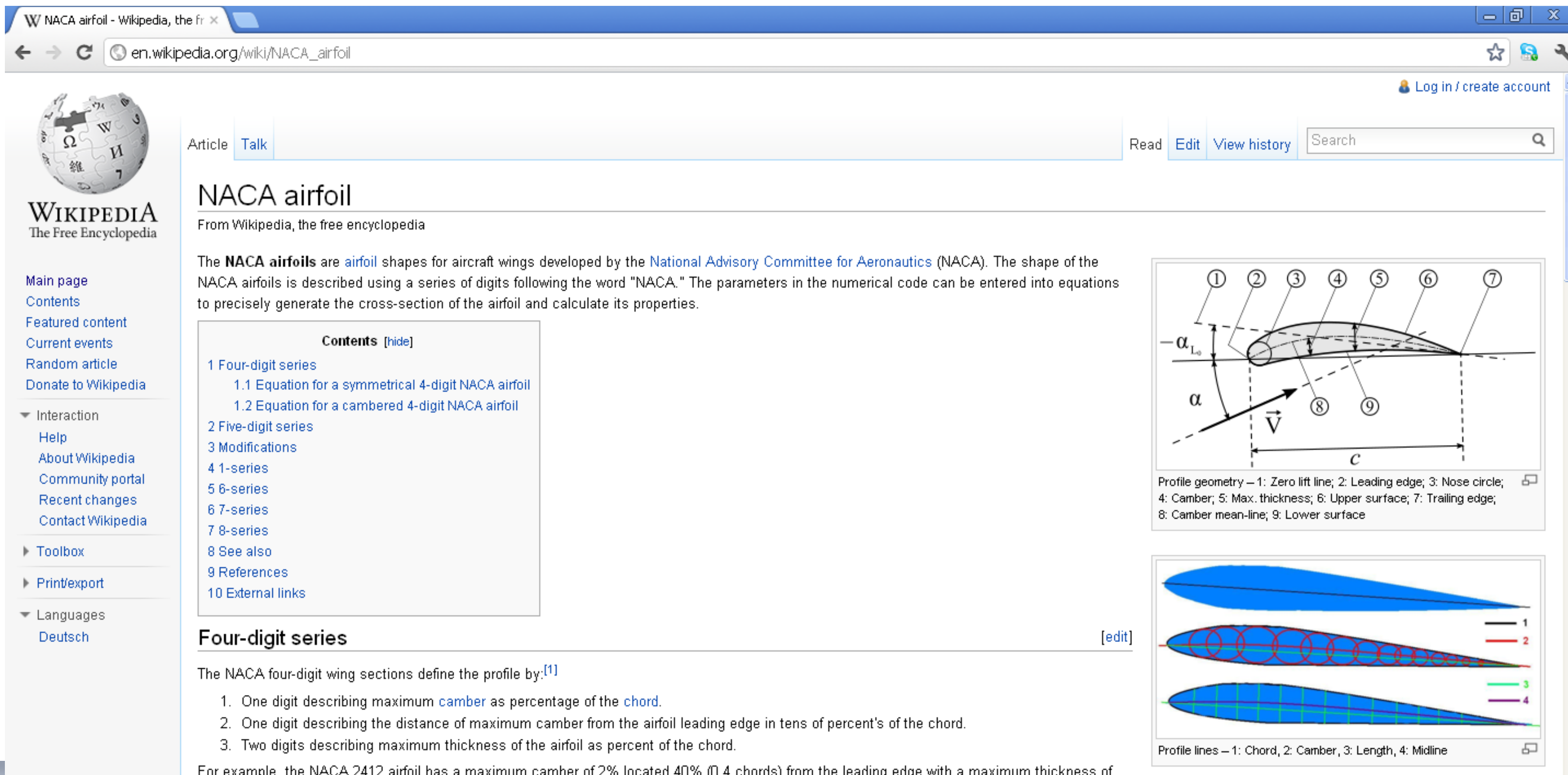
# Outline

- Introduction
- Requirements
- Definitions
- Examples
- Additional Considerations
- Discussion and Questions

# Introduction

- Components and structures are defined at the concept and design stages using Computer Aided Design (CAD), NACA aerofoil definitions or purely analytical descriptions - polynomials, splines, etc.



