Multi-mission Unmanned Aerial Vehicle Concept: Modeling Status

Sinha, A.K.*; Schauenburg, A.*/; Brueckner, B.****
***The Sir Lawrence Wackett Centre for Aerospace Design Technology, RMIT University, Australia**
****Lehrstuhl für Luftfahrttechnik *llt*, Technical University of Munich, Germany**

Keywords: *Re-configurable Multi-mission UAV*

Abstract

Presently Unmanned Aerial Vehicle (UAV) missions are met by a large inventory with operational and logistical challenges. In this paper the new design concept of re-configurable UAV (RC-UAV) is analysed by the development of a 3D-model in CATIA V5. The model demonstrates the payload design of the Unmanned Combat Aerial Vehicle (UCAV) as an illustration, being one with a wide range of systems onboard. The design process discussed covers the transformation of a conceptual design process to an intelligent system that produces the viability of module matching to reconfigure a multi mission UAV from a base-design module.

1 Introduction

In recent military operations Unmanned Aerial Vehicle (UAV) systems have proved valuable, especially in the "War on Terror" [1], [2], [3] paving the way for further investigations and technological development. The issues and challenges of UAV technology range from operational to logistical and budgetary support [4]. This places a key challenge on the operators who have to operate and support the large inventory.

The challenges to operate and support a large UAV inventory is acknowledged worldwide [4], however, no major attempts were made to address these. Sinha et al. [5] adopted a systems approach to address the issues and challenges of the large inventory. The result of this procedure was a multi-mission concept (Re-configurable UAV - RC-UAV) in contrast to the present uni-mission concept under technology demonstration and development [6]. The concept is based on "commonality of mission systems" on board UAVs and the slated "flight performance" (*Figure 1*). Sinha et al. [7], [8] demonstrated the application of commonality analysis of mission systems to form a multi-mission payload. Furthermore Nguyen et al. [9] explored the methodology developed by Sinha et al. [7], [8] to develop a Windows®-based software for modular matching and evaluation of system effectiveness of the multi-mission concept.

The RC-UAV is to cover a wide range of missions, endurance and altitudes. The mission payload is to include armament, survivability, observation, navigation, communication, obstacle detection & avoidance and control systems.

Further investigation focussed on the analysis of payload configurations to evaluate mission and performance effectiveness of the RC-UAVs by applying the developed software. It provided a comparison with existing single mission UAVs. The RC-UAV reduced the inventory of the UAV fleet significantly and provided the required multi-mission capability [9]. The RC-UAV software furthermore obtains a basis for a multi-mission payload analysis to derive the specific components of a multi-mission UAV (MM-UAV) fuselage. The preliminary CATIA V5 model has been improved in its design to allow a definition of the internal space allocation with all mission related payload components.

