Ultra-high Precision Predictive Assembly of Composite Fuselage Joins via Surrogate Model Based Control

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ABSTRACT

Ultra-high precision predictive assembly is vital for large-scale aircraft production. Current practice is low efficient, non-optimal and experience-dependent. We propose an automated optimal shape control system that can adjust composite parts to an optimal configuration efficiently. It is accomplished by (i) building and validating an FEA platform; (ii) developing a surrogate model considering uncertainties; (iii) conducting feed-forward optimal control. We show the system can significantly reduce assembly time and dramatically improve quality.

MOTIVATION

Problem Description

Inevitable dimensional variations due to multiple suppliers / manufacturing batches.

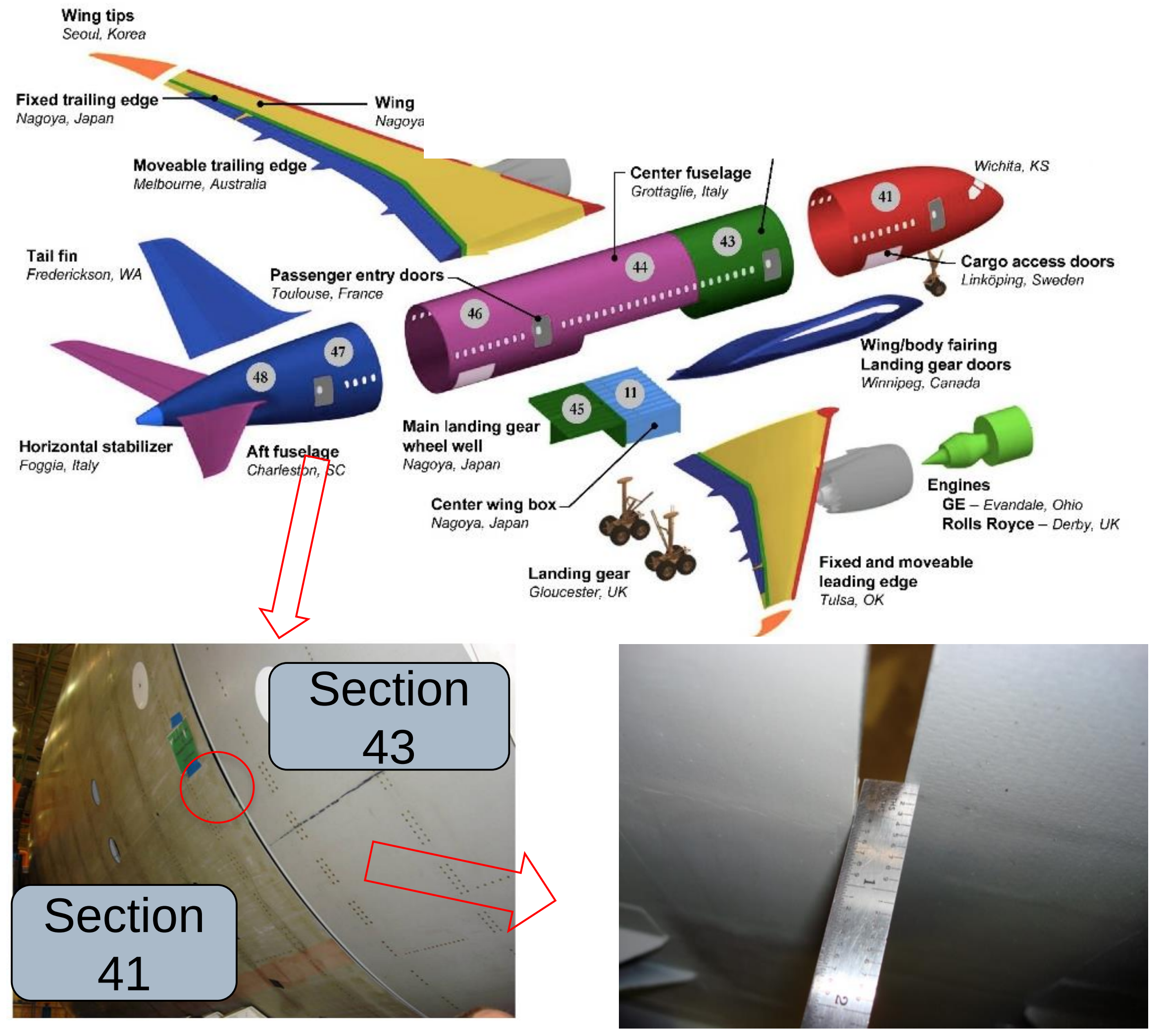


Fig. 1: Gap about 1.5 inches (Boeing 787)