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## NACA airfoil

From Wikipedia, the free encyclopedia

The **NACA airfoils** are airfoil shapes for aircraft wings developed by the National Advisory Committee for Aeronautics (NACA). The shape of the NACA airfoils is described using a series of digits following the word "NACA." The parameters in the numerical code can be entered into equations to precisely generate the cross-section of the airfoil and calculate its properties.

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Profile geometry – 1: Zero lift line; 2: Leading edge; 3: Nose circle; 4: Camber; 5: Max. thickness; 6: Upper surface; 7: Trailing edge; 8: Camber mean-line; 9: Lower surface

Profile lines – 1: Chord, 2: Camber, 3: Length, 4: Midline

### Four-digit series [edit]

The NACA four-digit wing sections define the profile by:[1]

1. One digit describing maximum camber as percentage of the chord.
2. One digit describing the distance of maximum camber from the airfoil leading edge in tens of percent's of the chord.
3. Two digits describing maximum thickness of the airfoil as percent of the chord.

For example, the NACA 2412 airfoil has a maximum camber of 2% located 40% (0.4 chords) from the leading edge with a maximum thickness of

# Introduction

- Used for aerodynamic or structural analysis using computational (numerical)/analytical methods and for physical testing
- Verification and validation is only possible by measurement
- Measurement data is always a set of discrete points commonly described as a point cloud of data of x-, y- and z-coordinates
- Very high accuracy and precision required to identify unwanted deviations from the intended design shape
- Objective is to characterise and parameterise these features

# BRIEF:

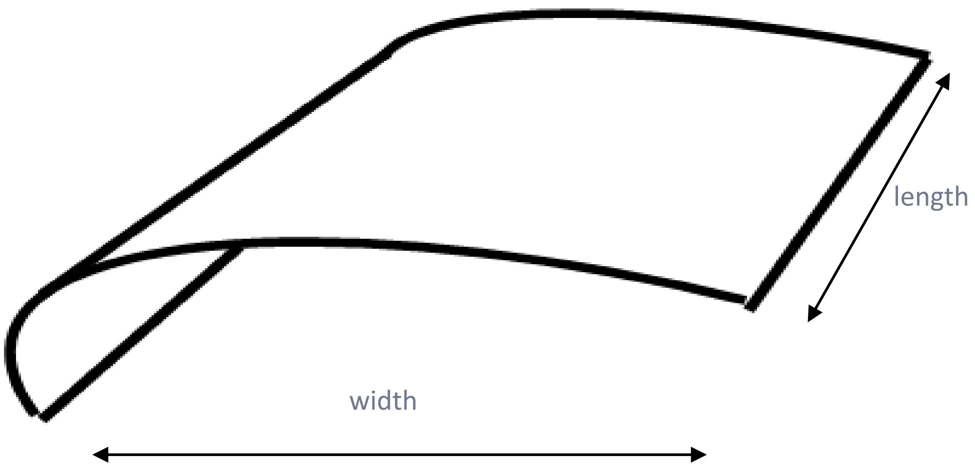
- Develop a suitable description of the geometry from the mathematical definition of shape
- Distinguish between the overall design shape and specific types of perturbations to the nominal shape
- Focus on characterising local deviations from design shape (described in detail in the following slides)
- Method should facilitate a simple comparison between the defined shape and the real surface of a manufactured article
- Characterisation should ideally yield physically meaningful parameters to allow parameter values to be related to actual recognisable features

# Requirements

- Quantitative characterisation of small cyclic or discrete perturbations to a surface
- Characterisation should be possible with a small number of parameters (< 50) describing surface geometry with high fidelity
- Capable of being able to characterise a few specific types of geometric perturbations which are deviations from the design specification
- All types of geometric definition (CAD, analytic, or discrete measured data) will be amenable to analysis by the method developed
- The approach must allow for a parametric description of out-of-surface perturbations from the nominal surface (design) quantified in terms of their magnitude (out of the surface) and their extent (in the plane)

# Requirements

- Perturbations are small by comparison to the surface area being evaluated
- A typical section of wing that will need to be analysed is shown below
- Dimensions can vary from a small section approximately 0.8m wide by 1.5m long to 10m long and 2m wide
- Data density will be of the order of 100,000 points per $m^2$.



