Development of a Variable Stability, Modular UAV Airframe for Local Research Purposes

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Outline

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- UAV Related Facilities at the CSIR
- CSIR's Role in UAV-related Research
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  - Stability and Control Prediction Tools
  - Systems Integration Laboratory
  - Operational use of the UAV
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A Brief History of UAV Developments at the CSIR

Date	Airframe
Early 1980's	Seeker prototype
1988	Delta Wing UAV demonstrator
1992	Skyfly Target Drone Prototype
1989	OVID / ACE technology demonstrator
1993	Keen-eye RPV
1992	Hummingbird 2-seat observation aircraft prototype
1994	UAOS/Vulture prototype
2005	Indiza – Mini UAV
2007	Sekwa – unstable, tailless UAV

…and some assistance with other airframes on the way…

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UAV related facilities at the CSIR

Low Speed W/T

M < 0.3

High Speed W/T

M < 4.3

2 metre W/T

V < 35 m/s

7 metre W/T

V < 35 m/s

Future UAV SIL

ASC Offices

Future UAV Laboratory

Medium Speed W/T

M < 1.5

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CSIR's Role in UAV-related Technologies

- In 2003 the Aeronautical Systems Competency of the CSIR decided to reassess its role in the development of UAV related technologies
- Discussions took place with industry, the military and academia
- It was identified that the CSIR could add the most value to the local UAV industry in the design, optimisation, characterisation and simulation of UAV airframes
- In 2005 a hand-launchable mini-UAV, Indiza, was developed to improve our understanding of flight control and our experience with UAV autopilots
- The development of an optimisation capability was initiated

Initial Developments of UAV Related Technologies

In 2006 funding was received from the CSIR Strategic Research Panel to pursue four UAV related research topics.

The four topics were:

- The development of a 3-D fully coupled inviscid/viscous boundary layer code
- Piezo-electric actuation of composite structures
- Stability augmentation investigation through the variable stability UAV Sekwa
- Initial research into Sense and Avoid technologies

The Sekwa UAV project required a close collaboration with the University of Stellenbosch's Electronic Systems Laboratory on the development of control algorithms and the use of their autopilot.

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Collaboration with Stellenbosch University

- CSIR contributions to the Sekwa project:
  - UAV Design, Optimisation, Flight Dynamics, Manufacturing and Flight Test Management
- SU contributions to the Sekwa project:
  - Control system design, HIL Simulation, Avionics and Ground Control Station
- The collaboration was very successful with both parties benefitting through the experience of the other
- The decision was made to continue the collaboration once further funding could be sourced
- Typically the research is funded in such a way that PhD work focused on the development of new algorithms, architectures or philosophies for UAV control and the MSc work typically focused on the application of these algorithms to a particular problem and demonstrated practical results

So where were we in 2008?

- CSIR had the Indiza and Sekwa airframes – the products of two internally funded projects
- While these were capable airframes they had limited or no payload carrying capabilities and were not easily adaptable to other requirements
- The need for a larger UAV platform had been identified for reduced development risk

Initial Requirements for a New UAV Platform

Some of the initial research areas identified were:

- Characterizing of power effects on small airframes – CSIR
- Autopilot development - University of Stellenbosch
  - Non-linear control of airframe – flight up to and beyond stall
  - Gain scheduling autopilots – increasing the controllable speed range
  - Systems Identification – ability to determine UAV behaviour in-flight
  - Re-configurable autopilot – control of damaged UAV
- Single axis autopilot evaluation - University of Pretoria
- Solar powered flight demonstrator - University of Johannesburg
- Platform for testing/demonstrating:
  - Piezo electric actuators
  - Small gas turbine engines
  - Lightweight sensors – radar, electro-optic and other for sense and avoid research
- UAV Flight Test Techniques training

Funding for an Initial Development of a National UAV Research Capability

- In August / September 2008 the South African Department of Science and Technology approved the first amount of funding of a “National UAV Research Capability”
- This funding is being used to develop both a modular UAV airframe and a UAV Systems Integration Laboratory
- A strong driver behind the funding for this UAV is the human capital development of young engineers but only post-graduate degrees are supported