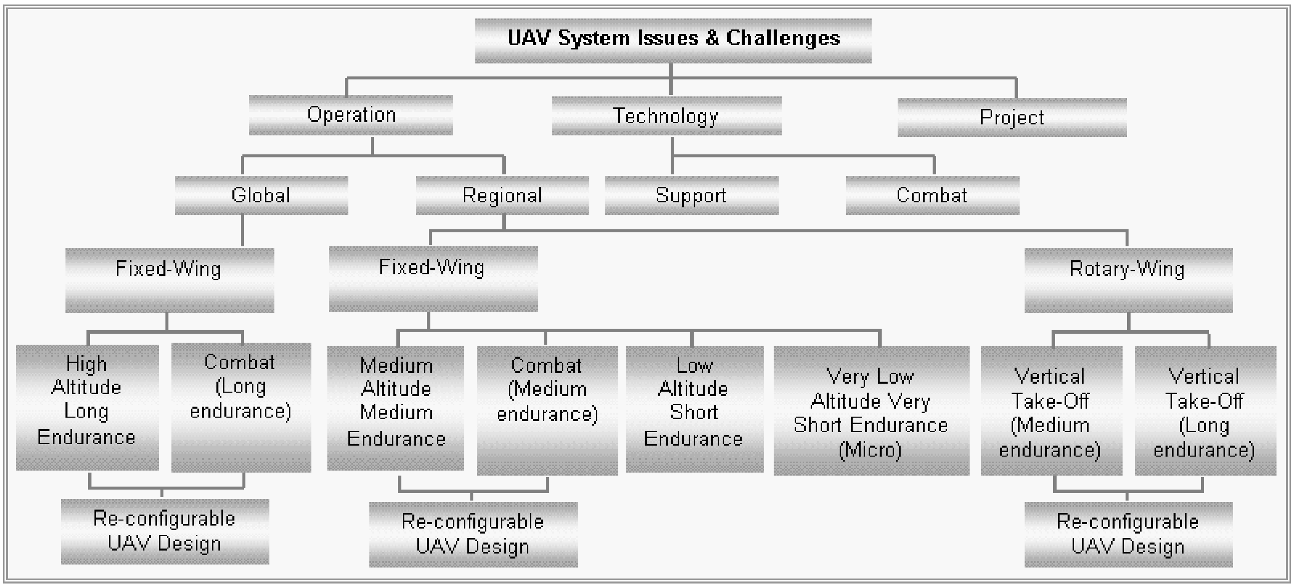


Figure 1*: Multi-mission Groupings of UAVs from an Operational Perspective*

This model provided a further base for centre of gravity (CG) evaluations to address weight and balance.

The research focus is currently on the wing design and the definition of the interfaces of the fuselage sections and wing attachments to address time bound re-configuration. Further investigations will cover the flight performances of all fully equipped configurations.

2 Design Specification

To define RC-UAV design specifications, UAVs in service and those under design and development were investigated [6]. The research led to four sets of design specifications to be achieved through the design process. The four classes of RC-UAVs considered are as follows: a) High altitude medium endurance – HAME; b) Medium altitude medium endurance – MAME; c) Low altitude medium endurance – LAME; and d) Unmanned combat aerial vehicle – UCAV. The technical specifications are presented in *Table 1*. The UCAV is considered to carry the widest range of payload and has therefore been focused on as the first vehicle to be modeled in the payload design analysis.

3 Modeling Process

The modeling process developed over seven months included a multi-mission analysis by using the MM-UAV software to obtain performance numbers like takeoff or landing field lengths, speeds, endurances, maximum ceilings, ranges and payload capacities. The next step involved the implementation of payload into the 3D model in accordance to off-the-shelf available mission systems. A fully loaded UCAV 3D-model was tested for its flight mechanical stability and balancing to position the CG.

4 MM-UAV Software

The developed Windows®-based MM-UAV software is the fundamental tool for the multi-mission analysis and provided the basis for a multi-mission payload definition. The software consists of a stepwise input process through a graphical user interface. The design specifications according to *Table 1* are entered in the first window. Every circle requires the user to define three missions which can be chosen out of four mission types: Surveillance, Communications, Light Attack and Cargo Deployment, where the surveillance and communications mission are of the same flight envelope. They practically can be operated in the categories HAME, MAME, LAME and UCAV. The software produces effectiveness numbers of each configuration as well as for the set of the combination of the three missions.

Table 1: *Design Specifications of Multi-mission RC-UAV – LAME, MAME, HAME and UCAV*

Requirement	**LAME**	**MAME**	**HAME**	**UCAV**
Cruise Speed (at mission Alt)	<Mach 0.3	<Mach 0.3	Mach 0.3	Mach 0.5-0.6
Loiter Speed (at mission Alt)	<Mach 0.3	<Mach 0.3	Mach 0.3	<Mach 0.5-0.6
Operational Altitude	<10,000 ft	20,000 ft	40,000 ft	20,000 ft
Payload Mass	100 kg	250 kg	350 kg	500 kg
Endurance	12 h	24 h	24 h	4 h
Range Radius	200 km	500 km	1000 km	1000 km