# Definitions

- There are three classes of perturbations; waviness, steps and discrete elements
    1. Waves on the surface. Wavelength and amplitude within very tightly defined bounds. Occurs in two main (orthogonal) directions which may or may not be aligned to the airflow. Airflow direction in relation to the direction of the waviness is a critical parameter. Waves can exist as singles or multiples.
    2. Steps. Oriented at any angle to the airflow are considered a step. Step height is very small in relation to the spatial extent of the surface. The edge of the step could be a straight line or a curve. The normal to this line can be in any orientation in relation to the airflow. The extent of the step is very large in relation to its height.
    3. Discrete 3D perturbations. Characteristically circular or elliptical (in plan view), protruding normal to the plane of the surface. The boundary of an isolated perturbation is a step.



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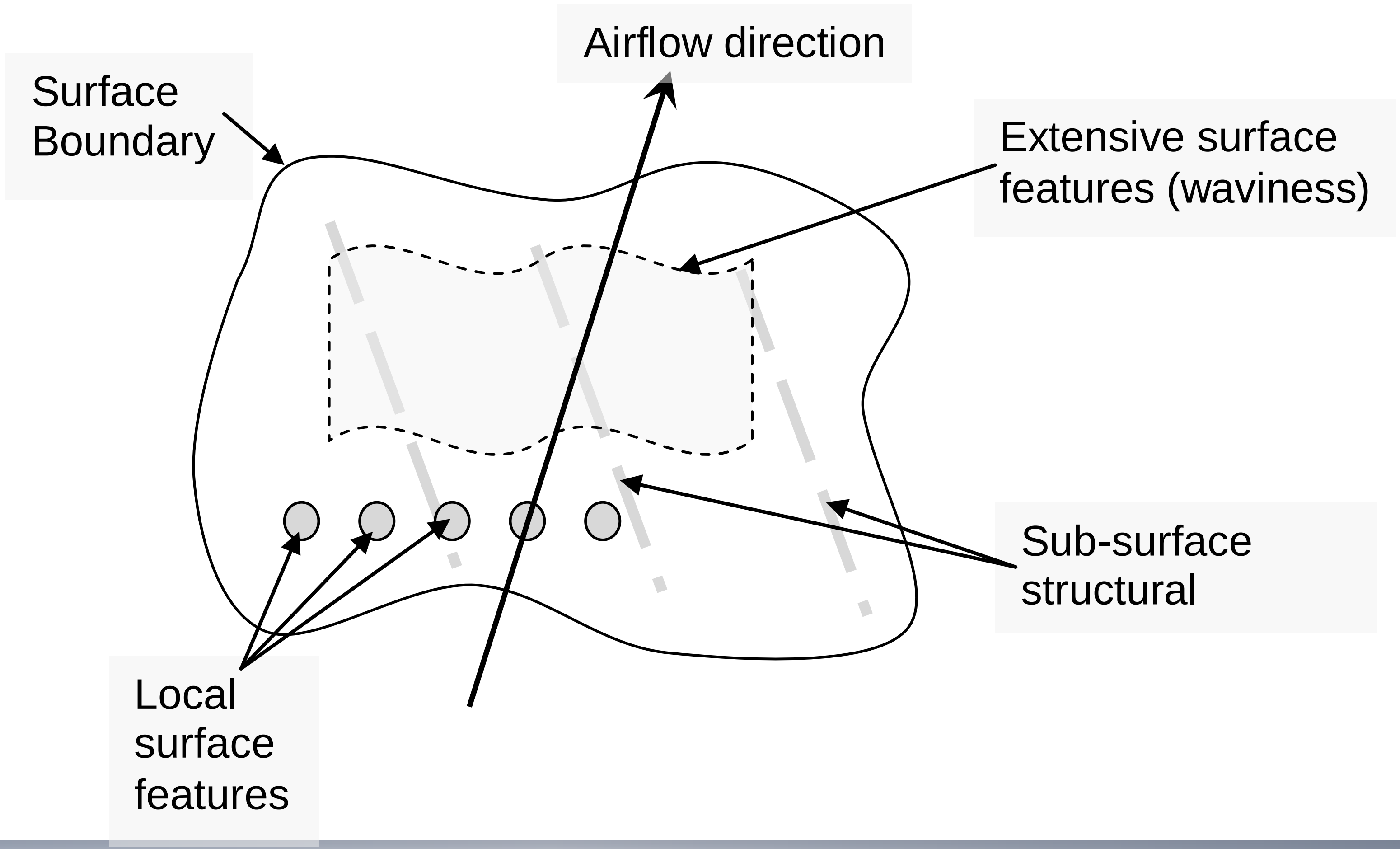
# Definitions