Current Practice

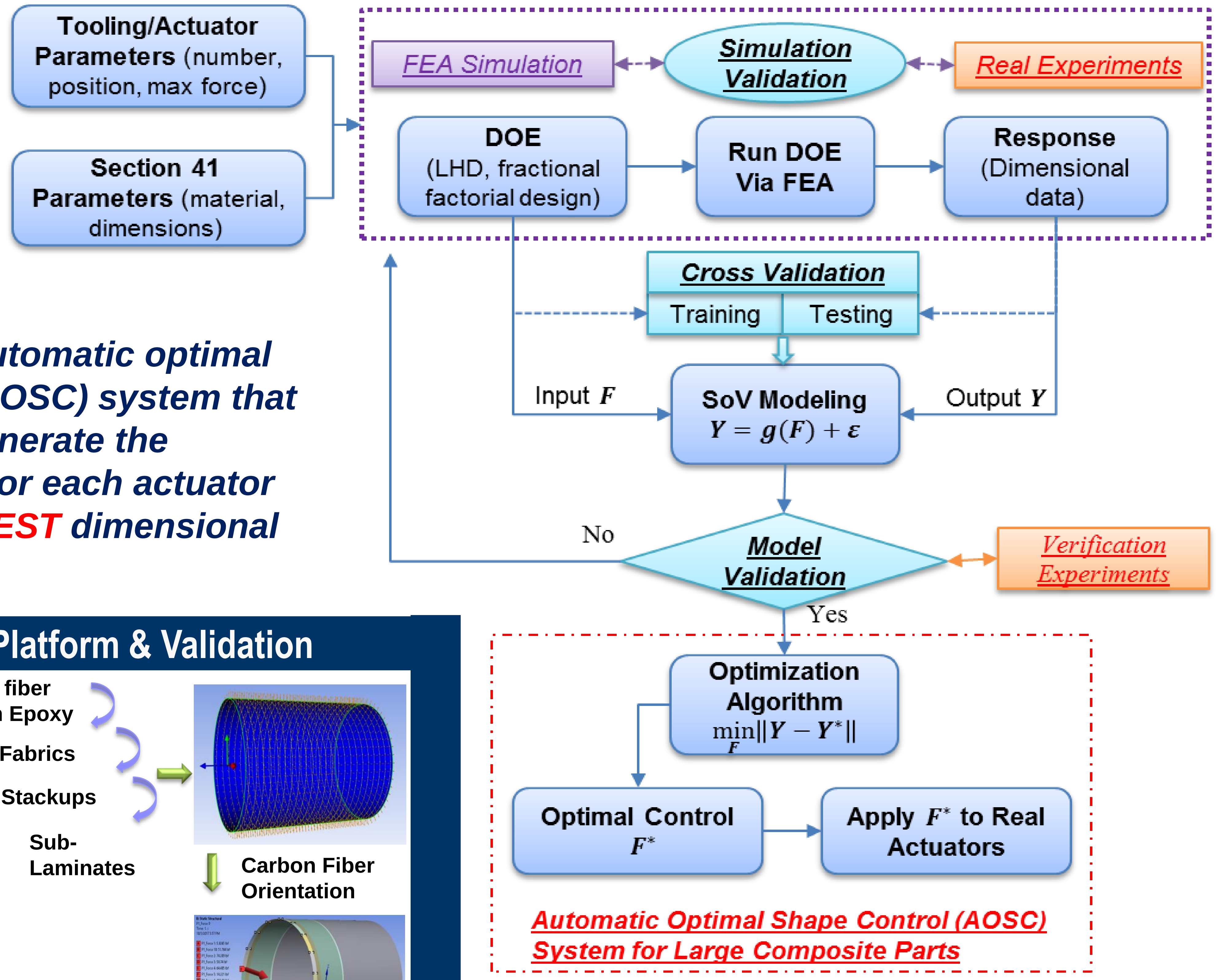
Ten adjustable actuators are used by trial and error method.