The iteration circle of the MM-UAV software is presented in *Figure 2*. The mission categories are combined with the four mission types surveillance, observation, light attack and cargo deployment. These four main tasks of the MM-UAV combined with four categories result in 16 pairs. However, only nine have been found appropriate to be operated by the RC-UAV in service. These are surveillance and observation respectively in HAME, MAME and LAME as well as the cargo deployment being operated in the UCAV and MAME

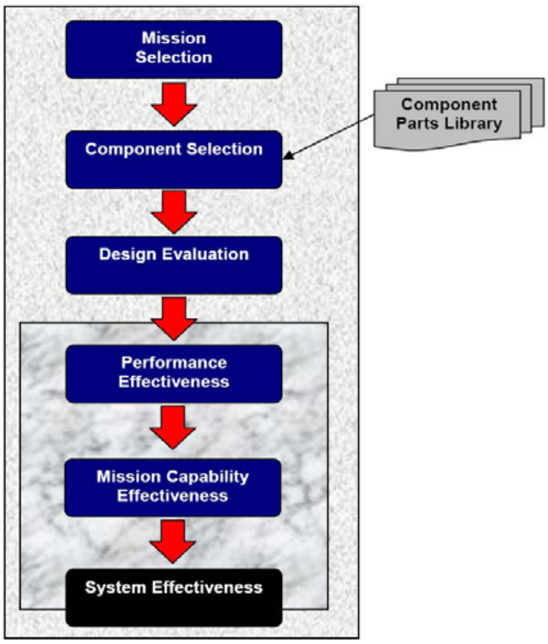


Figure 2*: MM-UAV Software Flow-Chart*

category. The light attack mission is only performed in combination with the UCAV category. Other combinations like a communications mission flown by the UCAV or cargo deployment in a HAME mission are not suitable in the RC-UAV mission range. The first window furthermore requires the user to enter a maximum required takeoff and landing field length. The second window employs the component parts library where the type of fuselage, wing, tail and engine design is defined. The modular system as shown in *Figure 3* allows various combinations of parts to assemble two complete UAV systems in the same time. Each part is associated with performance characteristics. The turbofan engine is for UCAV, MAME and HAME missions and the piston engine for LAME operations. The "design evaluation" window provides an idea of the performance achieved by the configuration by reviewing the entered numbers compared to the actual performance of the UAV. Next, the "performance effectiveness" window allows the possibility to enter priority vectors and weighting scores for each performance number and mission (*Figure 4*).