- Schematic diagram of surface and perturbations



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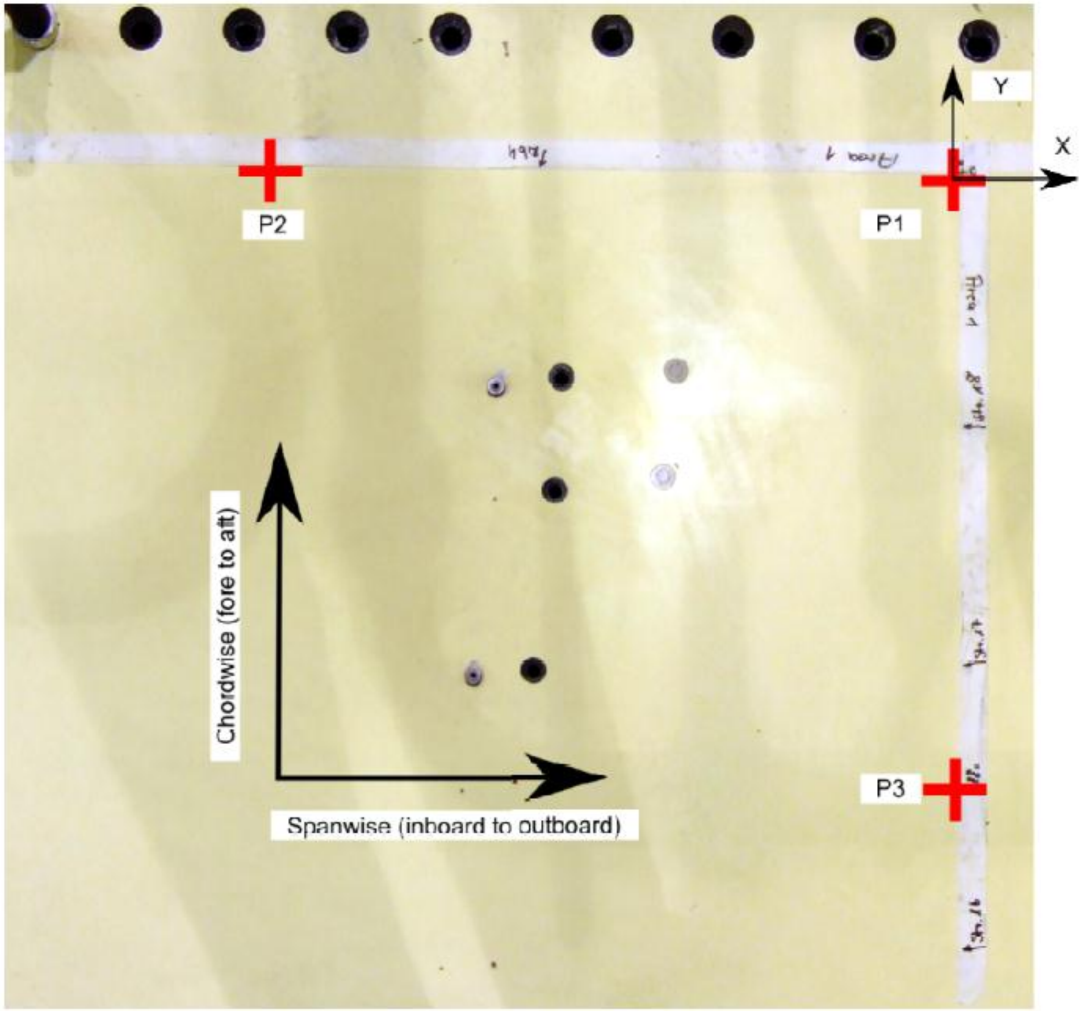
# Example – Demo wing top cover trailing edge

