MILITARY TECHNICAL ACADEMY

Problems in designing UAV airframe: challenges and solutions

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Presentation layout

- ❖UAV applications and classification
- ❖Problems in designing UAV airframes
- ❖Challenges and solutions
- ❖Conclusions

UAV applications and classification

UAVs and applications

❖Civil applications:

- Entertainment
- Environmental monitoring
- Agriculture and forestry
- Humanitarian aid

❖In warfare:

- Surveillance and reconnaissance
- Attack
- Demining
- Target practice

UAV classification

❖UAV classification can be based on

- Range and endurance
- Size
- Weight
- Altitude
- Configuration

Group	Group 1	Group 2	Group 3	Group 4	Group 5
Size	Small	Medium	Large	Larger	Largest
Max takeoff weight	< 20 lb (9.1 kg)	> 20 & < 55	> 55 & < 1320	> 1,320 lb (600 kg)	> 1,320 lb (600 kg)
Operating altitude	< 1,200 ft (370 m)	< 3,500 ft (1,100 m)	< 18,000 ft (5,500 m)	< 18,000 ft (5,500 m)	> 18,000 ft (5,500 m)
Speed	< 100 kn (190 km/h)	< 250 kn (460 km/h)	< 250 kn (460 km/h)	Any speed	Any speed

Classification of UAVs by United States Department of Defense

Orbiter-2 (Israel)

Lancet (Russia)

Ziyan (China)

MQ-1 Predator (USA)

Problems in designing UAV airframes

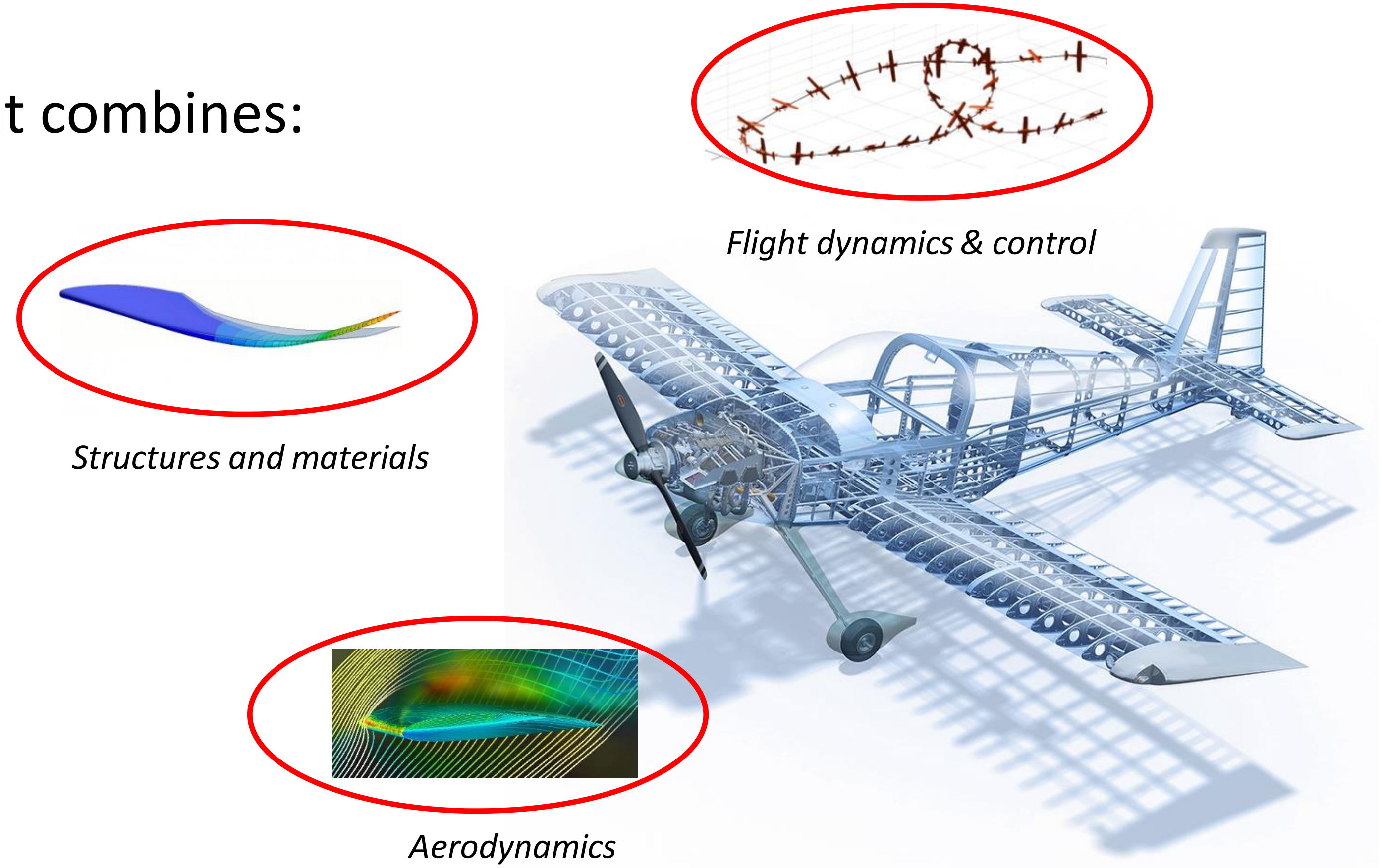
UAV airframes

UAV airframe

- UAV airframe is the mechanical part of an UAV including fuselage, wing, tail, landing gear, etc.

Airframe design

- A field of aerospace engineering that combines:
  - Aerodynamics
  - Materials technology
  - Structures
  - Manufacturing methods
- Focus on the optimization of:
  - Weight
  - Strength
  - Energy consumption
  - Flight performance
  - Cost



UAV airframes' design process

❖The design process of UAV airframe includes

Conceptual design → **Preliminary design** → **Detail design**

Conceptual design

- What does it look like?
- What requirements drive the design?
- What trade-offs should be considered?
- What should it weigh and cost?

Preliminary design

- Validate the UAV concept and freeze the configuration
- Increasing level of detail
- Start sub-system analysis and design
- Lab-scale test results are available

Detail design

- High level of detail and confidence
- Design the tooling and fabrication processes
- Regular checks of designs requirements
- Major item test and full-scale test results are available

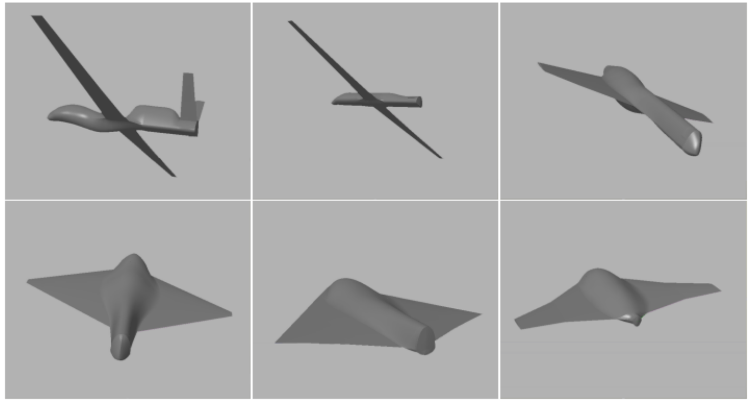
UAV airframes' design process

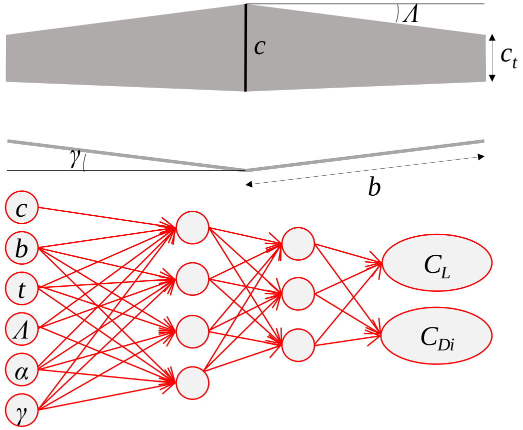
❖Conceptual design

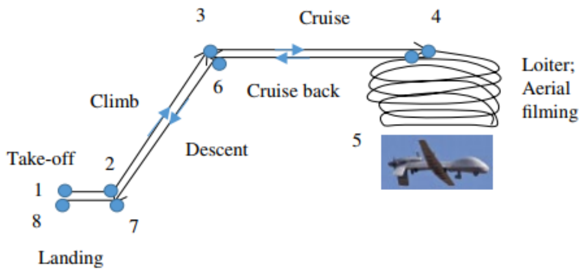
Requirements
- Large number of alternatives
- Low-cost analysis