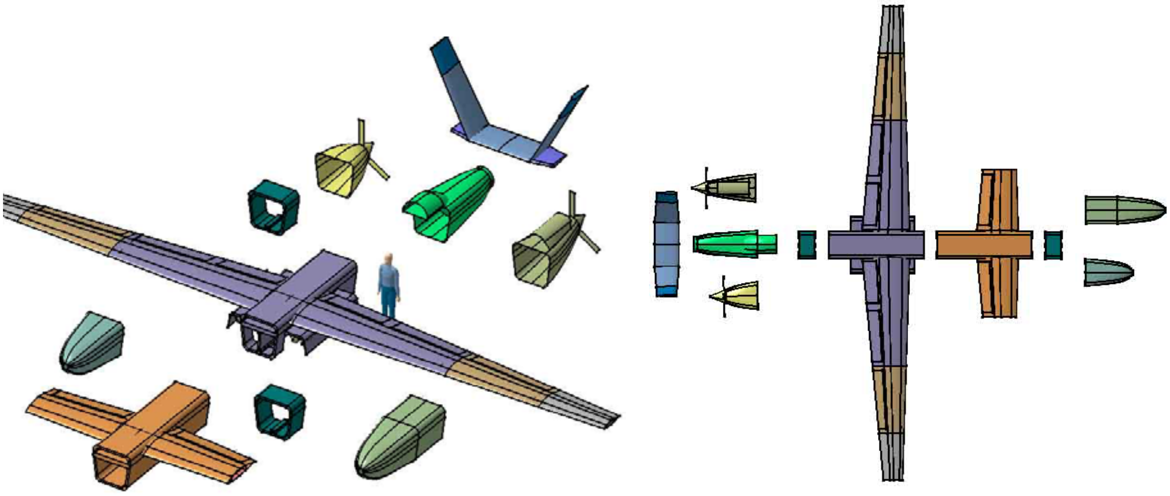
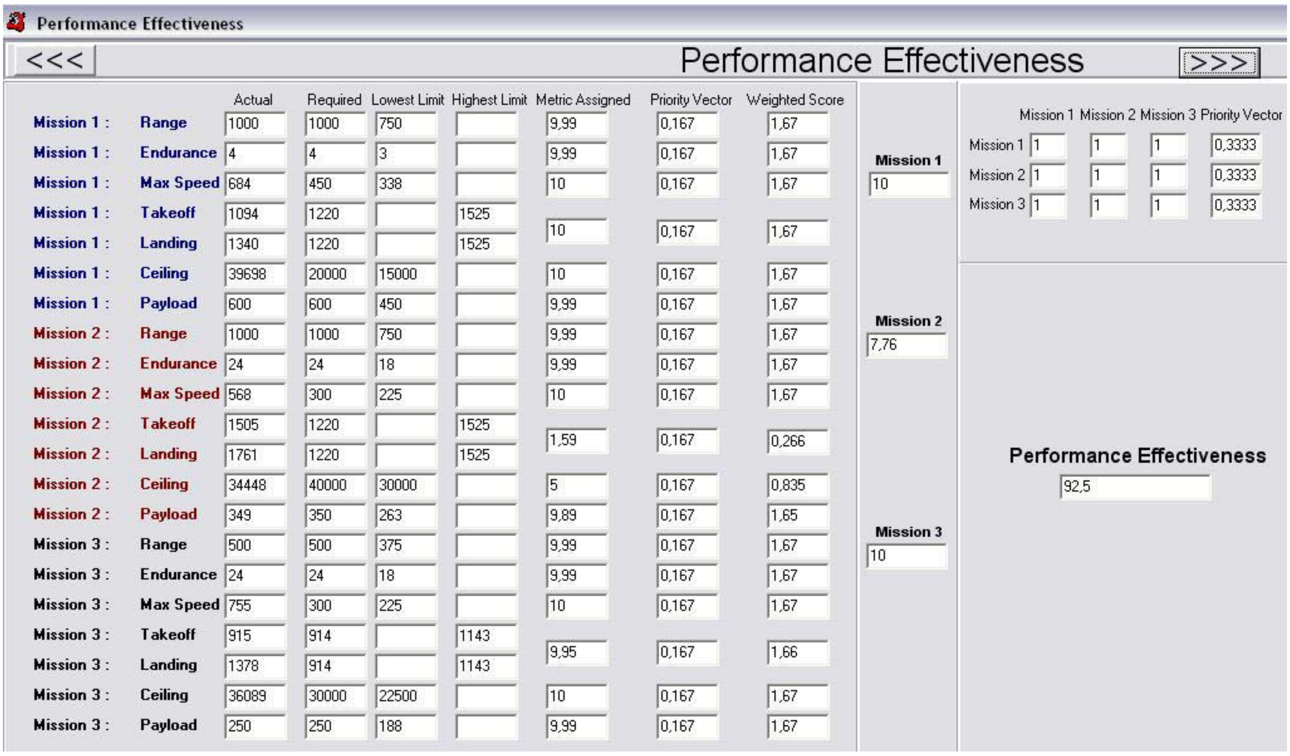