- Underlying features:
  - Stringers
  - Ribs



# Example – Top cover trailing edge

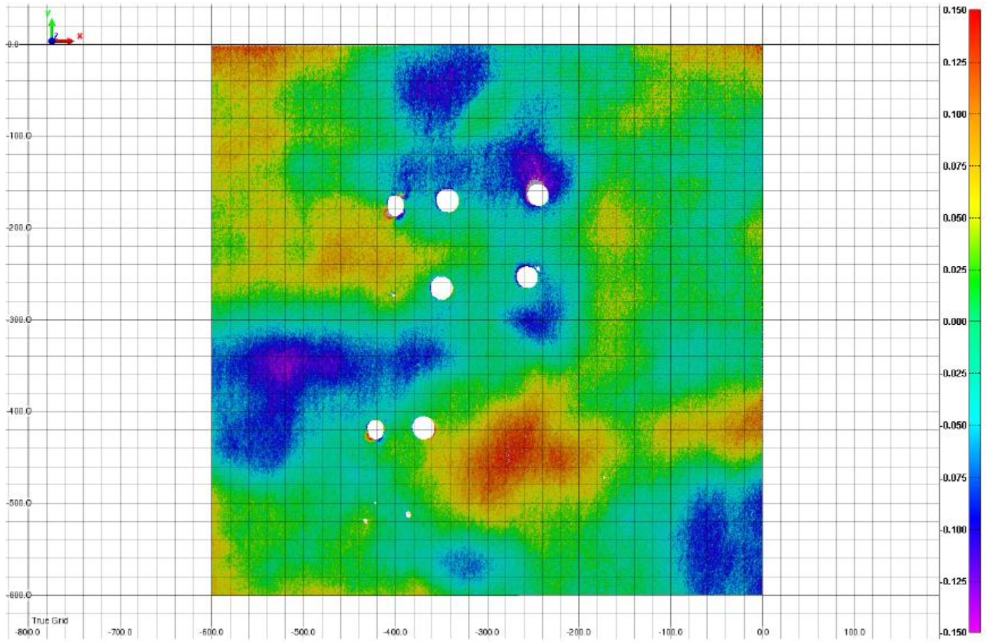
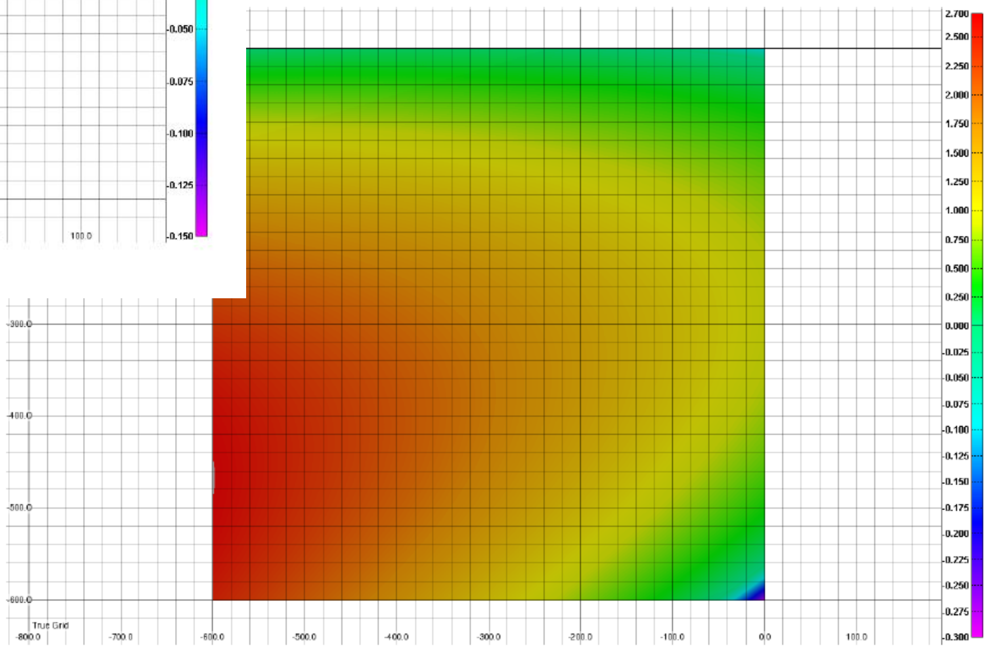