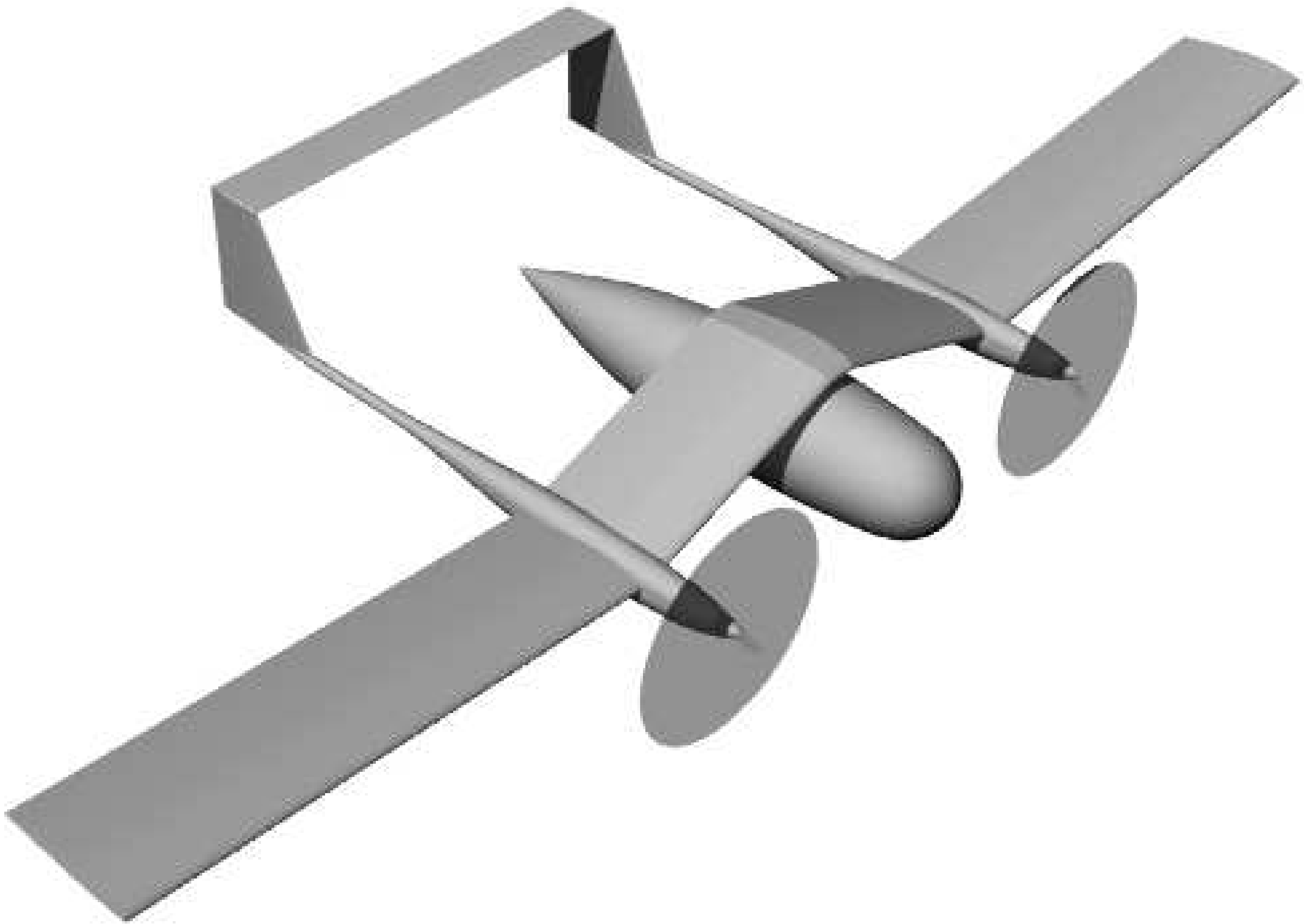
Modular UAV Conceptual Design

- The UAV had to be developed as a modular test bed for the testing of various airframe and payload technologies
- In order to improve reliability and hence reduce the flight test risks, electrical power systems were chosen
- Redundancy was included where possible in flight controls and propulsion systems
- All flight surfaces were to be as ‘configurable’ as required by the research (plug-on wings, tail etc)
- Video cameras were to be fitted to monitor various systems during flight tests
- A baseline model of 4 m span and 10 kg payload capability was chosen
- Typical flight durations were chosen to be of the order of 40 minutes

The Modular UAV Concept

- The baseline UAV airframe consists of two fuselages with constant chord wings and horizontal stabiliser
- Each of the two fuselages is functionally independent of each other and each contains the electric motors, propellers, controllers, batteries and flight control systems
- Typically the fuselage geometry limits the utility of UAVs so a payload pod (typically supplied by the client) is mounted under the central wing module carrying a maximum payload of 10 kg
- The mechanical interface between the payload pod and the wing is fixed but the payload pod geometry is not

Conceptual Geometry



UAV Conceptual Design (cont.)

- To maximise the potential range of payload masses and speed requirements, both the wings and stabiliser have been designed with constant chords
- The associated moulds allow relatively easy adjustment of the manufactured span or lateral spacing of the fuselages
- The root and tip fittings of these surfaces are formed by the placement of end units into the wing or stabiliser moulds
- The horizontal stabiliser has been designed both as a fixed stabiliser and elevator configuration and as ‘all flying’ stabilator with a servo tab for variable stability research
- The fixed stabiliser and elevator can be mounted at either the tips or roots of the fins
- All aerodynamic control surfaces are duplicated to reduce the chance of losing control and to allow the research into reconfigurable autopilots

Stability and Control Prediction Tools

- Work has begun on the further development of stability and control prediction codes based on the low order panel code CMARC and the in-house developed GUI and meshing tool
- Provides the capability to rapidly evaluate new configurations
- Power effect predictions are to be upgraded in the future
- Evaluations are also being done on some open source VL codes such as AVL and XFLR5
- Final validation of these tools will be carried out through comparisons with wind tunnel data

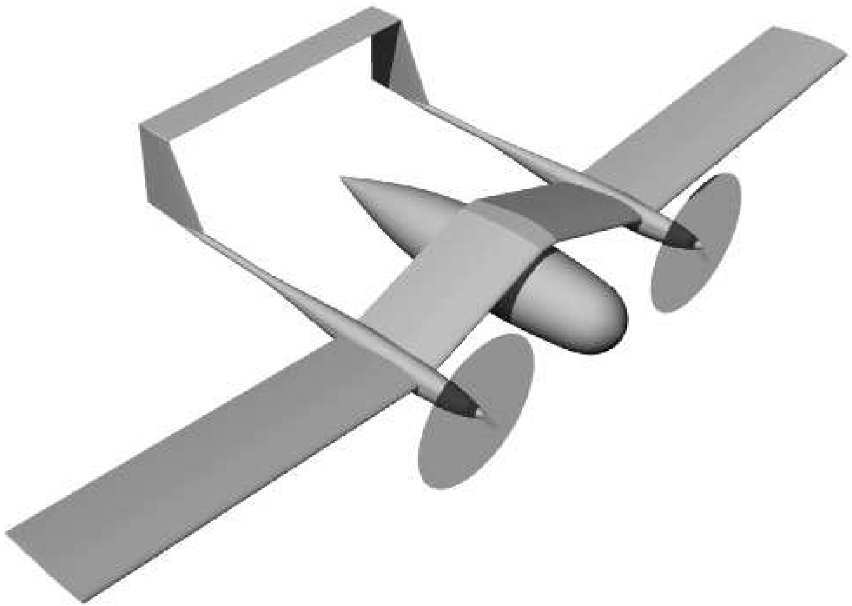
Current Research Partners

The funding is currently supporting Post-graduate research:

- University of Stellenbosch
  - Redundancy and Adaptation
  - Non-linear flight control
  - Sense and avoid technologies
- University of the Witwatersrand
  - Variable Longitudinal Stability
  - Non-linear Aerodynamics
- University of Pretoria
  - Multi-disciplinary Optimisation
  - Adjoint Methods in Optimisation

Research Areas – University of Stellenbosch

- Redundancy and Adaptation
  - Online system identification
  - Online diagnosis of UAV system failures
  - Redundant avionics with no single point of failure
  - Deterministic adaptation and reconfiguration of an autopilot for safe return to base



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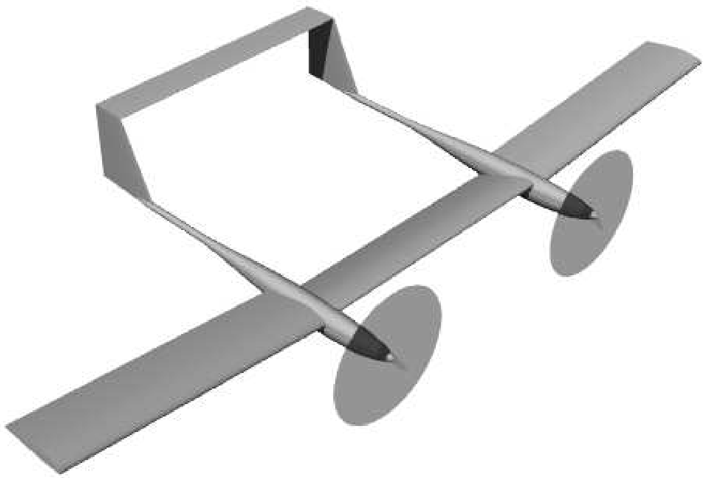
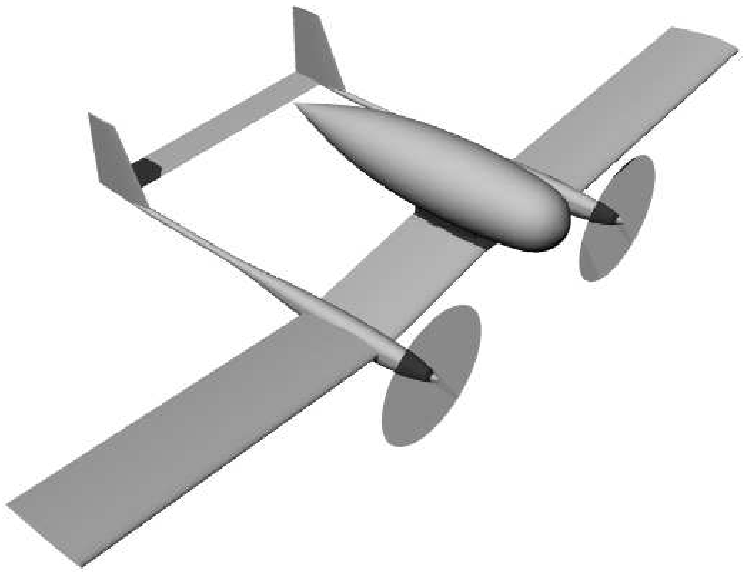
Further Research Areas

- Non-linear flight control:
  - Control algorithms for the prevention of stall
  - Algorithms for stall recovery
  - Algorithms for sustained near stall, high drag flight (useful for short landings)



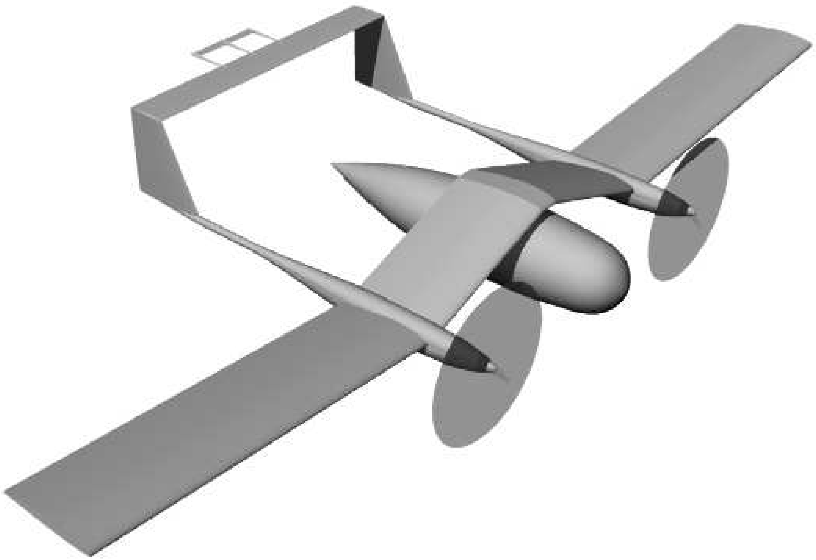
Further Research Areas

- Sense and avoid technologies:
  - Detection systems
  - Risk calculation
  - Avoidance algorithms