Figure 3: *Modular Design Concept for Re-configurable Unmanned Aerial Vehicle*



Performance Effectiveness

<<< Performance Effectiveness >>>

		Actual	Required	Lowest Limit	Highest Limit	Metric Assigned	Priority Vector	Weighted Score
Mission 1 :	Range	1000	1000	750		9,99	0,167	1,67
Mission 1 :	Endurance	4	4	3		9,99	0,167	1,67
Mission 1 :	Max Speed	684	450	338		10	0,167	1,67
Mission 1 :	Takeoff	1094	1220		1525	10	0,167	1,67
Mission 1 :	Landing	1340	1220		1525			
Mission 1 :	Ceiling	39698	20000	15000		10	0,167	1,67
Mission 1 :	Payload	600	600	450		9,99	0,167	1,67
Mission 2 :	Range	1000	1000	750		9,99	0,167	1,67
Mission 2 :	Endurance	24	24	18		9,99	0,167	1,67
Mission 2 :	Max Speed	568	300	225		10	0,167	1,67
Mission 2 :	Takeoff	1505	1220		1525	1,59	0,167	0,266
Mission 2 :	Landing	1761	1220		1525			
Mission 2 :	Ceiling	34448	40000	30000		5	0,167	0,835
Mission 2 :	Payload	349	350	263		9,89	0,167	1,65
Mission 3 :	Range	500	500	375		9,99	0,167	1,67
Mission 3 :	Endurance	24	24	18		9,99	0,167	1,67
Mission 3 :	Max Speed	755	300	225		10	0,167	1,67
Mission 3 :	Takeoff	915	914		1143	9,95	0,167	1,66
Mission 3 :	Landing	1378	914		1143			
Mission 3 :	Ceiling	36089	30000	22500		10	0,167	1,67
Mission 3 :	Payload	250	250	188		9,99	0,167	1,67

Mission 1	10
Mission 2	7,76
Mission 3	10

	Mission 1	Mission 2	Mission 3	Priority Vector
Mission 1	1	1	1	0,3333
Mission 2	1	1	1	0,3333
Mission 3	1	1	1	0,3333

Performance Effectiveness

92,5

Figure 4*: Screenshot of Performance Effectiveness Window*

It defines the mission effectiveness on a scale from 0 to 10 (*Figure 5*) for each of the three missions and a performance effectiveness for the whole set. According to the actual performance and the number of parameters met by the configuration, a maximum of 100% can be achieved. This number is furthermore dependant on the lower and higher limits defined by the user. The fifth window obtains the user the mission capability effectiveness. This performance figure considers the weight and volume penalty of the MM-UAV compared to a single mission UAV. The last window is the “system effectiveness” number derived from the MM-UAV inventory and mission capability effectiveness. The cycle through the software is an iteration circle which is repeated until the mission requirements are met by the defined configuration from window one and two.

