# Research on Gap Measurement Method Based on 3D Laser Scanning Technology

**Youtao Shao[a], Zhiqiang Yin[b], Jiefeng Jiang[a]**

[a]School of Engineering,Hangzhou Normal University,Hangzhou 311121,China

[b]Geely Automobile Research Institute (Ningbo) Co.,Ltd.,Ningbo 315336,China

## Introduction

### Background

- Traditional aircraft assembly gap measurement methods (e.g., feeler gauges) suffer from insufficient accuracy (large average errors), low efficiency (reliance on manual expertise), and difficulty in measuring complex structures.
- Manufacturing deviations in composite materials lead to assembly gaps, necessitating efficient and precise measurement technologies.

### Technical Status

- Advantages of 3D laser scanning: Non-contact, high precision (0.02mm), high efficiency (650,000 points/sec scanning speed).
- Reverse engineering applications in aerospace: High-precision 3D model reconstruction from point cloud data (e.g., Geomagic Design X).

### Research Gap

- Existing reverse engineering studies lack specific applications for aircraft assembly gap measurement.

## Aim

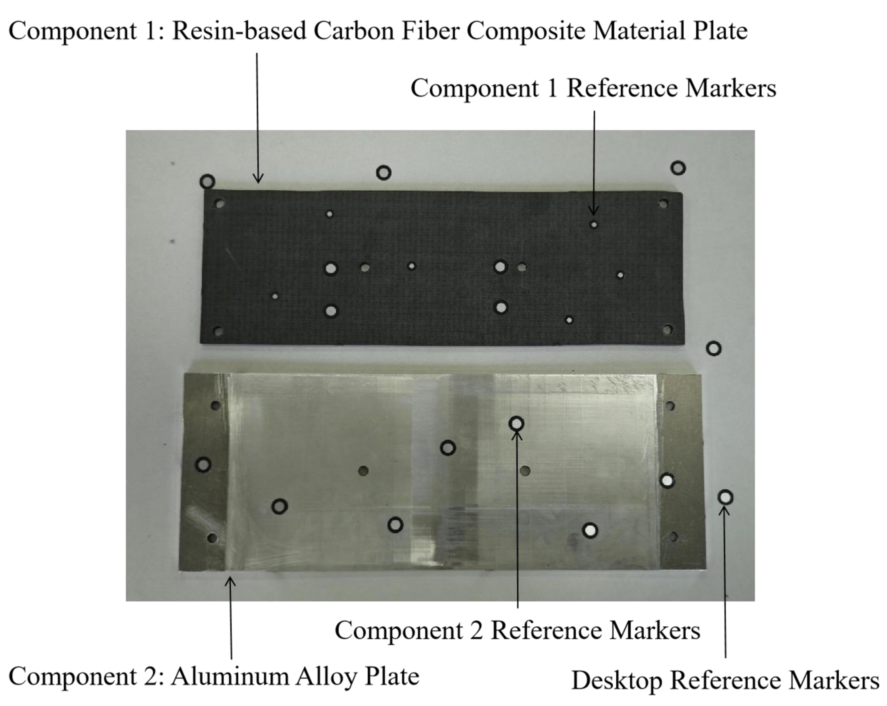
Develop a gap measurement method based on 3D laser scanning and reverse engineering to achieve:

- Efficient measurement of gaps in complex structures (reduced assembly cycle time).
- Improved measurement accuracy (target error ≤0.2mm).
- Digital quality control for assembly processes (supporting aerospace manufacturing needs).

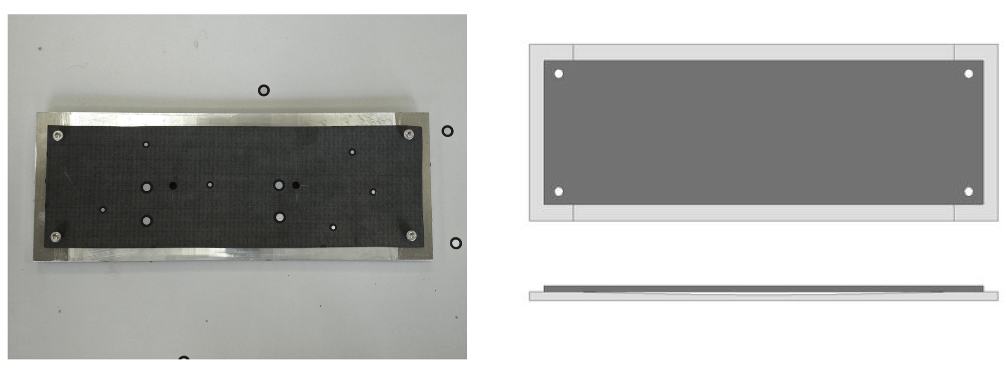
## Method

### Sample Preparation

- Resin-based carbon fiber plate (simulating aircraft skin).
- Aluminum alloy plate with arc-shaped groove (max depth 2.2mm).
- Bolted connection to replicate assembly conditions.