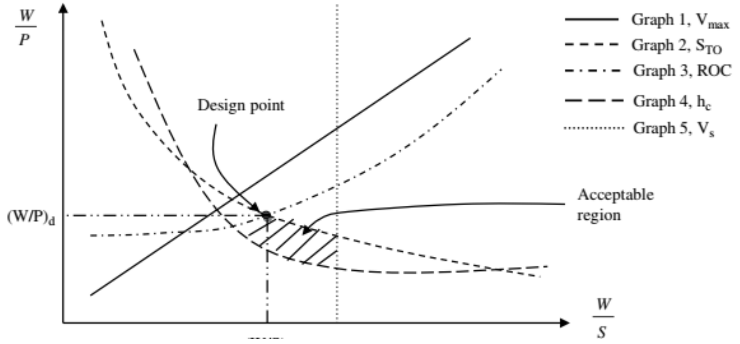
Method
- Optimization (gradient-based search, genetic algorithm, PSO, etc.)
- Matrix plot
- Neural network to accelerate the process

Results
- UAV configuration with basic shape and geometric parameters
- Predicted flight performance (range, speed, endurance)
- Estimated weight and cost









UAV airframes' design process

❖Preliminary design

Flight load conditions (FAR, STANAG)

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Material and structural design

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FEM analysis and sub-system test

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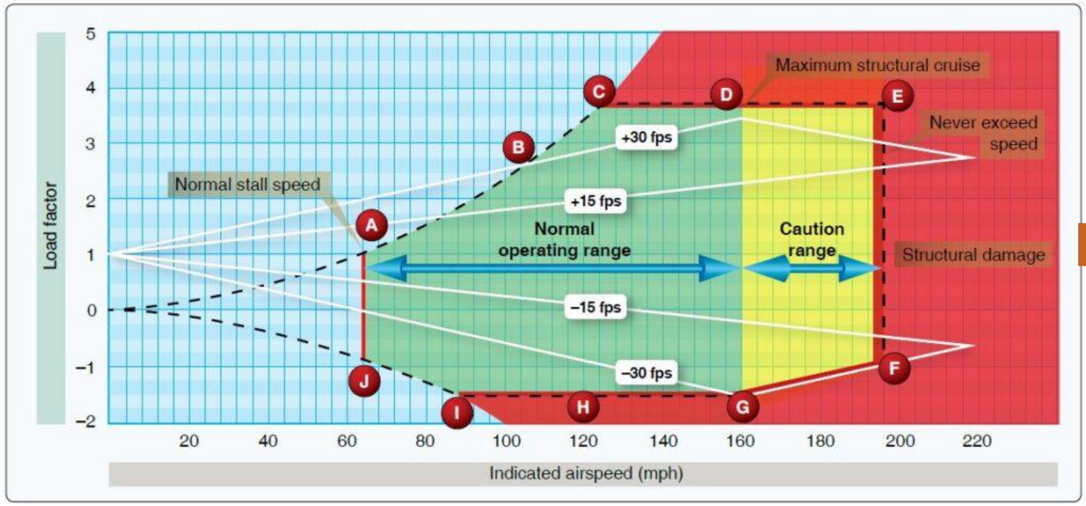
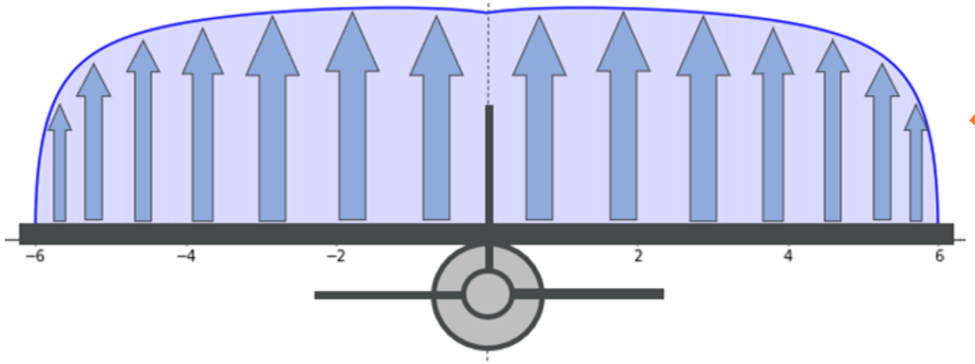
Structural dynamics and flutter analyses



V-n diagram



For large UAVs (>150 kg)

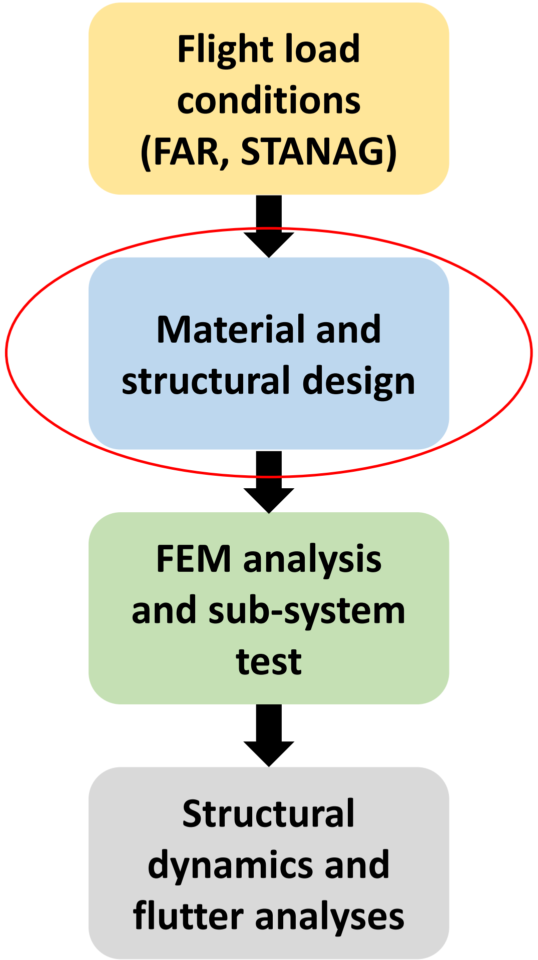
- FAR 23 (Federal Aviation Administration)
- STANAG 4671 (NATO)

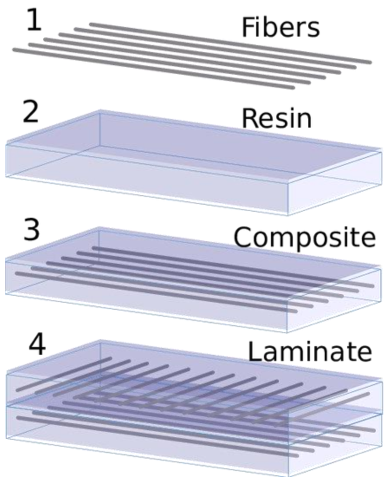
For light UAVs (<150 kg)