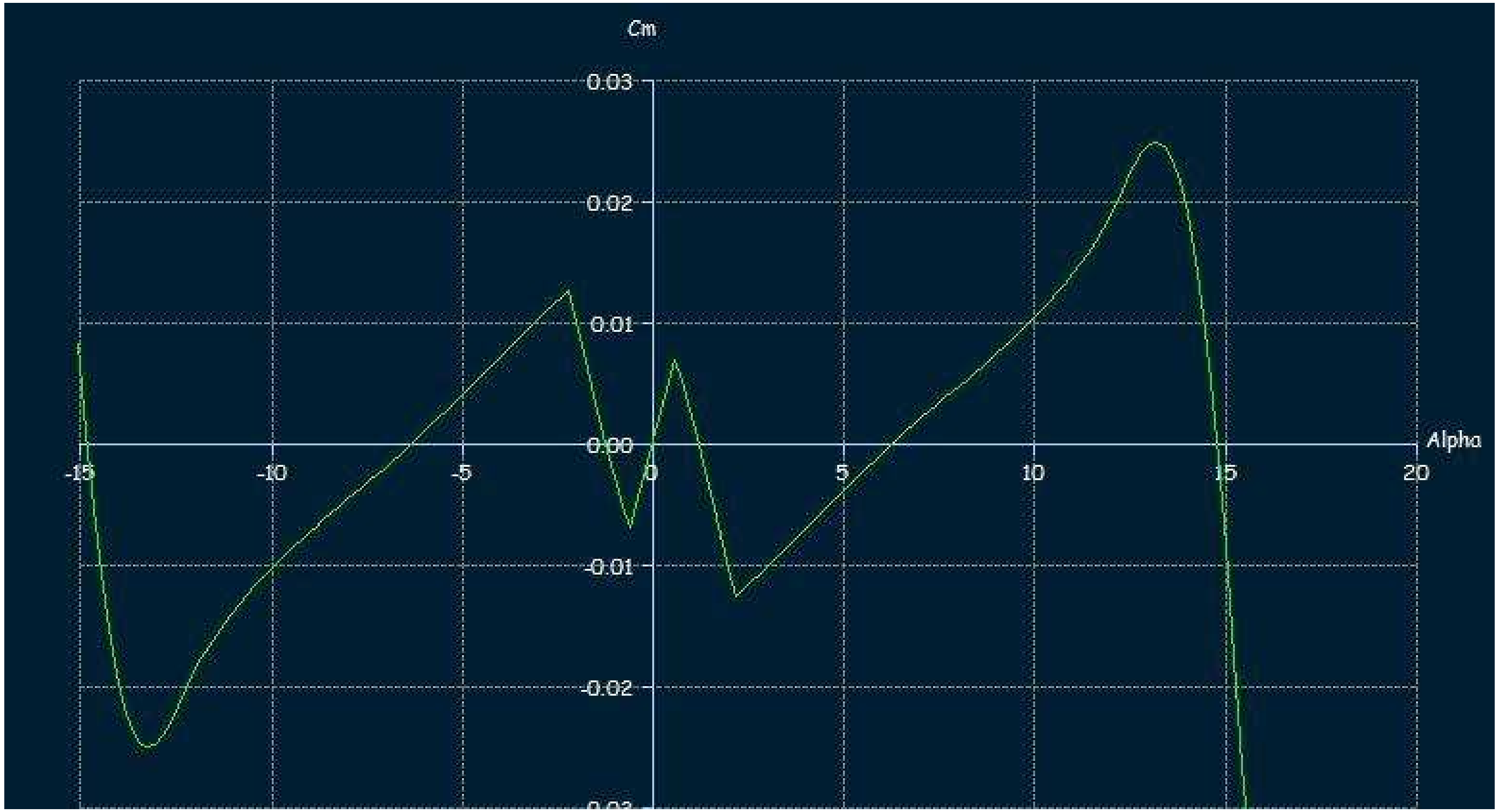


Research at the University of the Witwatersrand

- Variable pitch stability through the active control of the horizontal stabiliser – not a NACA 0012
  - This requires a ‘floating’ stabilator with a servo tab controlling the stabiliser deflection angles
  - The contribution of the stabiliser forces to the overall stability of the airframe is measured through fin tip mounted load cells and the effectiveness of the stabiliser actively controlled by the autopilot through the servo tab
  - The resultant effect is the ability to actively move the neutral point as required in flight