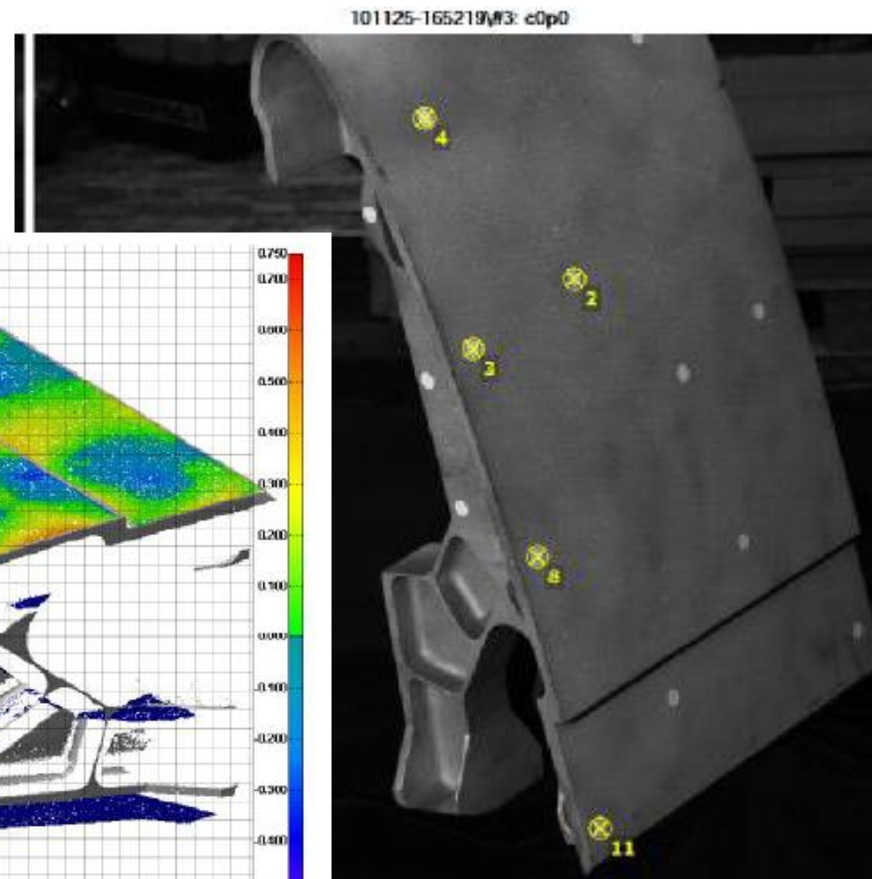
Figure A-4:

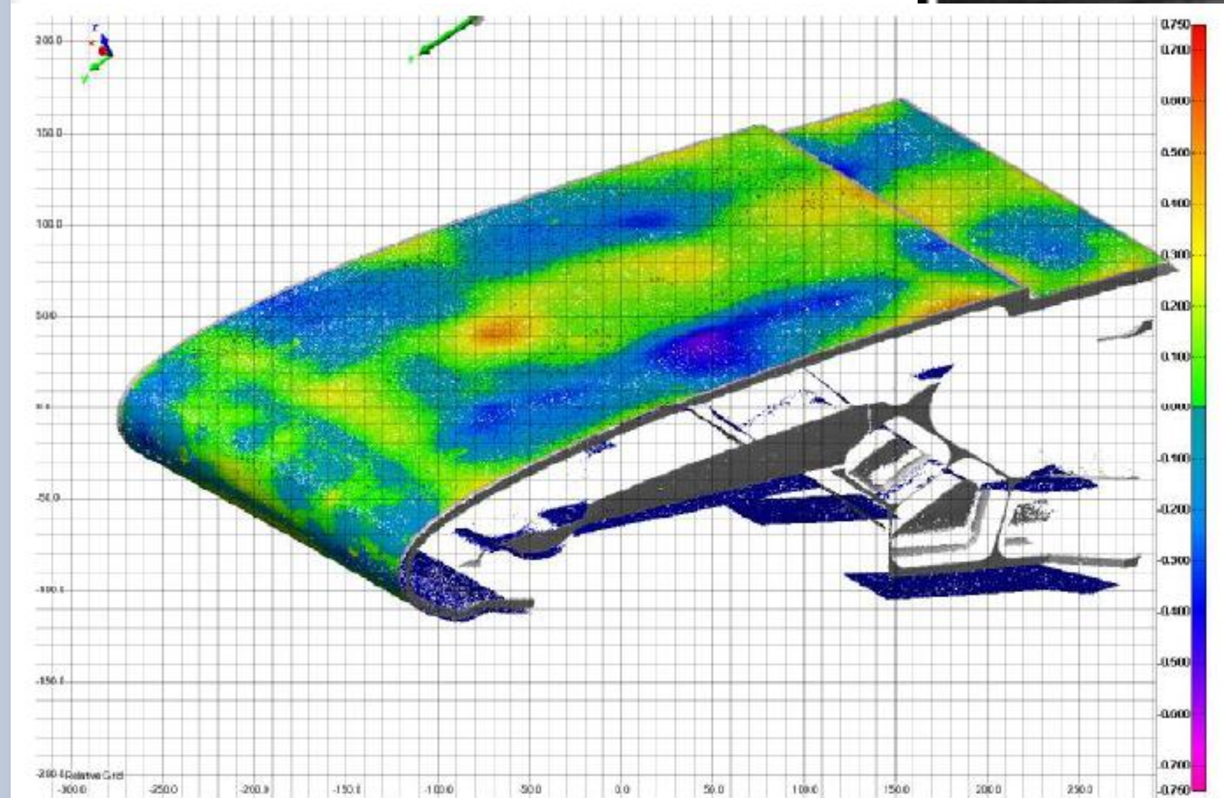
- Deviation from polynomial surface (top left)
- Best fit surface, 2nd order polynomial – not design



# Example – Experimental leading edge

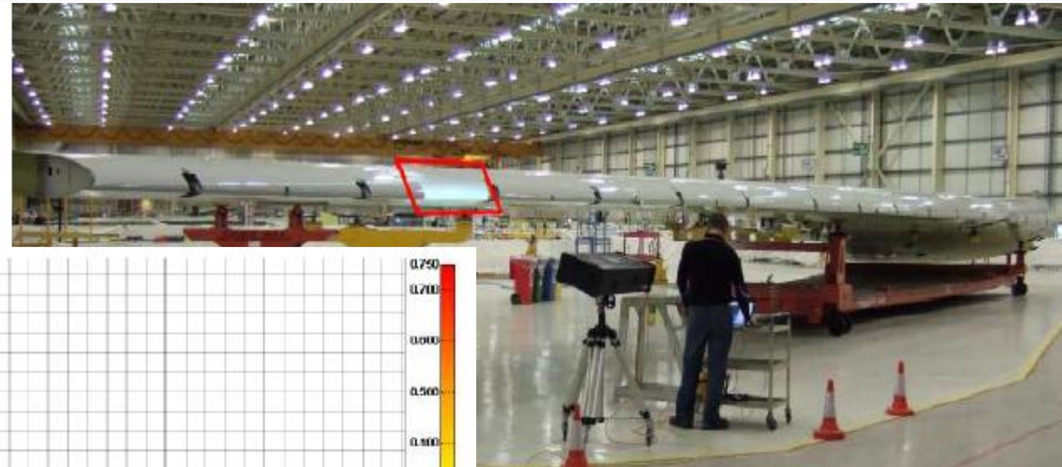
- Deviation from $2^{nd}$ order polynomial surface  (bottom left)