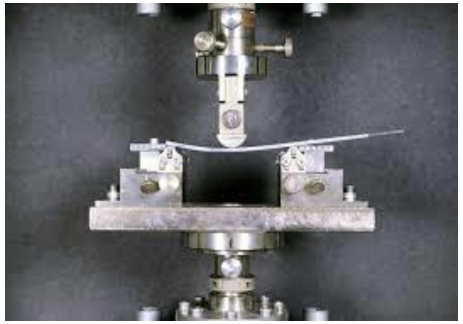
- STANAG 4703 (NATO)

UAV airframes' design process

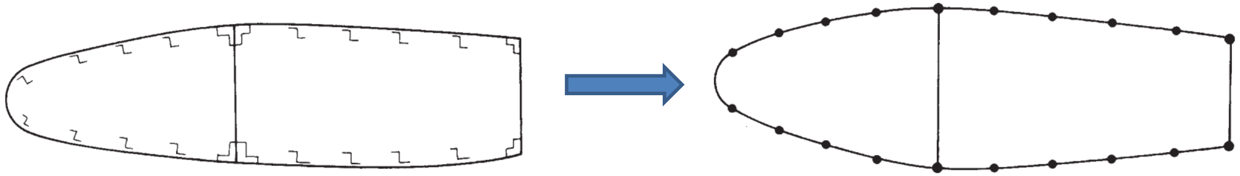
❖Preliminary design



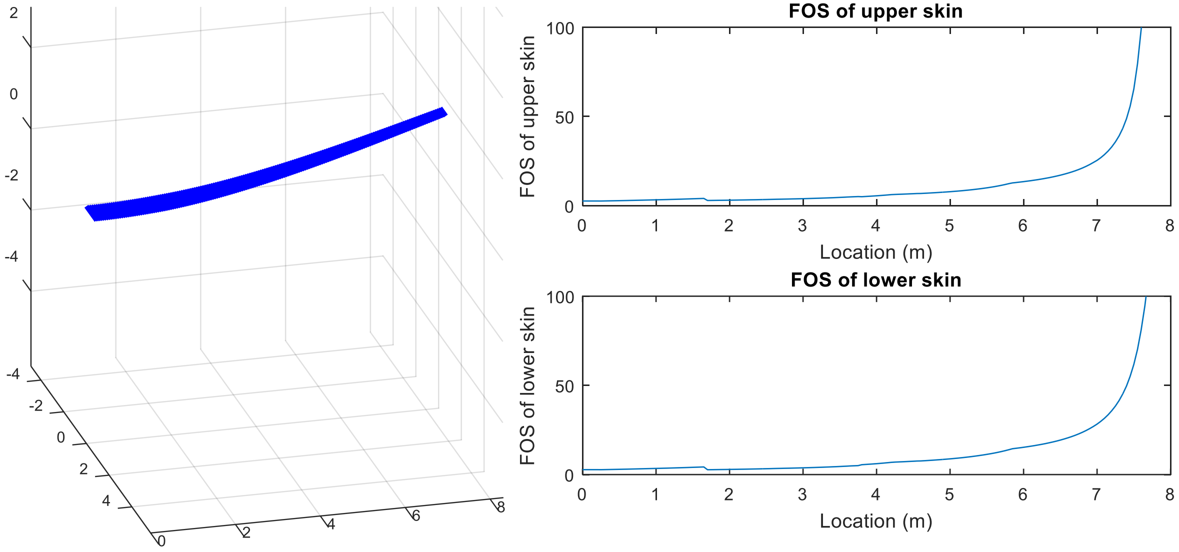




Composite material modelling and tests



Thin-walled structure modelling



Structure deformation and Factor of safety (FOS) analysis by a reduced-order modelling method

UAV airframes' design process

❖Preliminary design

Flight load conditions (FAR, STANAG)

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Material and structural design

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FEM analysis and sub-system test

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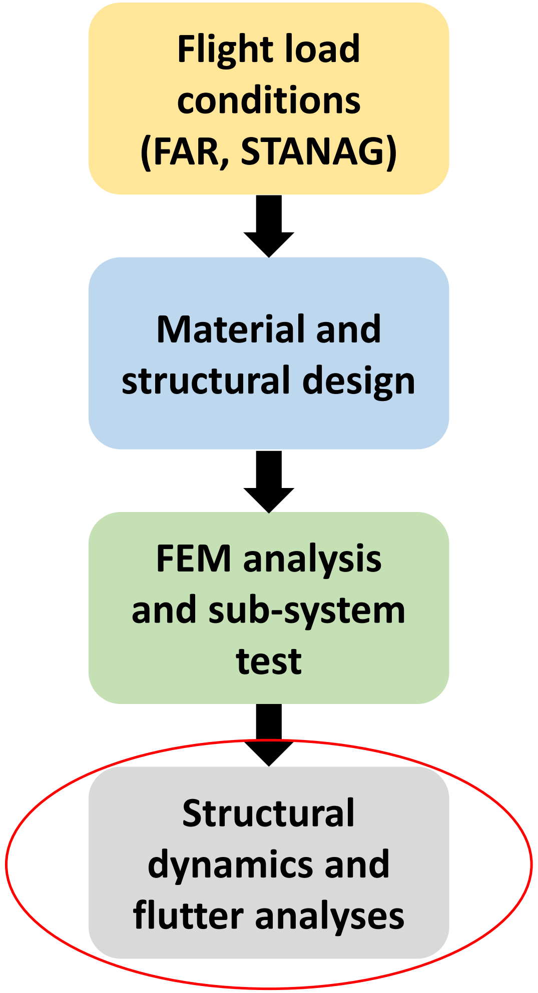
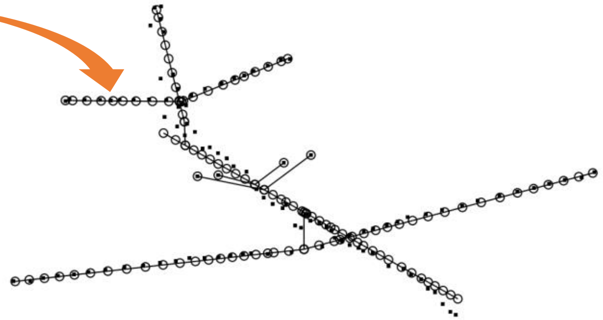
Structural dynamics and flutter analyses

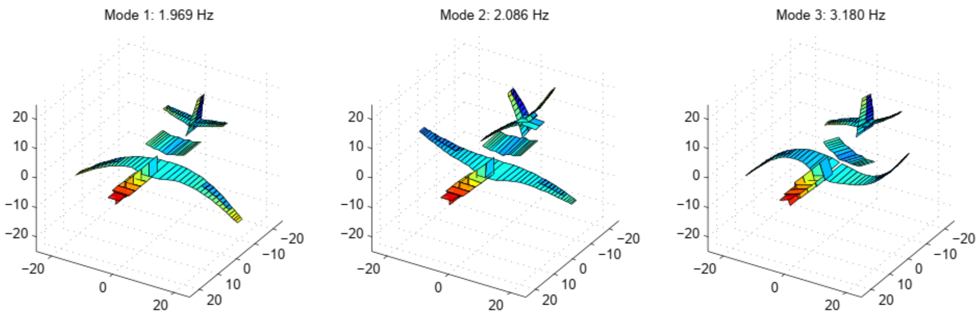
UAV airframes' design process

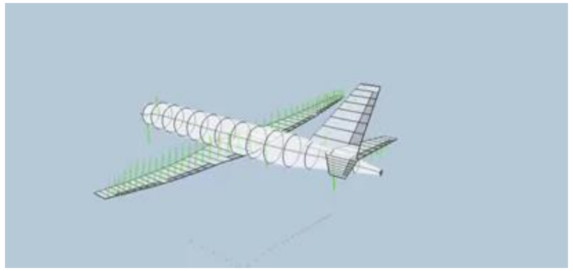
❖Preliminary design





Lumped-mass modelling





Dynamic response and modal analyses

Aircraft flutter

UAV airframes' design process

❖Detail design

High-level 3D design and CFD/FEM analysis

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Wind tunnel and full-scale tests