Fig. 2: Actuators Setup

Limitations

- **Low efficiency**: long flow time
- **Non-optimality**: acceptable rather than optimal
- **Highly skilled engineers required**

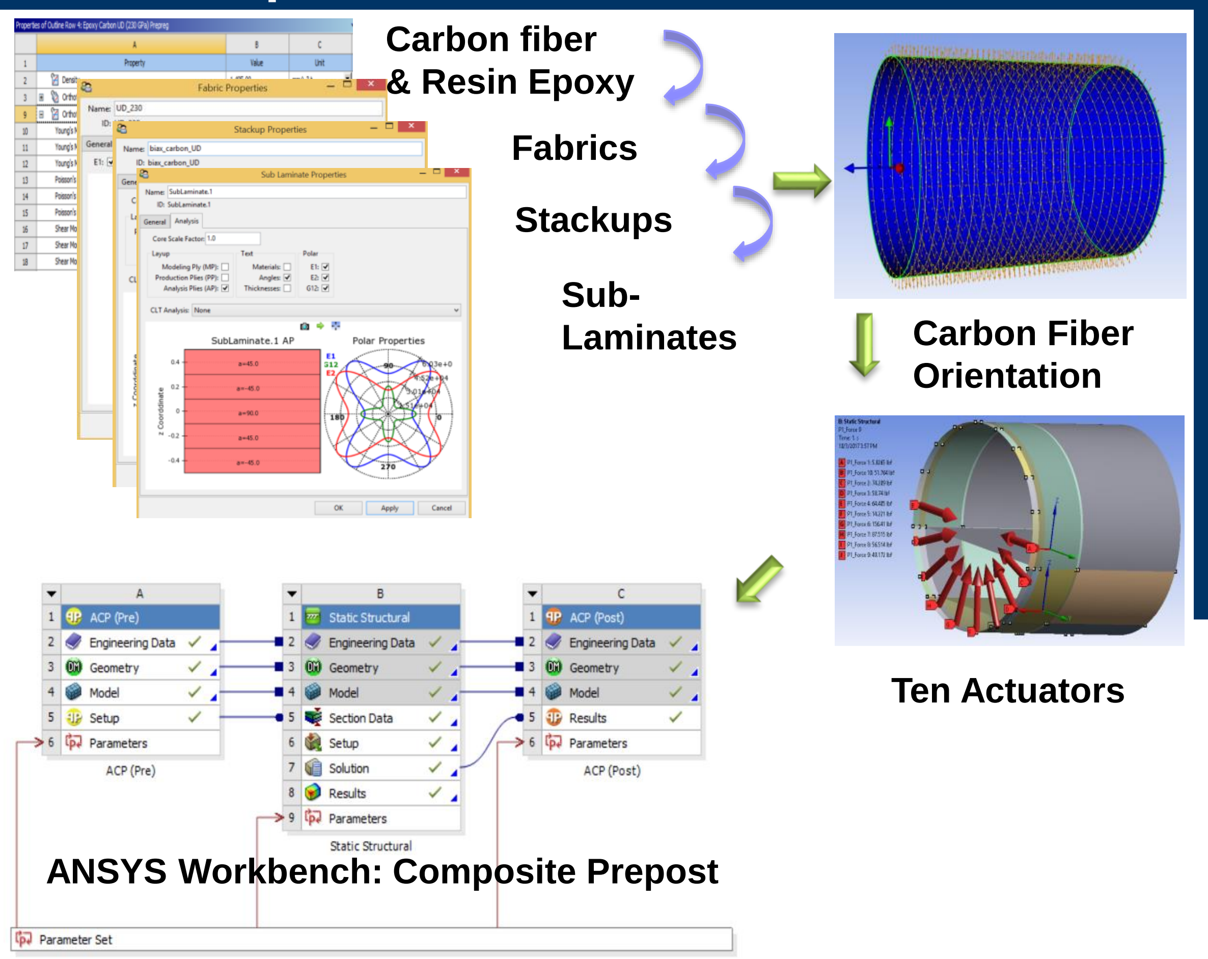
PROPOSED METHODOLOGY



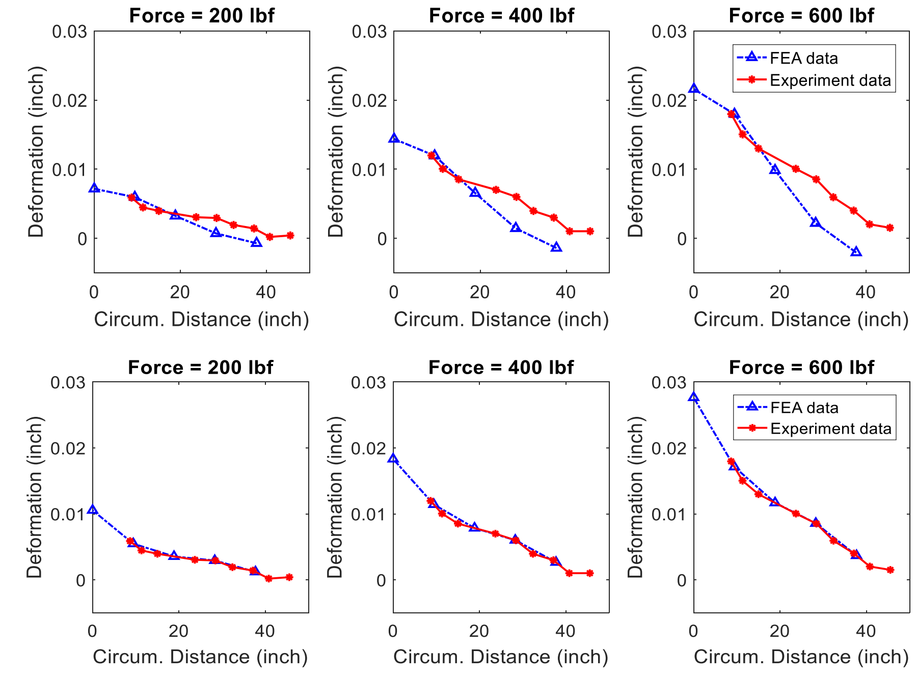
OBJECTIVE:

To develop an automatic optimal shape control (AOSC) system that can QUICKLY generate the OPTIMAL force for each actuator to achieve the BEST dimensional shape control.