*Composite Material Plate and Aluminum Alloy Plate.*



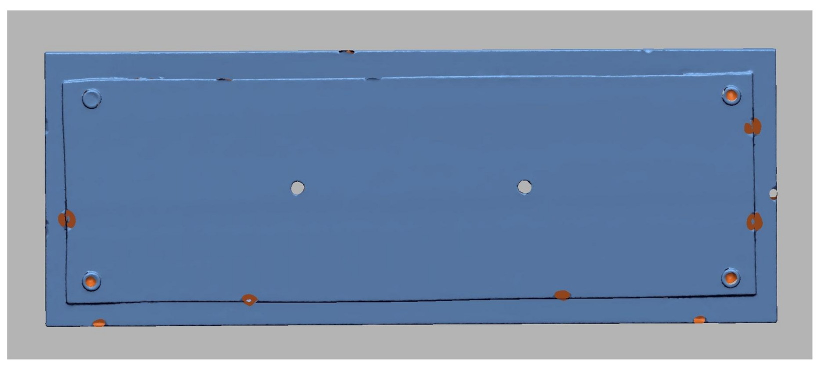
*Assembly Model and Theoretical Digital Model.*

### Data Acquisition

- Device: ZCSCAN-K30 handheld laser scanner (0.02mm accuracy).
- Workflow:
  - Environmental stabilization (temperature/humidity/lighting control).
  - Positioning marker placement (minimum 30mm spacing).
  - Multi-angle scanning (front/back surfaces + assembled components).

| Parameter | |
|---|---|
| Accuracy | 0.02mm |
| Scanning Speed | 650,000 measurements per second |
| Resolution | 0.02mm |
| Minimum point error | 0.064 mm |

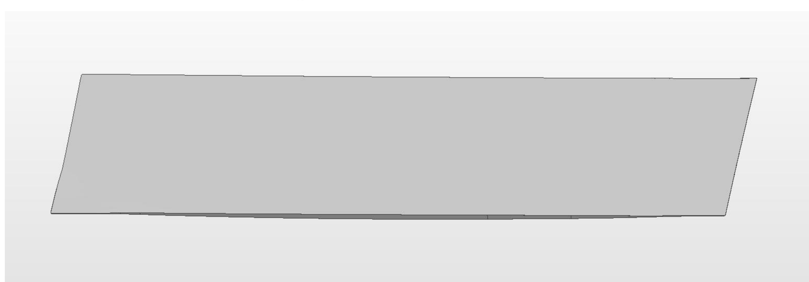
*ZCSCAN-K30 Handheld 3D Laser Scanner and Parameter.*



*ZCSCAN-K30 Handheld 3D Laser Scanner and Parameter.*

### Reverse Modeling

- Software: Geomagic Design X.
- Key Steps:
  - KNN adaptive filtering for noise removal.
  - Marker-based alignment (X-Y-Z coordinate system).
  - Region segmentation (sensitivity parameter: 15).
  - Solid modeling.