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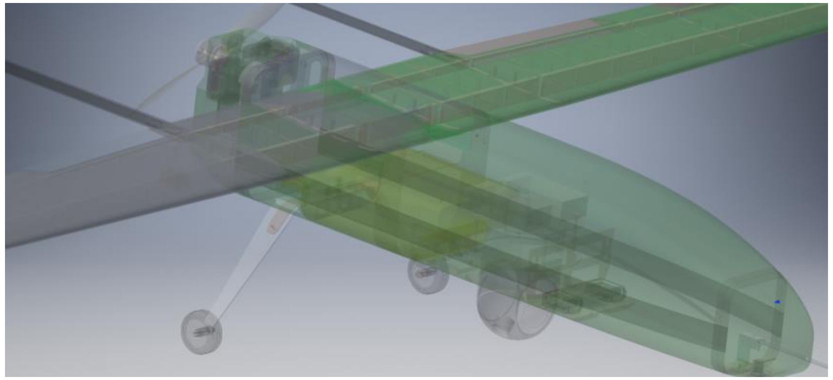
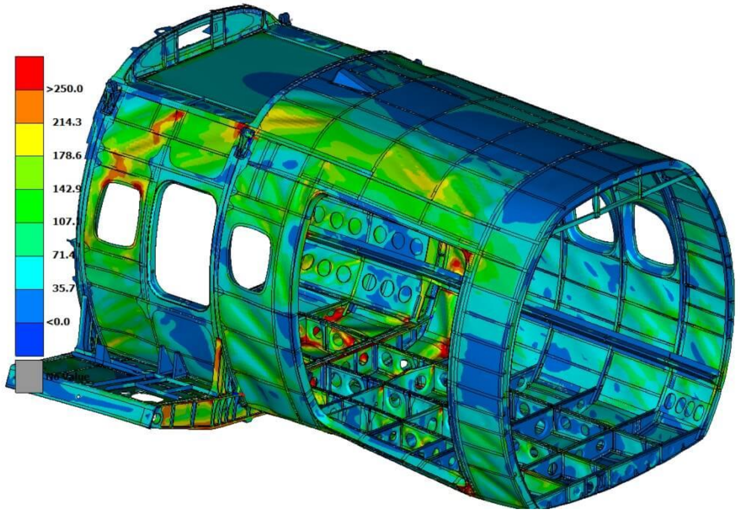
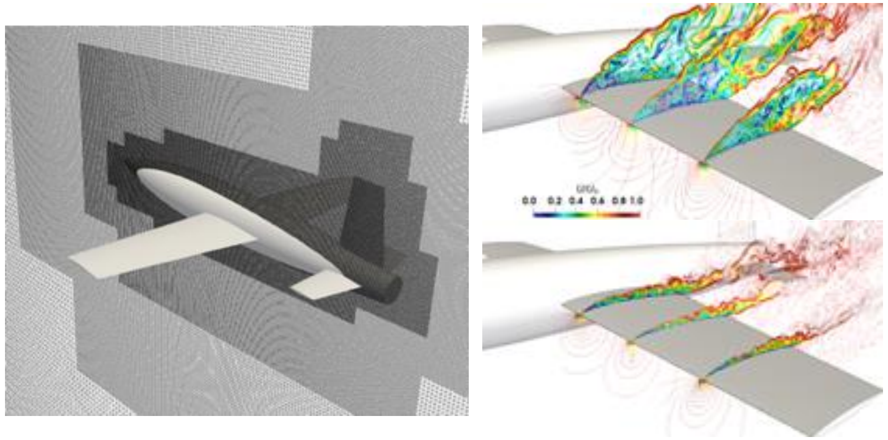
Check the requirements and adjust the design

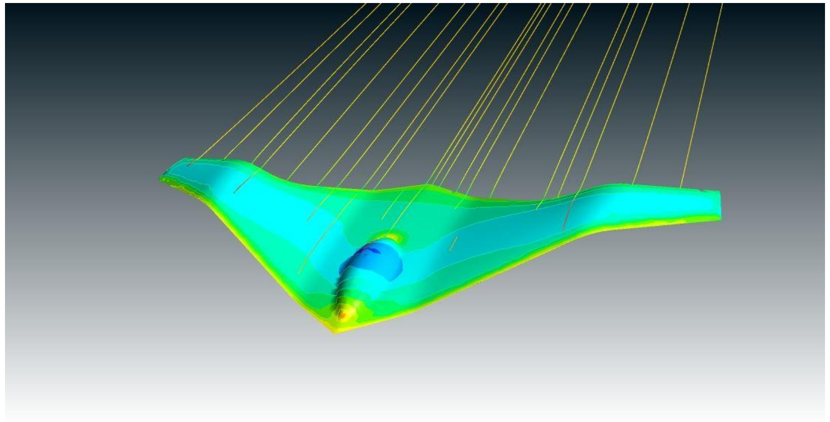


Detailed 3D design



High-level FEM analysis





CFD meshing and analysis

UAV airframes' design process

❖ Detail design

High-level 3D design and CFD/FEM analysis

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Wind tunnel and full-scale tests

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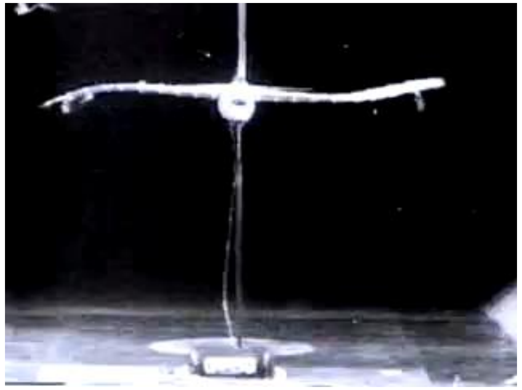
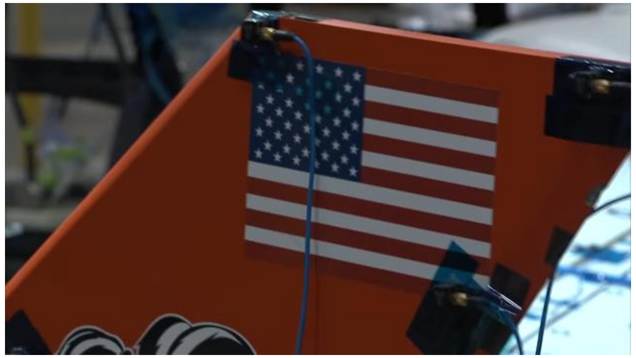
Check the requirements and adjust the design



Wind tunnel tests



Ground vibration test (GVT) for full-scale UAVs

UAV airframes' design process

❖Detail design

High-level 3D design and CFD/FEM analysis

↓

Wind tunnel and full-scale tests

↓

Check the requirements and adjust the design

Design requirements:

- Flight performance: Range, Maximum/Stall speeds, Endurance, Ceiling, Maximum take-off weight (MTOW)
- Structure: Factor of safety (FOS), Buckling critical load, Flutter critical speed
- Control and stability: Controllability, Damping ratio
- Manufacturing readiness: Cost, Risk

Challenges and solutions

Challenges and solutions

❖Determine design requirements

- UAVs are new type of aircraft with many unconventional designs
- Lack of UAV design standard documents

NATO STANDARD

AEP-83

LIGHT UNMANNED AIRCRAFT SYSTEMS AIRWORTHINESS REQUIREMENTS

STANDARDIZATION AGREEMENT
(STANAG)

SUBJECT: UNMANNED AERIAL VEHICLES SYSTEMS AIRWORTHINESS REQUIREMENTS (USAR)