SD-8020 Low Reynolds Number Aerofoil Cm Curves



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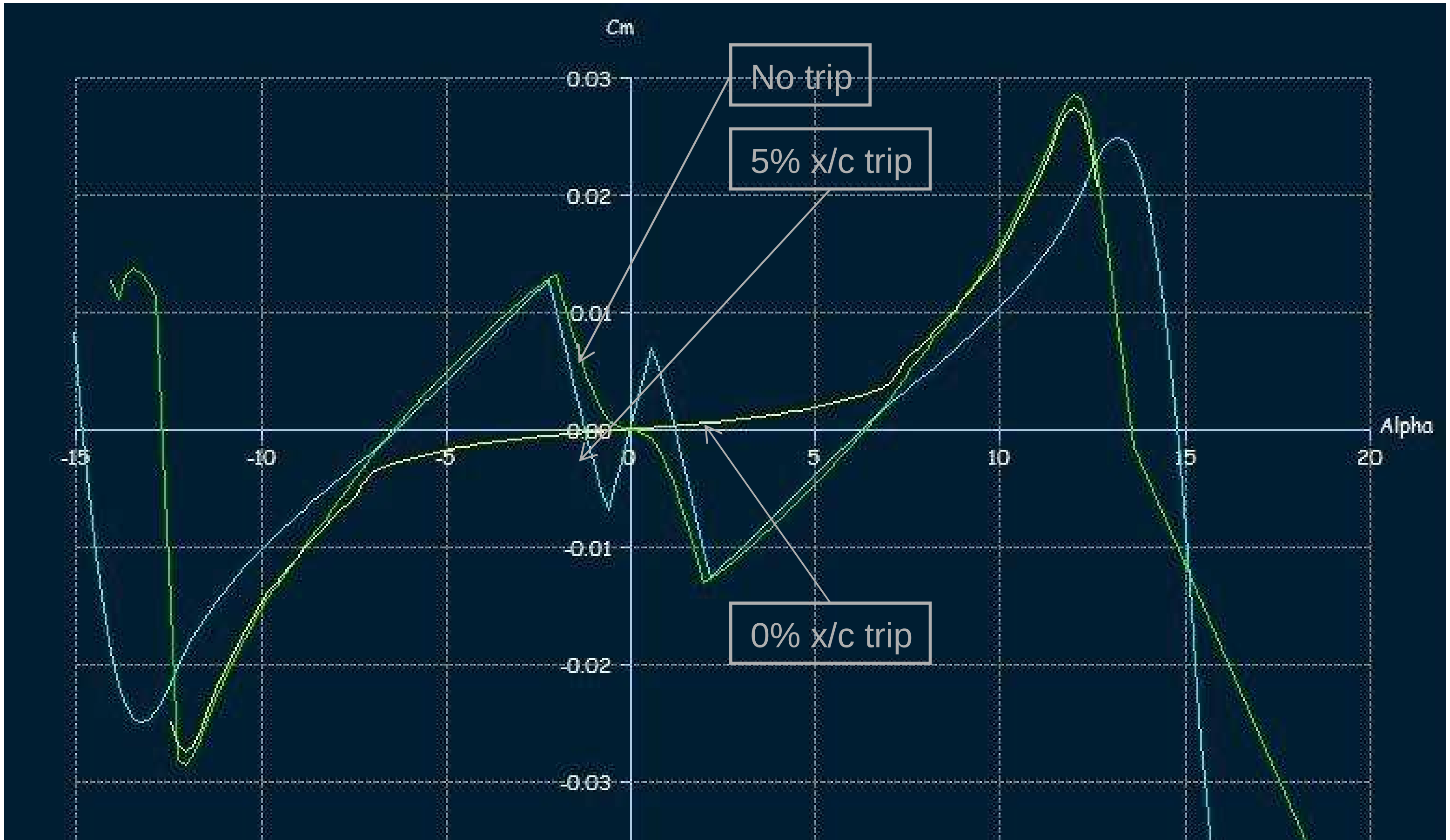
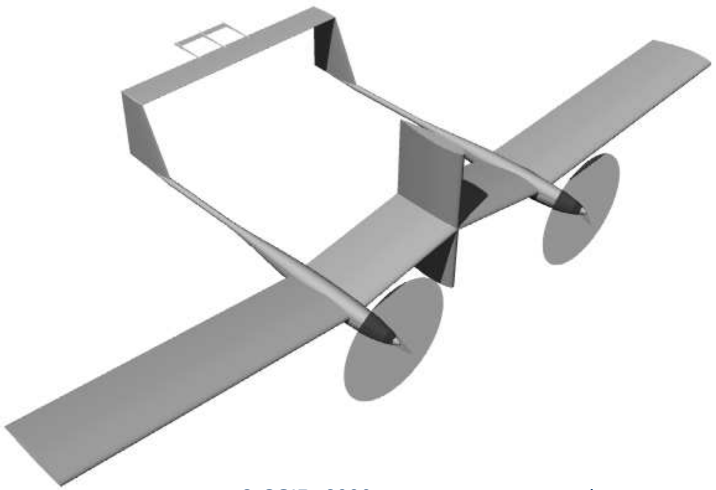
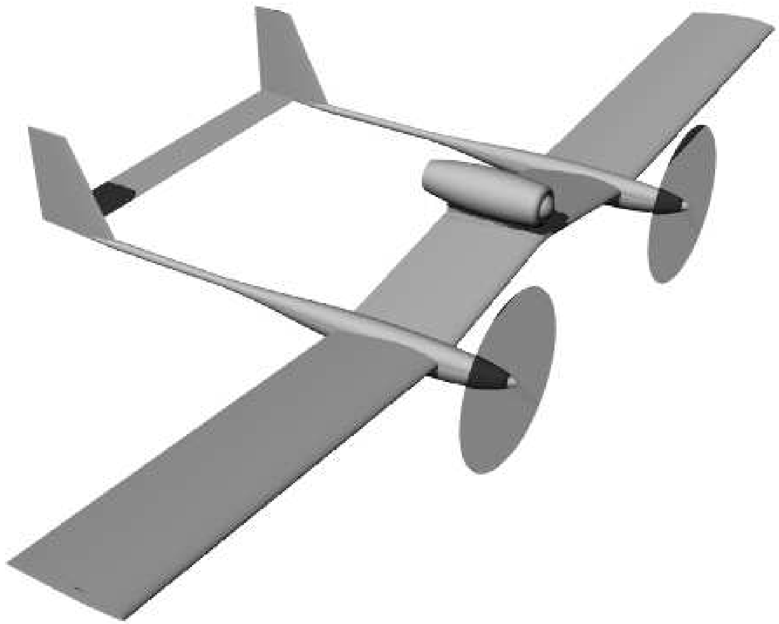


Future Research Areas

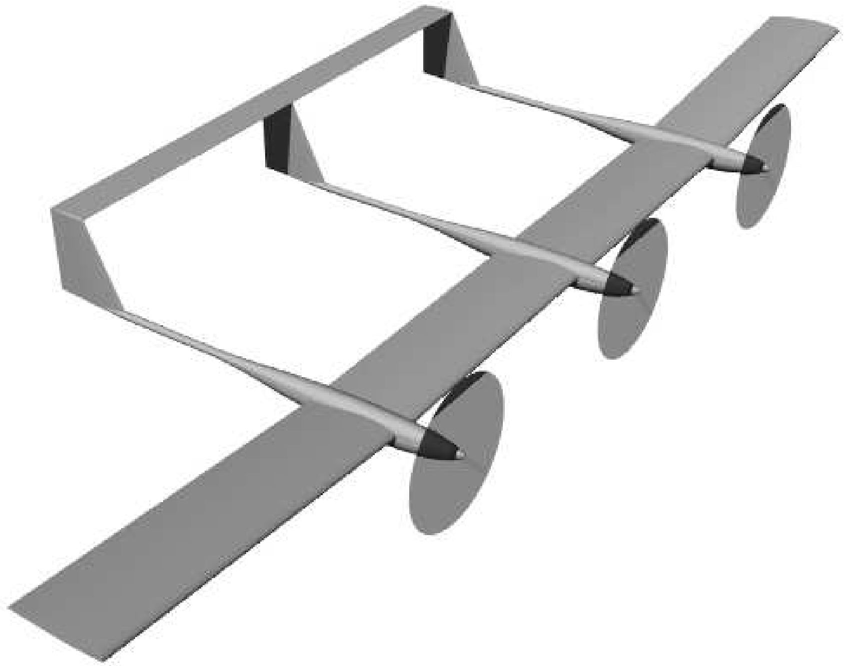
- The adjustment of the static stability derivatives in all three axes through the use of active control surfaces is envisaged for the future
- Side force generators would be included on the central wing module to modify the lateral derivatives
- Separate control surfaces mounted on the upper and lower surfaces would provide the capability to correct the lateral force induced rolling moments
- The emulation of the behaviour of a range of UAV platforms with a single research platform is the ultimate goal of this work