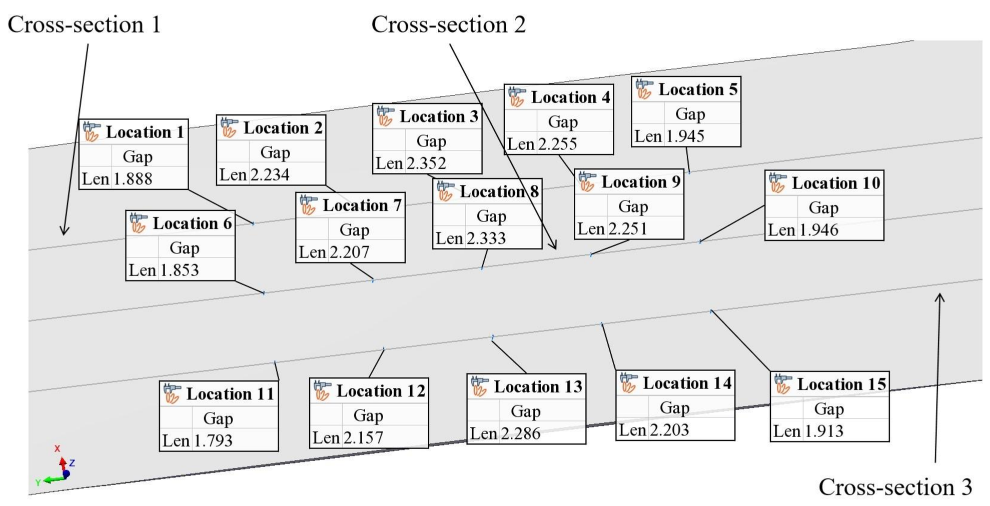


*Gap Model.*

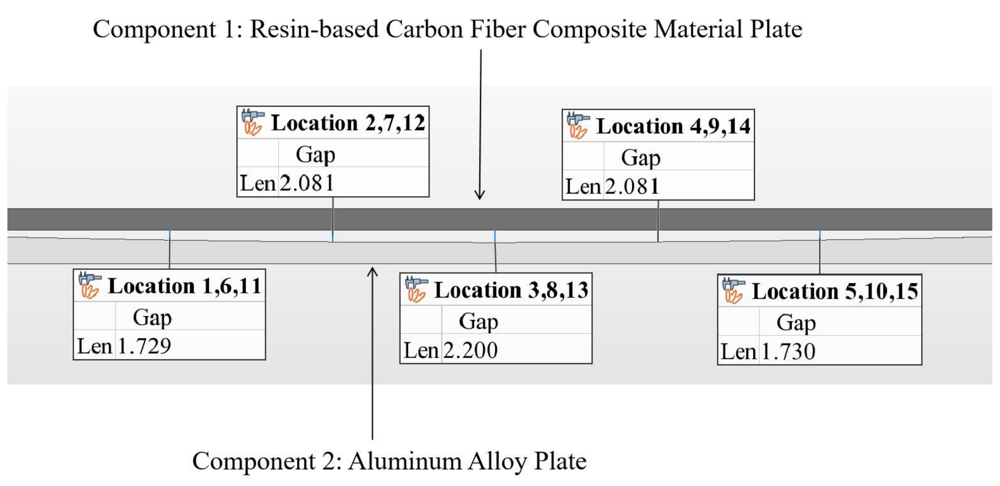
### Gap Measurement

Software: PolyWorks.

Method: Extract 15 measurement points across 3 cross-sections, calculate Euclidean distances.




*Gap Size Measurement.*




*Theoretical Gap Dimensions.*

## Results

### Key Data

| Metric | Value |
|---|---|
| Average absolute error | 0.140 mm |
| Average relative error | 6.76% |
| Maximum point error | 0.216 mm |
| Minimum point error | 0.064 mm |

### Error Distribution

- Largest errors in Cross-section 1 (avg. 9.19%), smallest in Cross-section 3 (avg. 4.42%).
- Outliers at Points 5/10/15 (attributed to machining errors or material warping).

### Engineering Applicability

- Meets aerospace industry tolerance standard (0.2mm error threshold).
- Efficiency improvement over traditional methods (eliminates disassembly iterations).

## Conclusion

### Technical Advantages

- Non-contact rapid measurement for complex gaps (650,000 points/sec scanning).
- Accuracy meets engineering requirements (avg. error <0.2mm).

### Practical Value

- Supports digital assembly workflows (point cloud → solid model → automated measurement).
- Reduces manufacturing costs (minimizes manual intervention and rework).

### Future Work

- Optimize machining stability to reduce sample errors.
- Develop automated error compensation algorithms.

## References

[1] Gong, H. J., Zhou, T., Li, H., et al., "Reverse Modeling and Die Casting Die Design of Aluminum Alloy Parts Based on Geomagic," Foundry 17(6), 596–601 (2020).

[2] Wang, D. C., Wang, Y., Liu, S. L., et al., "Optimisation of the column structure of a small drilling machine based on reverse engineering," Manufacturing Technology & Machine Tool 44(3), 94–101 (2024).

## Acknowledgements

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