CODE OF FEDERAL REGULATIONS

14

Parts 1 to 59
Revised as of January 1, 2017

Aeronautics and Space

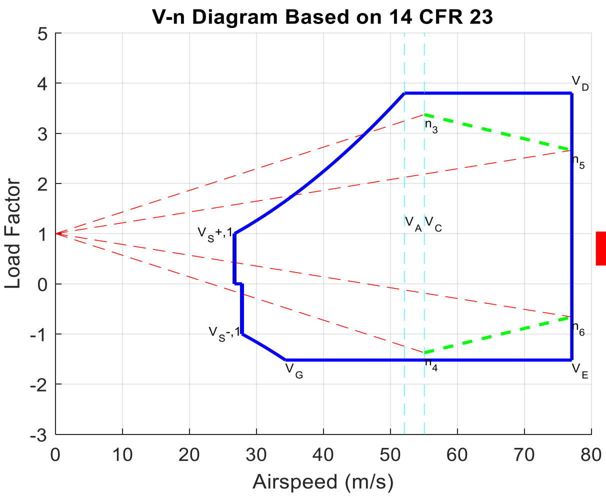
NATO airworthiness standards for UAVs

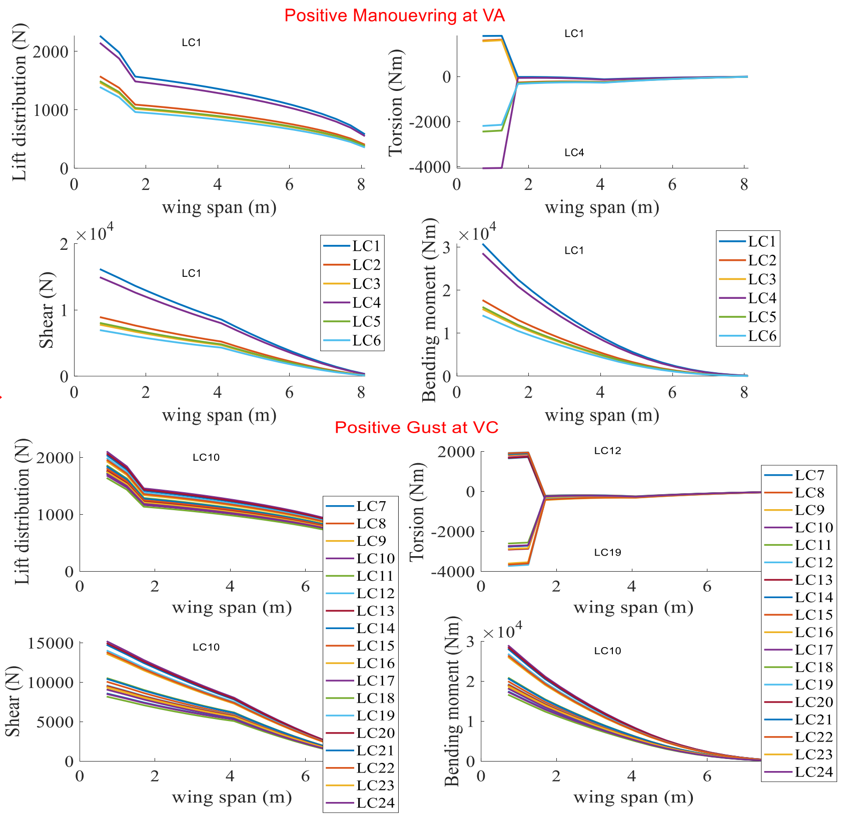
FAA airworthiness standards

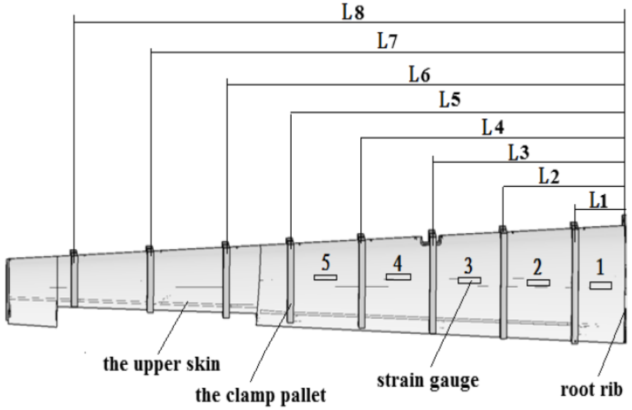
Challenges and solutions

❖ Determine design requirements

- Develop in-house code to determine flight loading conditions based on available airworthiness standard documents