Step 1: FEA Platform & Validation



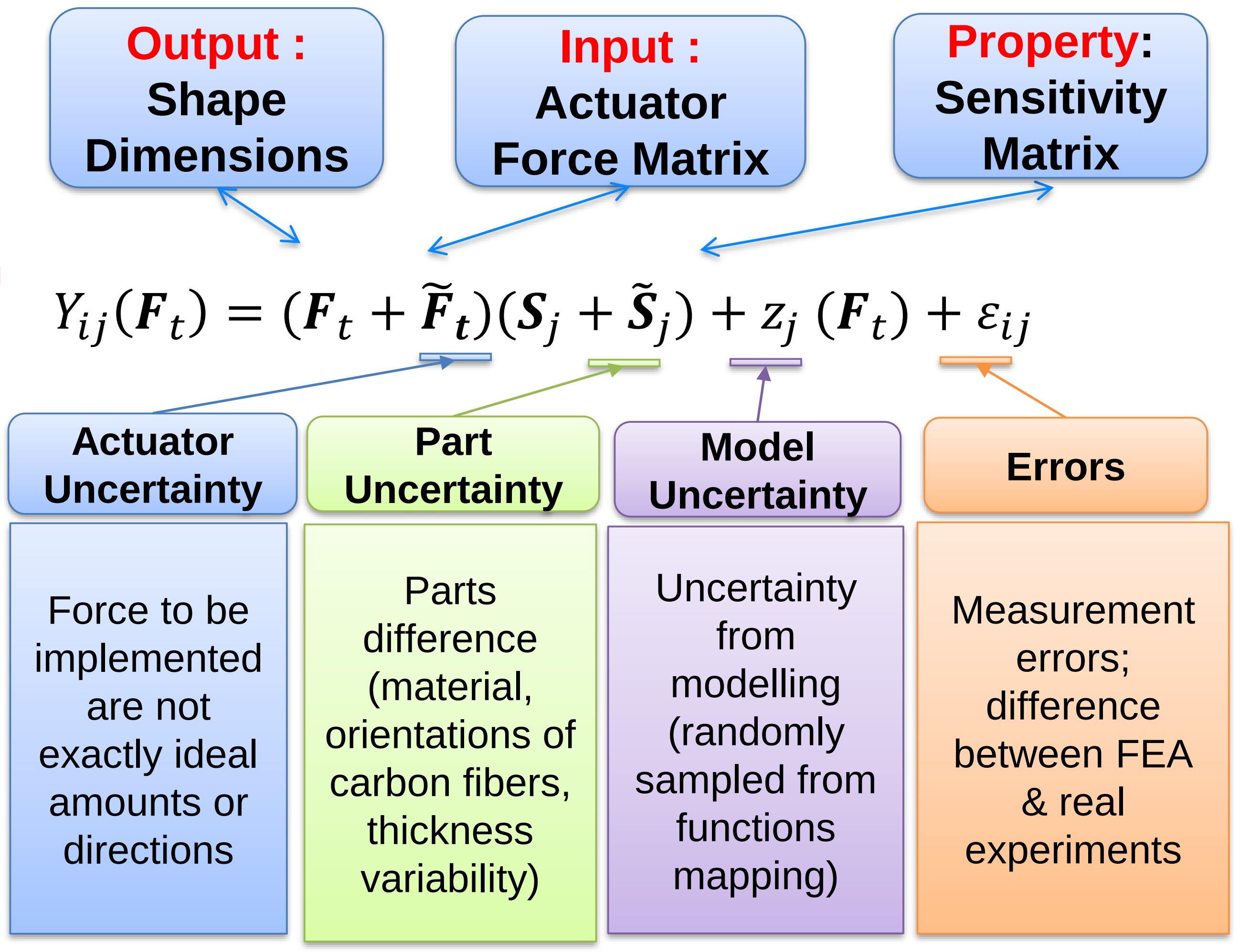
The FEA model **mimics the real fabrication process** of composite fuselages.



Model Calibration

The FEA results are quite **consistent** with experimental results after calibration.