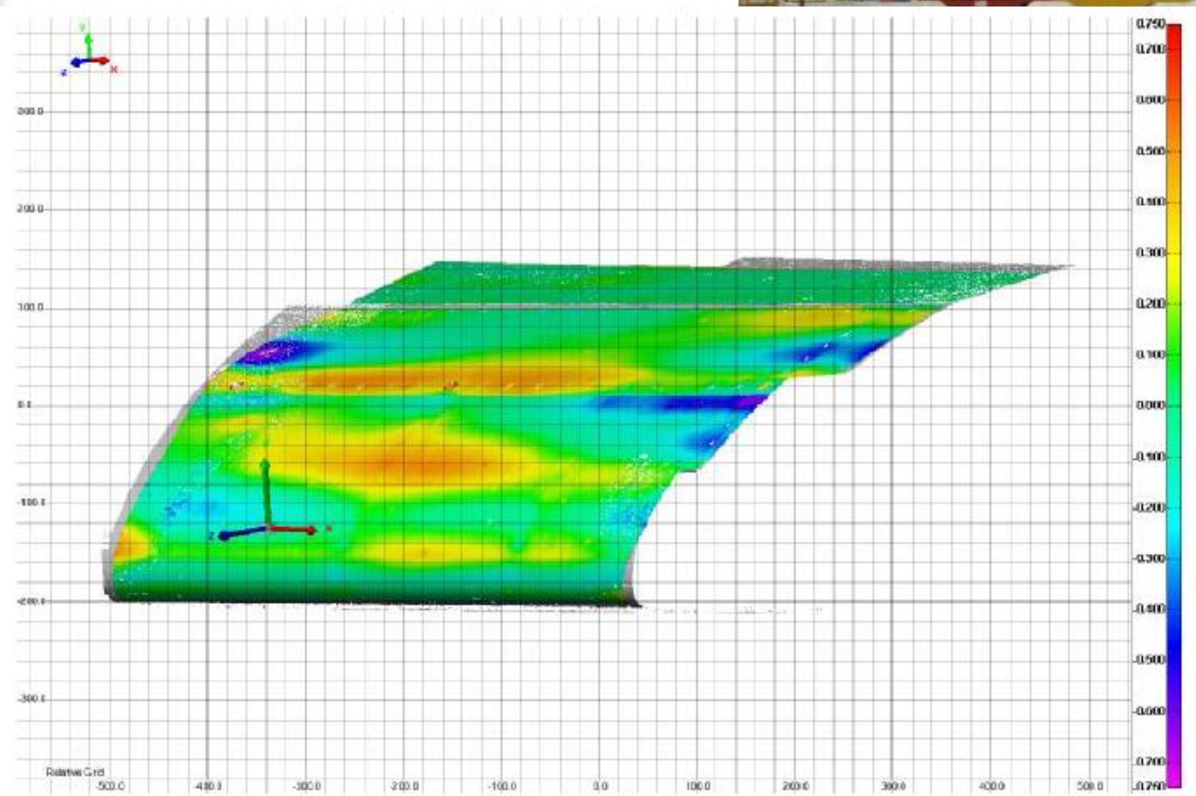




# Example – Production wing outer leading edge

- Deviation from 2nd order polynomial surface (bottom left)






- Shape measurement made on production line (top right)

# Example

- Data format – simple text file

```
-30.238905 -0.779151 -0.110335
-29.543318 -0.863929 -0.116519
-29.196364 -0.929276 -0.098566
-28.848248 -0.974027 -0.091369
-28.502444 -1.067428 -0.055027
-28.155440 -1.134230 -0.033544
-27.817712 -1.441379 0.151327
-27.784134 -0.927286 0.198426
-33.749493 -0.802388 -0.224176
-33.401895 -0.861835 -0.210505
-33.054593 -0.927954 -0.190174
-32.708826 -1.033797 -0.143297
-32.359814 -1.050169 -0.157611
-32.014216 -1.159236 -0.114822
-31.666190 -1.191589 -0.123326
```

# Additional Considerations

- It would be beneficial to consider if there is a link between a wave and a step i.e. a step is a single half wave of very high frequency
- Isolated 3D perturbations might be considered as a single square wave
- There may be a benefit of considering all perturbations as different manifestations of the same underlying geometry as it may allow for a single generalised description of all perturbations
- Point cloud data must be amenable to a parametric description in the same way as the analytical design description so that a comparison can be made between the two
- It would be acceptable for the discrete data to be fitted to an analytical description if necessary and the fidelity with which the analytical description fits the data must be quantified



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- Any Questions?