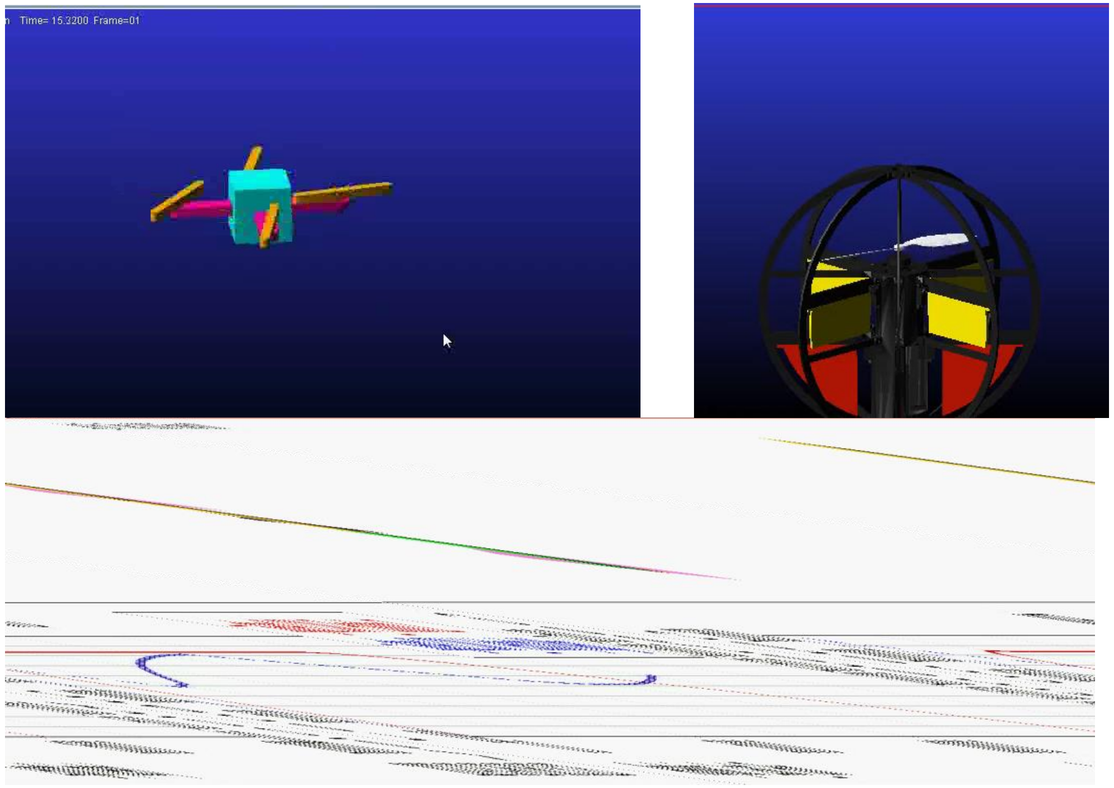


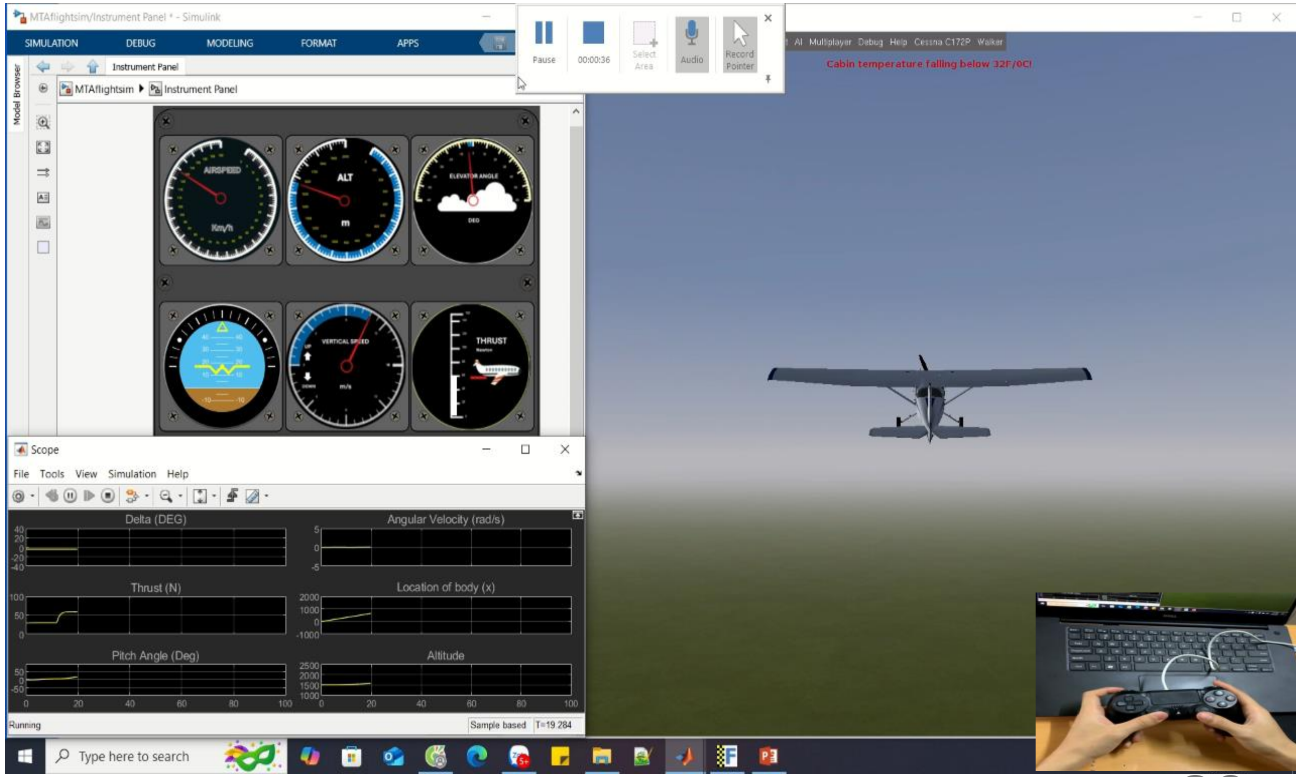


Challenges and solutions

❖Determine design requirements

- Develop in-house flight simulation software to obtain the loading requirements in simulation flight

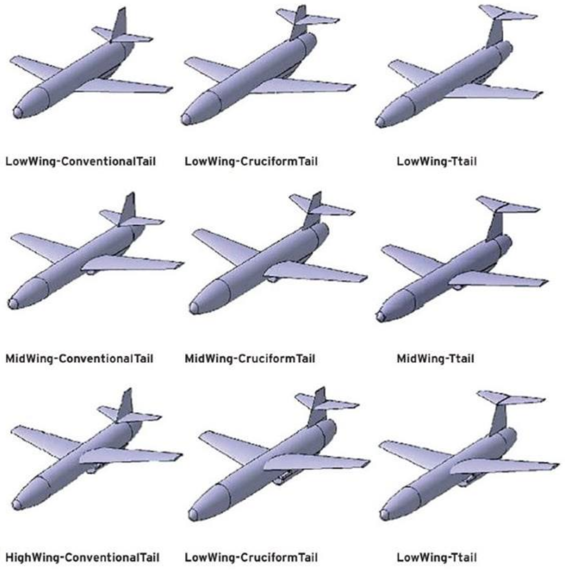


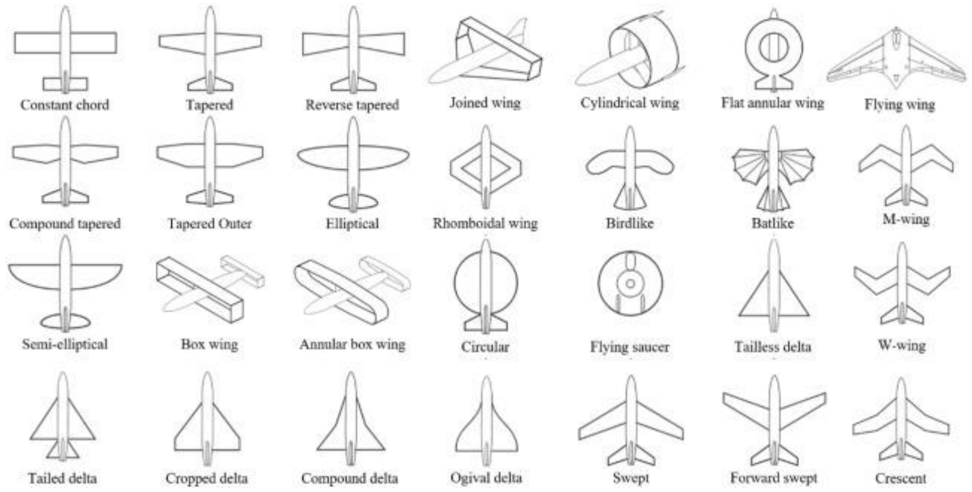


Challenges and solutions

❖Requirements of rapid prediction and sizing

- In the conceptual design and preliminary design phases, a large number of cases and alternatives are required to analyzed
- Rapid prediction methods with acceptable fidelity are required