Step 2: SoV Modeling



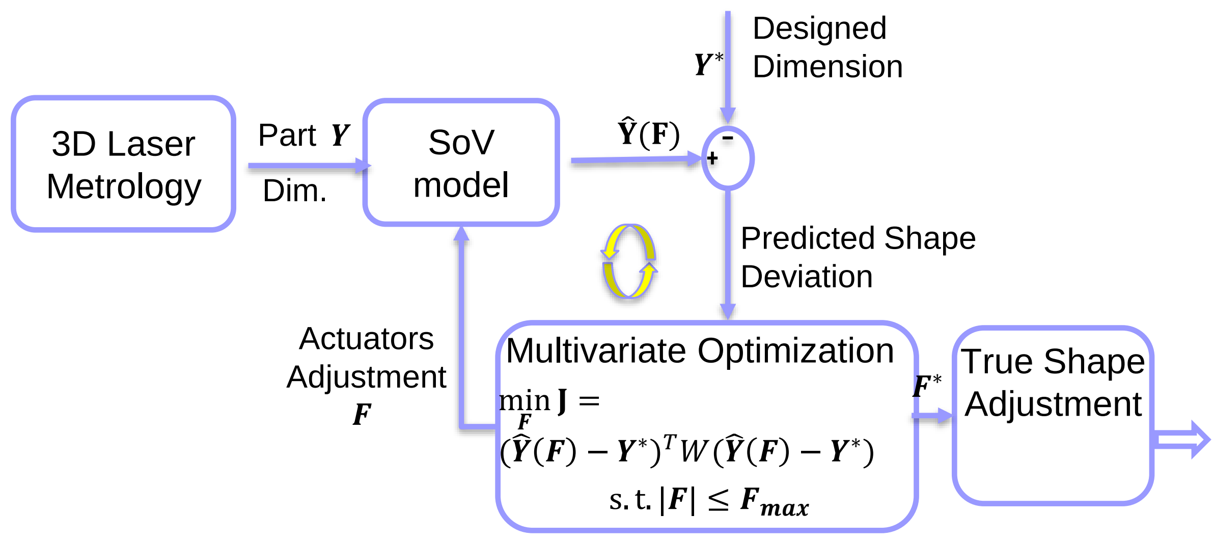
$$Y_{ij}(\boldsymbol{F}_t) = (\boldsymbol{F}_t + \widetilde{\boldsymbol{F}}_t)(\boldsymbol{S}_j + \tilde{\boldsymbol{S}}_j) + z_j\,(\boldsymbol{F}_t) + \varepsilon_{ij}$$