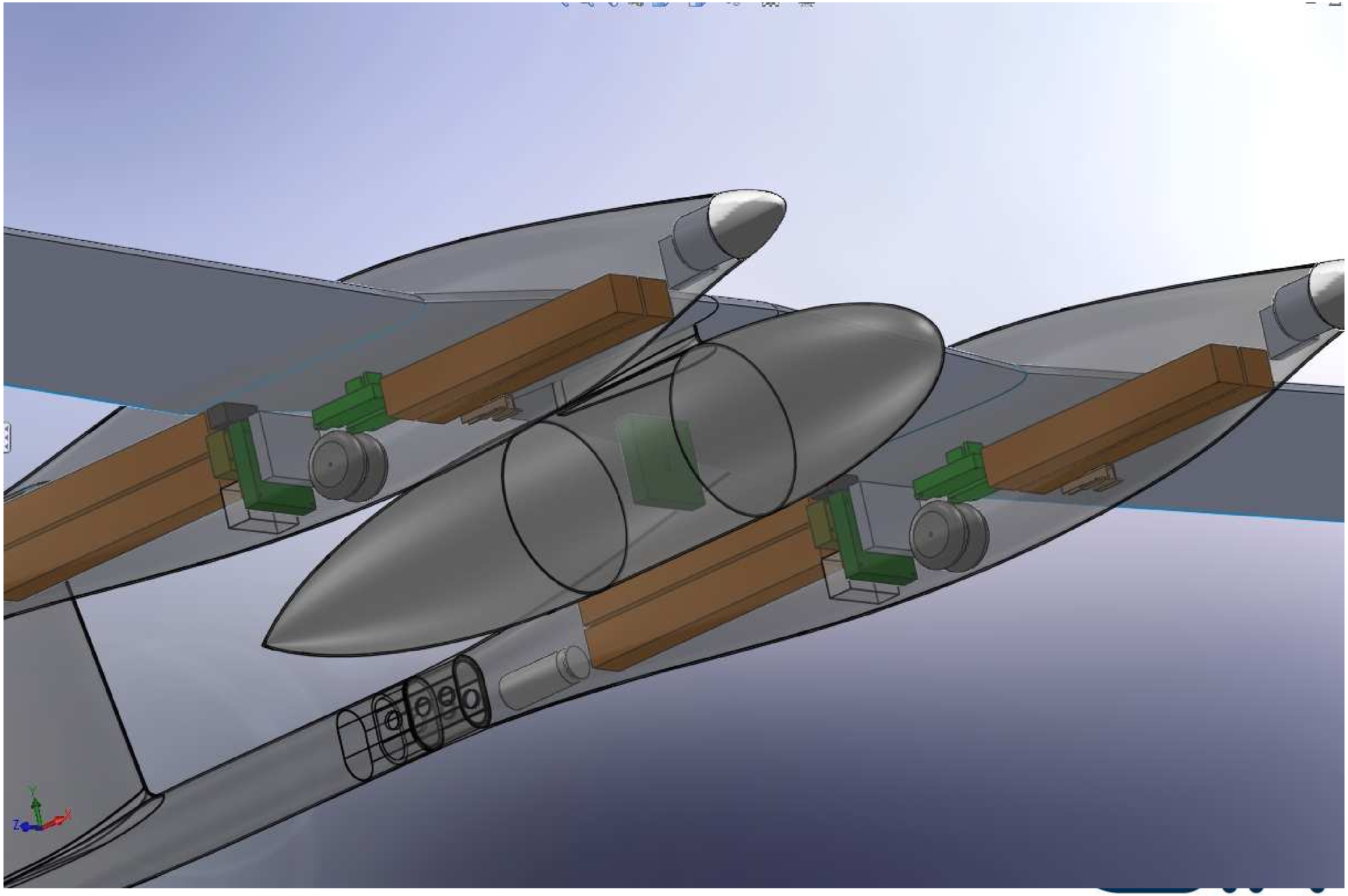
Gas Turbine Engine Platform?



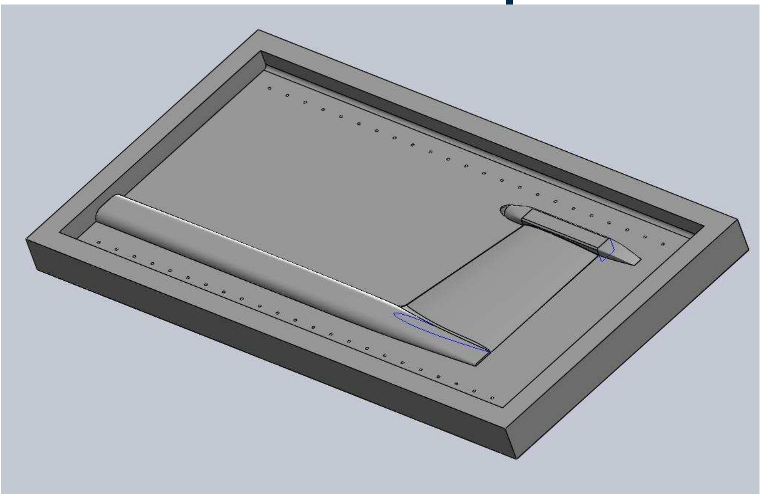
Solar UAV Demonstrator Platform?