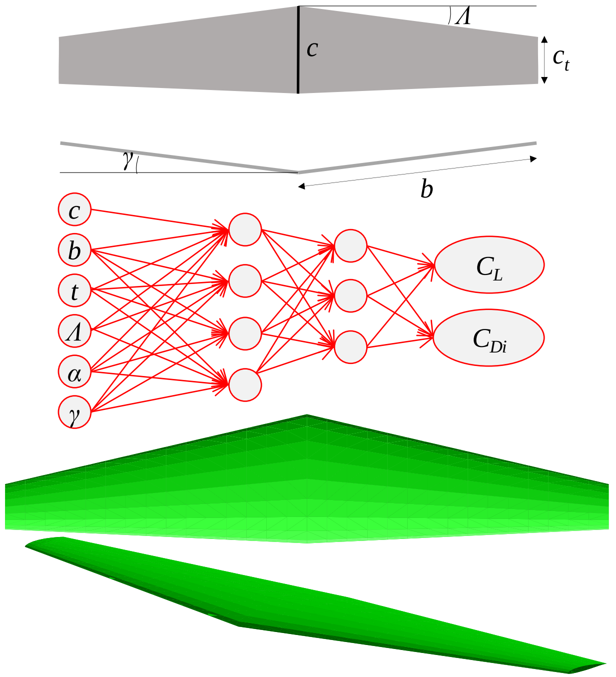




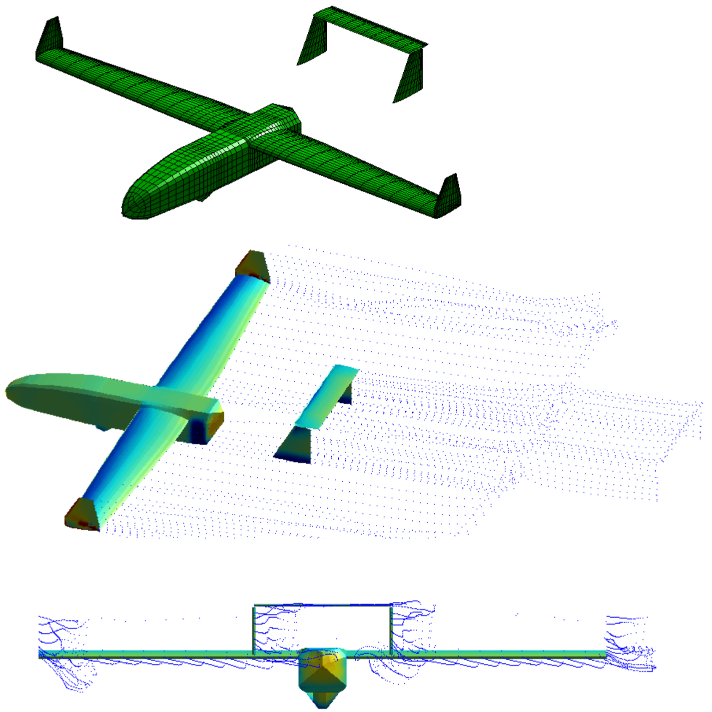
Challenges and solutions

❖Requirements of rapid prediction and sizing

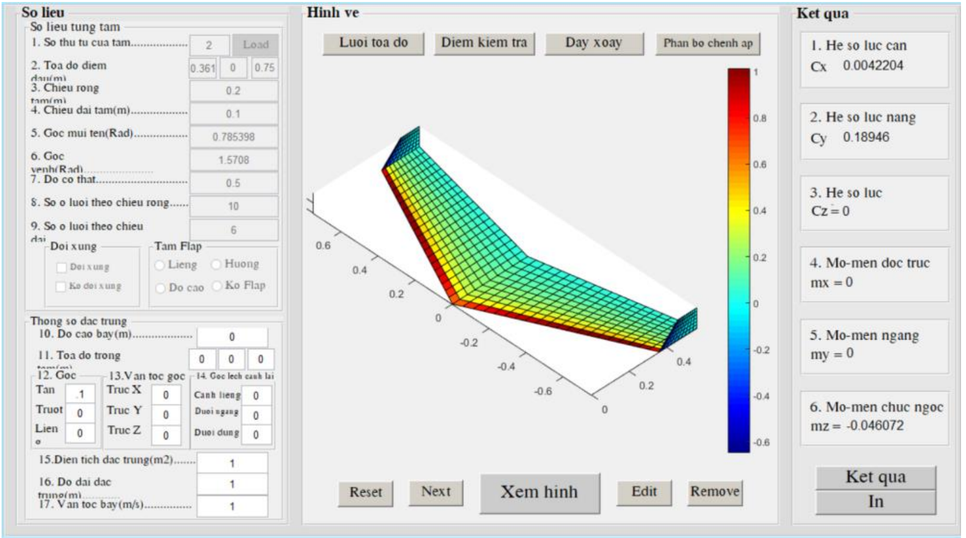
- Develop multi-fidelity and multi-order computation software and methods
- Using neural network and parallel computing to acceleration the prediction process



Neural network to predict the aerodynamics of an UAV



Aerodynamic simulation using in-house parallel computing program

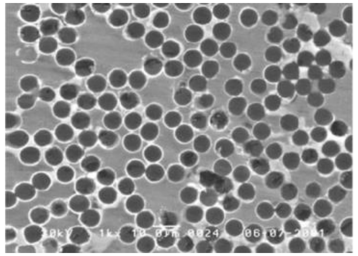


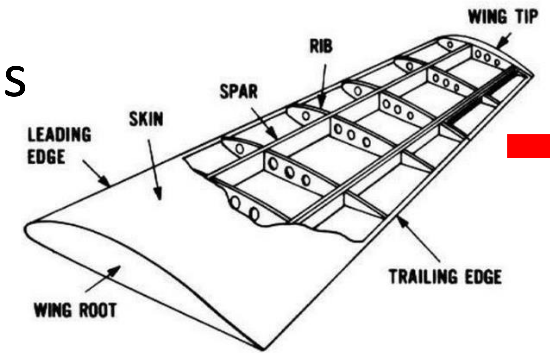
In-house reduced-order aerodynamic software

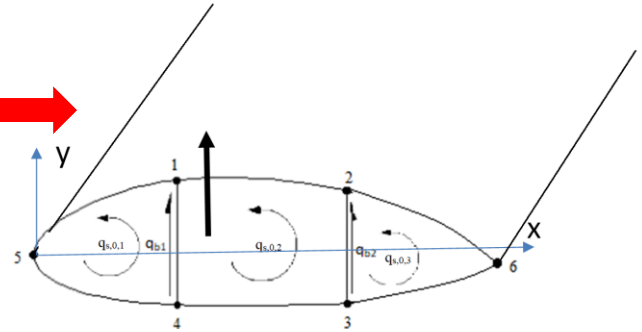
Challenges and solutions

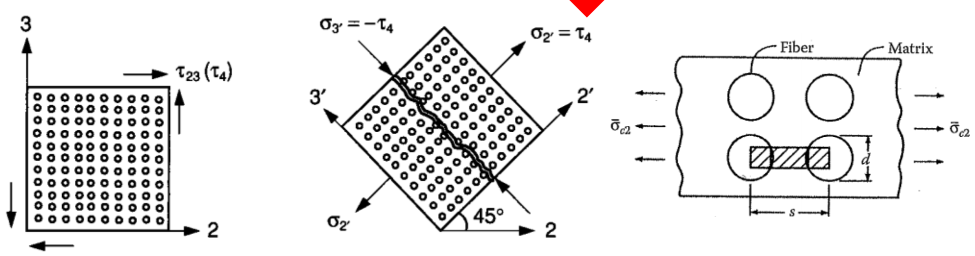
❖Requirements of rapid prediction and sizing

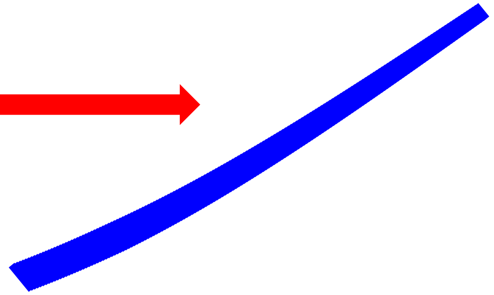
- Develop in-house codes for reduced-order modelling composite materials and structures