Actuator Uncertainty	Part Uncertainty	Model Uncertainty	Errors
Force to be implemented are not exactly ideal amounts or directions	Parts difference (material, orientations of carbon fibers, thickness variability)	Uncertainty from modelling (randomly sampled from functions mapping)	Measurement errors; difference between FEA & real experiments

The SoV model is an **analytical equation** to link shape, actuator forces, and fuselage properties.

Step 3: Automatic Optimal Shape Control

Optimization Algorithm:



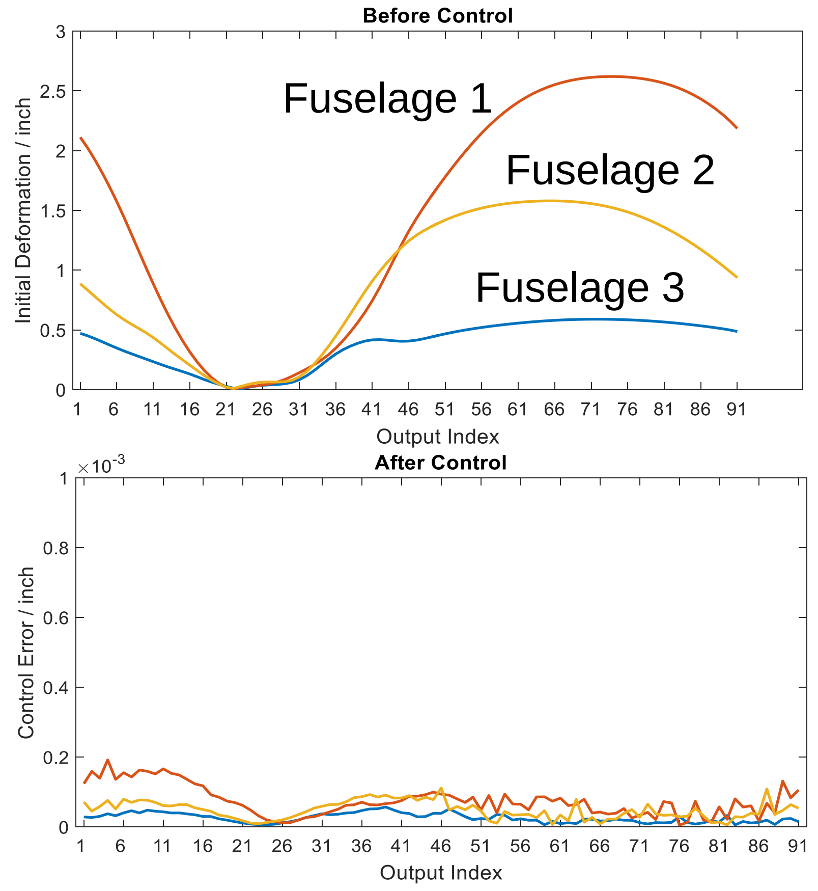
$$\min_{F} \mathbf{J} = (\hat{\boldsymbol{Y}}(\boldsymbol{F}) - \boldsymbol{Y}^*)^T W (\hat{\boldsymbol{Y}}(\boldsymbol{F}) - \boldsymbol{Y}^*)$$
$$\text{s.t.}\ |\boldsymbol{F}| \le \boldsymbol{F}_{max}$$

Feed-Forward Automatic Compensation

APPLICATION CASE

Before Control

After Control



The AOSC system can achieve **ultia-high dimensional accuracy (less than 0.001 inch)** with **large initial deformation (3 inches)**.

SUMMARY & CONTRIBUTIONS

- Develop a physics-based computational model for large composite fuselages with nonlinear anisotropy properties;
- Quantify the influence of actuator uncertainty, part uncertainty, modeling uncertain, measurement uncertainty;
- Provide methodology for the development of the AOSC system
- Extend the methodology to other applications

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