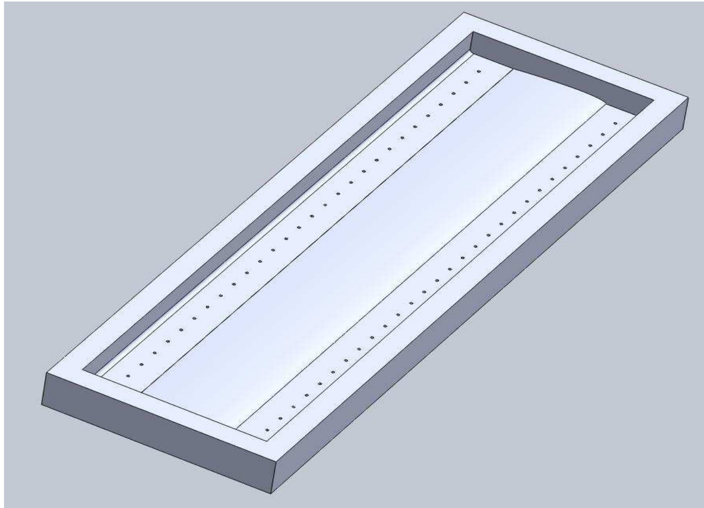


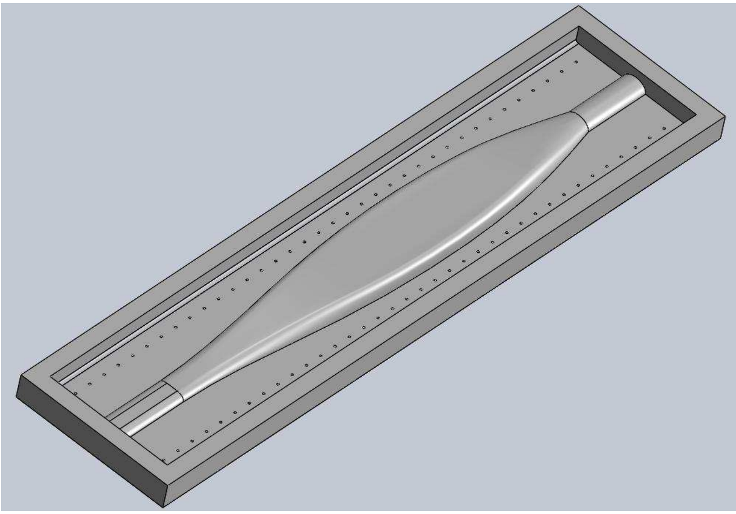
Current Design Progress

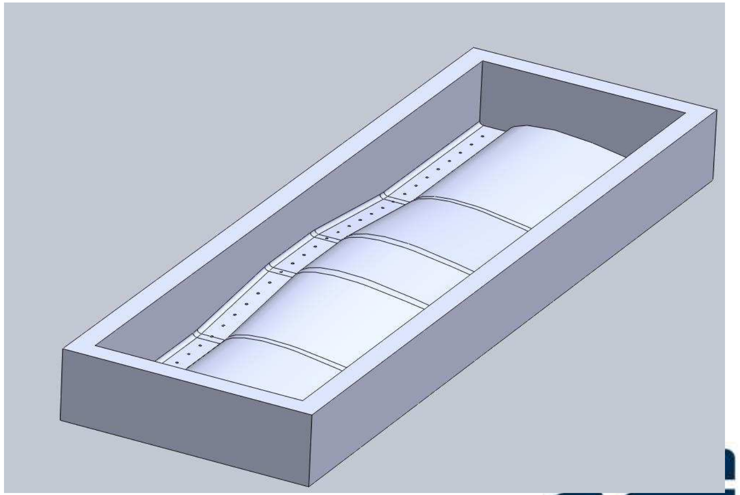


Pattern Concepts









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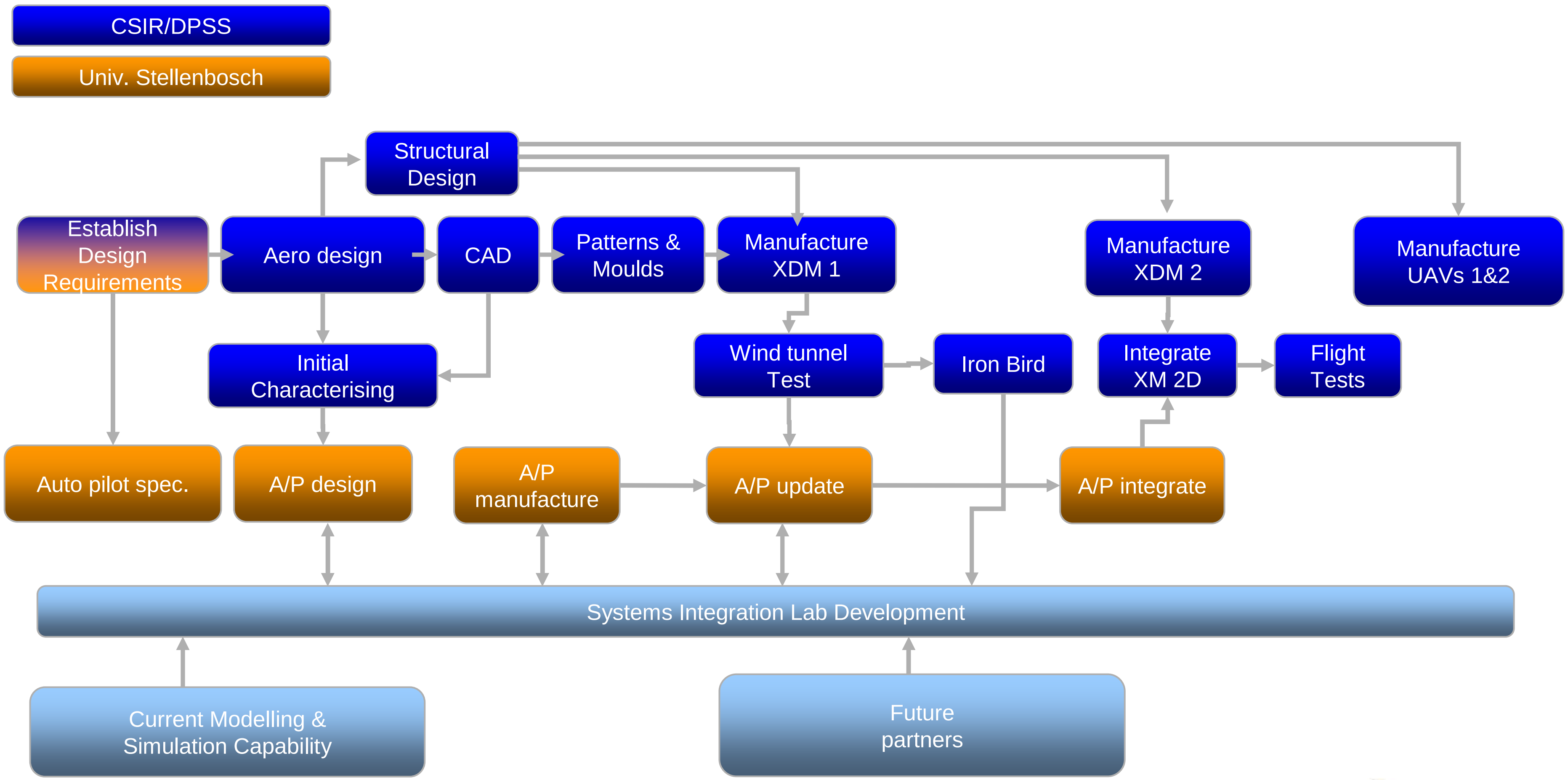
Operational Use of the UAVs