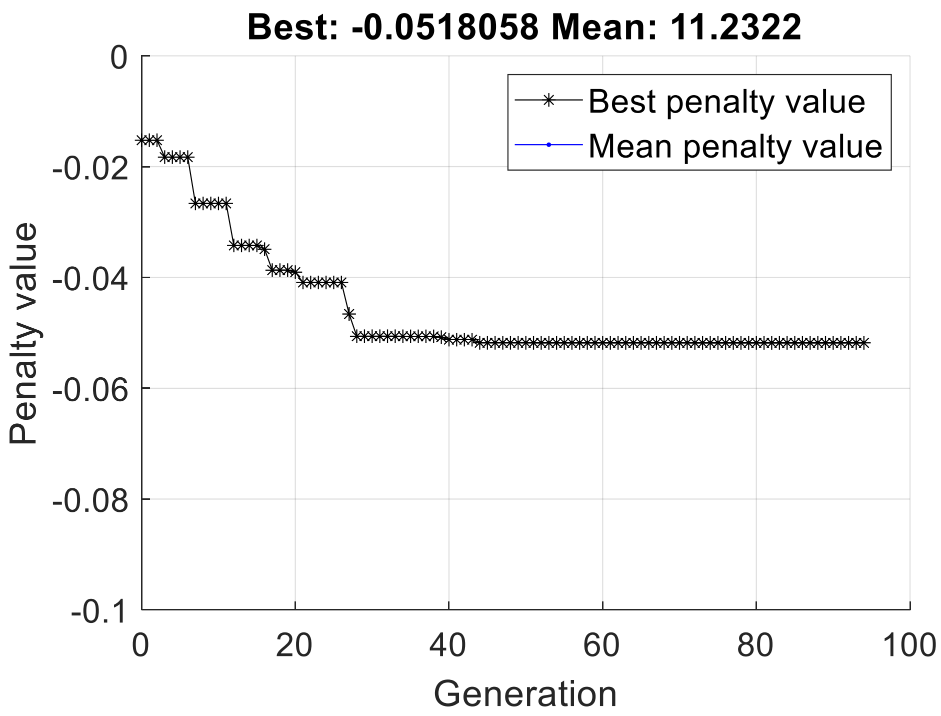






Challenges and solutions

❖Requirements of rapid prediction and sizing



	FOS	layer ID	y-coord (m)
upper skin	2.60133568	4	0.25
lower skin	2.71619211	2	1.70
upper reinforced skin	2.33813393	3	3.80
lower reinforced skin	3.47282684	3	3.80
upper end of front spar	4.88419451	11	1.70
lower end of front spar	3.45171318	2	1.70
upper end of aft spar	3.17730687	7	3.80
lower end of aft spar	3.08075236	2	3.80
upper cap of front spar	1.96140165	3	1.70
lower cap of front spar	2.24315115	3	1.70
upper cap of aft spar	2.47047202	3	0.25
lower cap of aft spar	2.98959355	3	1.70
upper side cap of front spar	2.85870416	1	0.25
lower side cap of front spar	2.67014848	2	0.25
upper side cap of aft spar	4.29909475	1	0.25
lower side cap of aft spar	3.68384631	2	1.70
front edges of ribs	5.89428556	2	3.60
rear edges of ribs	5.89428556	2	3.60
skin buckling	3.88054900		3.85
rib buckling	1012.56615713		3.85
skin deflection (%chord)	0.00000000		0.00
************************************			
wing mass (kg)	108.32419574		

Optimization of UAV structure by genetic algorithm combined with in-house composite material & structural analysis code

Challenges and solutions

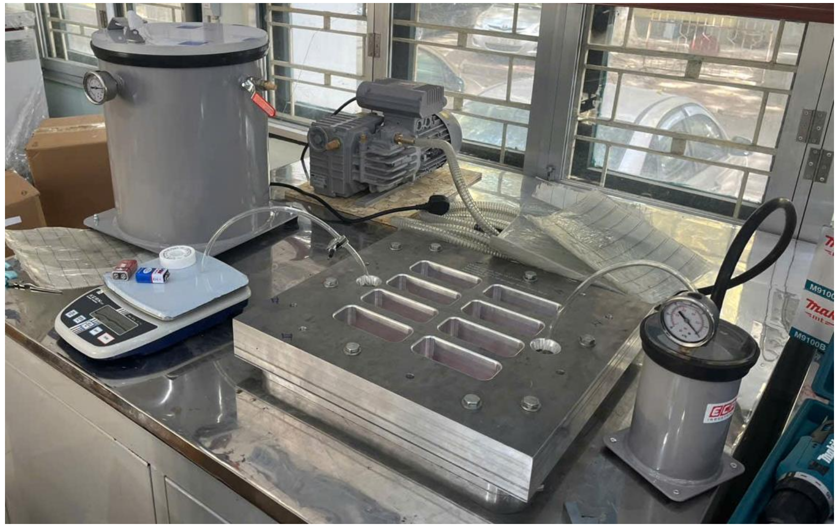
❖Lack of full-scale test platforms and facilities

- UAV design requires various test platforms related to aerodynamics, materials & structures, flight dynamics & control
- Test results used for validation and provide data that cannot be obtained by software

Challenges and solutions

❖Lack of test platforms and facilities

- Develop lab-scale test platforms

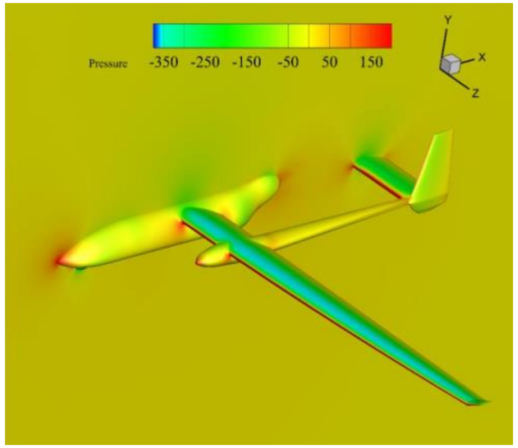


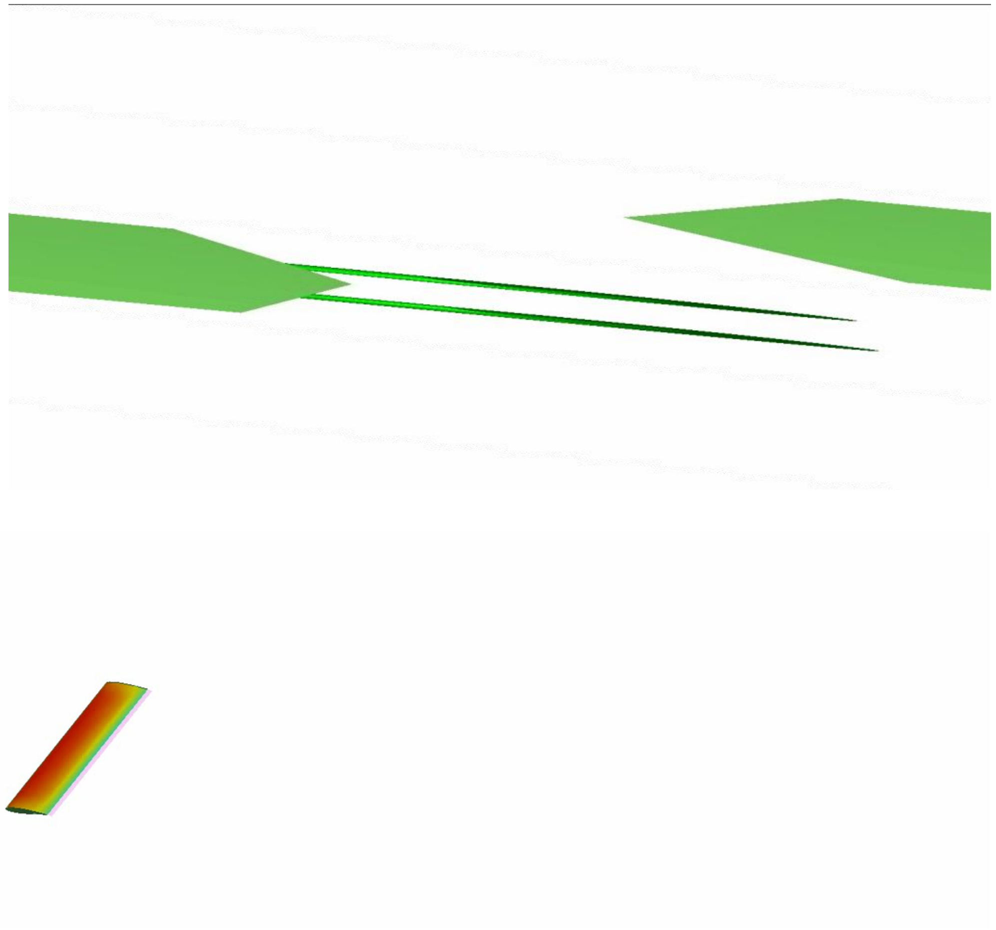
Lab-scale test platforms at the UAV laboratory

Challenges and solutions

❖Lack of test platforms and facilities

- Using high-fidelity commercial software





Conclusions

- UAV airframe design is a multi-disciplinary task that requires knowledge of many fields:
  - Mathematics
  - Computer science
  - Aerodynamics
  - Materials and structures
  - Flight dynamics and control
- UAV airframe design requires multi-scale test platforms and computation software as validation and analysis tools
- As full-scale tests are not available now, developing multi-fidelity in-house design codes combined with high-fidelity commercial software is necessary
- Lab-scale tests are important in the preliminary design phase
- High-performance and cluster computers are also required for neural-network training, parallel computing, optimization, and high-fidelity commercial software

Thank you for your attention!