- Four UAV airframes are being constructed, one for wind tunnel testing, one for initial flight tests, one each for the CSIR and University of Stellenbosch for future research
- Both institutes have a strong UAV flight test background and both institutes will have full flight test authority on the airframe
- Any system destined for testing on the UAV is first tested in the systems integration laboratory – for functionality and safety

UAV System Development Plan



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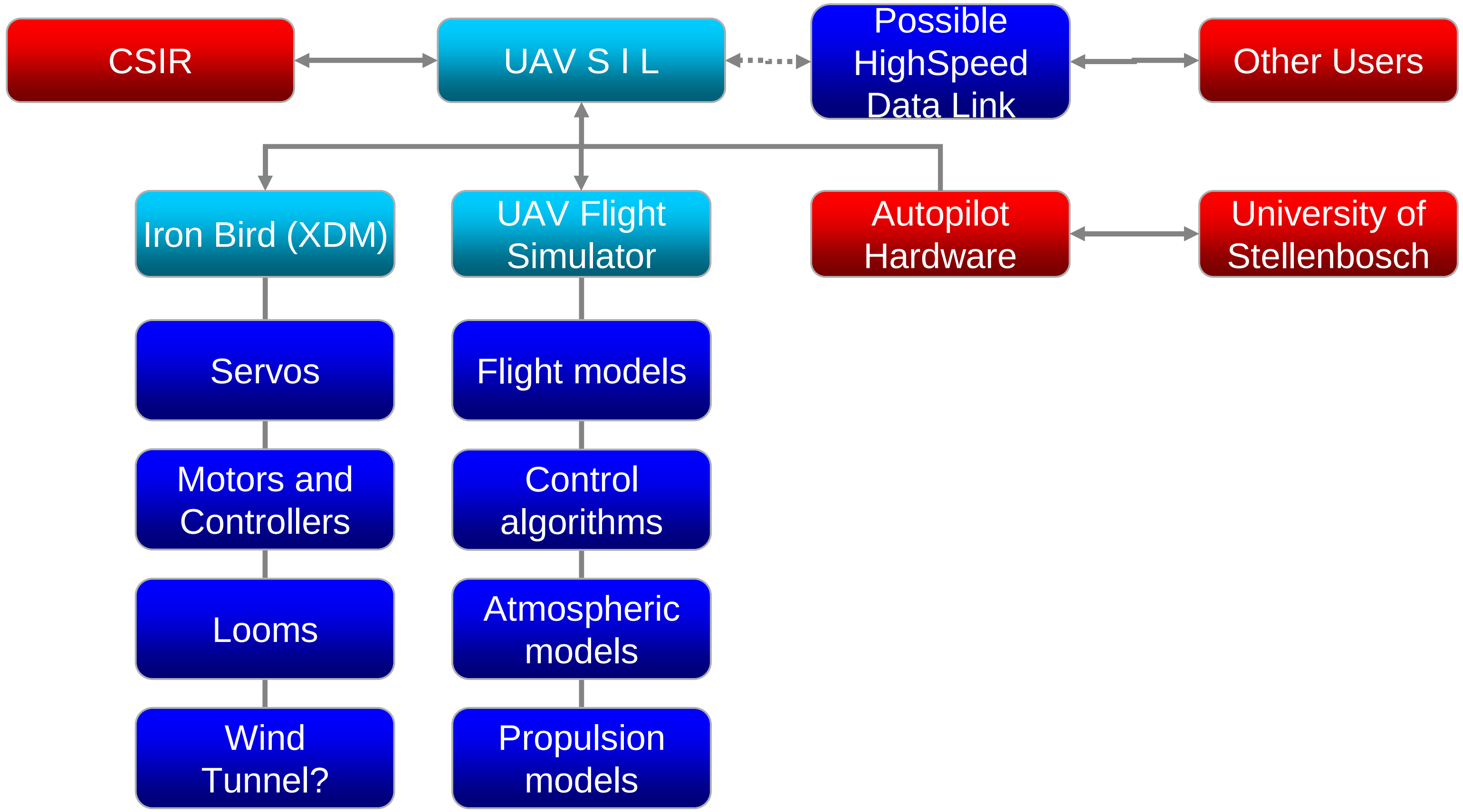
UAV Systems Integration Laboratory



Concluding Comments

- A UAV is not necessarily the optimum platform for the demonstration of research capability
- There are many items that could be more efficiently tested on a manned aircraft

Having said that…

- It is however a great passion driver for students

The modular UAV will ultimately be used as a flight demonstrator for most of the previously mentioned research topics