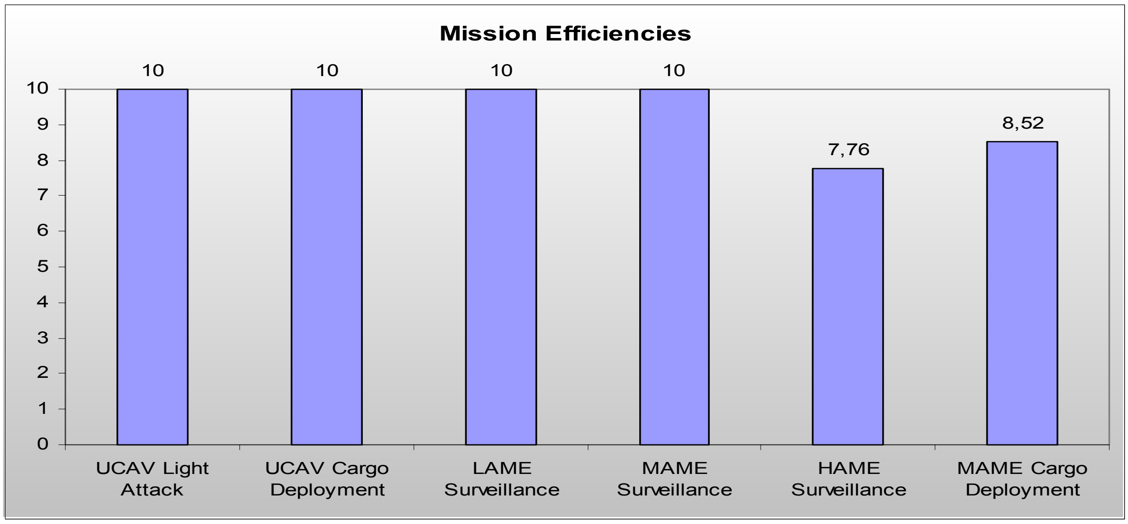


***Figure 5**: Mission Efficiencies*

Over a period of seven months the MM-UAV software has been used to obtain the most efficient UAV configurations for each mission type. In this frame the surveillance and observation missions have been considered to be of the same nature as their flight envelopes are identical. This reduces the complexity of the investigation. However, the MM-UAV design philosophy justifies itself by covering a wide range of missions. The performance effectiveness numbers decrease if similar mission types or categories are entered in one circle, as e.g. a MAME cargo deployment, UCAV light attack and a HAME surveillance mission. All three mission specifications are located in a narrower frame regarding range, altitude and endurance. These combinations have been found less efficient as the main task of the RC-UAV is to employ a wider range of missions. *Figure 5* shows the results of the mission system efficiency analysis. It can be seen that out of the six mentioned pairs; four pairs meet the requirements given in *Table 1*. The HAME surveillance / observation and the MAME cargo deployment mission cannot achieve the maximum ten points due to the necessity of a longer takeoff and landing field length. The HAME and MAME configurations employ a FJ44-1 turbofan engine of 1900 lbs thrust to meet the required field length. The landing distance is a matter of the use of right brake coefficients and is measured without thrust reverser and a brake parachute for assistance. The analysis helps to identify the requirement of a more powerful engine and stronger brakes and the consideration of employing a brake assistant device (e.g. parachute, thrust reverser). Depending on the failure of the performance values compared to the original set requirements, the mission efficiency is decreased. The system has currently been upgraded to the FJ44-2A engine providing 21% more thrust (2300 lbs). The most efficient UAV configurations are generally the ones employing minimum fuselage length to reduce the takeoff weight. This reduces the potential payload capacity, however, as long as no cargo or weapons are carried in the centre fuselage, sufficient space is available to satisfy the payload's internal space requirements. Therefore the UCAV features the maximum fuselage length by combining the large nose, the mid-forward and -rear fuselage extensions and the large tail section. As seen in *Figure 5*, the UCAV still meets the requirements due to the relatively low endurance of 4 hours compared to 24 hours in the HAME and MAME configurations.

5 Payload Analysis and implementation in CATIA V5 Model

The multi mission configuration analysis led to the identification of the required payload by comparing the specific task of the MM-UAV defined through the software with exiting UAVs in the category of 200kg and more takeoff weight [6]. The identified payload comprises of the following categories:

- *Surveillance & Observation Equipment:* The surveillance and observation equipment employs electro optical and infra red cameras (EO/IR, FLIR) as well as a synthetic aperture radar including a moving target indicator (SAR/MTI).
- *Communications Equipment:* The communications system uses various frequency bands for Line of Sight (LOS) and Satellite Communication (SATCOM). The system employs two bands for SATCOM, (Ku-Band and Ultra High Frequency - UHF) consisting of two antennas and various control devices in the fuselage. The LOS communication is performed through Data Link and UHF transceiver antennas.
- *EW Systems:* The electronic warfare (EW) system is assembled on a modular base dependant on the mission requirement. The system utilises mainly radio and IR jammers, a towed decoy, a radar warning receiver, chaff and flare dispenser and an IFF (Identification Friend / Foe) system. The chaff and flare dispenser is combined with a missile approach warning receiver. The system is only implemented in operations over combat areas due to its high complexity and weight.
- *Integrated Systems:* The integrated system hosts flight control and command systems. It includes navigation computers, remote control systems for the equipment (cameras, sensors, Electronic Warfare (EW) systems, radars, etc.), weather information processing, and weapons control system, etc. The external assembled Global Positioning System (GPS) and optional Differential GPS (DGPS) antennas provide information for the system.
- *Weapons:* One of the two centre fuselages has been primary designed for the use of four Rockwell Hellfire missiles. Presently it is investigated if the weapons inventory can be enlarged by other air-to-ground (AGM) missiles (like Stinger).
- *Cargo Deployment System:* The cargo deployment system is currently in its preliminary design. The deployment procedure will be a low velocity air drop (LVAD) as performed from larger cargo aircraft in military and civil operations.
- *Basic Components:* The basic components include the electrical power distribution unit, a generator, the Pitot tube, fuel tanks, actuators, the landing gear, the hydraulic and electronic systems or the air cooling fans for the avionics compartment and others.

The systems have been implemented into CATIA V5 according to the suppliers' specifications to define the internal space allocation and the CG (*Figure 6*). However, specific parts could not be characterised due to the preliminary design of the UAV. This applies to the hydraulic and electric system as well as the design of actuators and the landing gear. It will be addressed when the flight mechanical and aerodynamical performances and forces are sufficiently investigated.

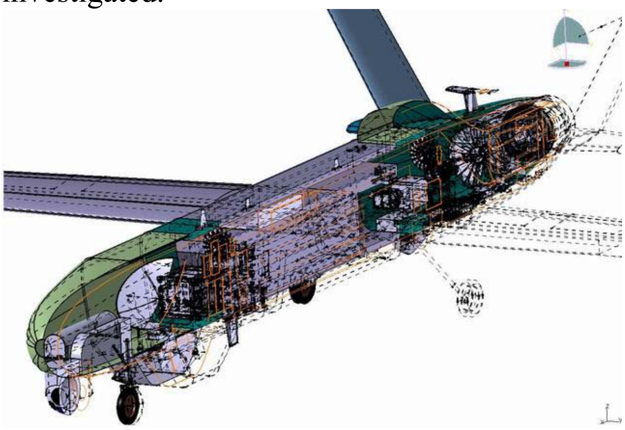


***Figure 6**: MM-UAV payload design*

The assembly of the payload in the CATIA V5 model facilitates the CG calculation and obtains inertial matrices as well as payload- and internal volumes of parts together with the surfaces. The CG calculation performed by CATIA identifies the quality of the configuration.

6 Balancing of the UCAV

The UCAV comprises of the widest range of systems as its mission includes search, identification and tracking of targets with the option of attack. The multi-mission payload analysis defined surveillance and communication equipment beside the MTI and EW systems as the major devices onboard the UCAV. It also carries up to four Hellfire missiles in the internal weapons bay with a range of 2000 km. The communication equipment is of the largest bandwidth available with real-time imagery/data downlink requirement due to the necessity of immediate action in case of target identification. The mission fuel of approximately 550*l* kerosene is carried in the wings to allow a range of 2000 km and 4 hour loiter time over the target area. All these components increase the takeoff weight of the UCAV and make it the heaviest vehicle in the MM-UAV inventory. In the balancing process (*Figure 7*) and the placement of the components in CATIA special attention has been paid in the outweighing of the engine and other related components such as the Full Authority Digital Engine Control (FADEC) unit or generator. The surveillance equipment is located in the nose; the nose landing gear is located between the EO/IR cameras and the MTI/SAR assembled under the mid-forward fuselage. The current balancing process requires an adjustment of the design of the fuselage components to the specific needs of the payload, e.g. fairings for the MTI/SAR or antennas.

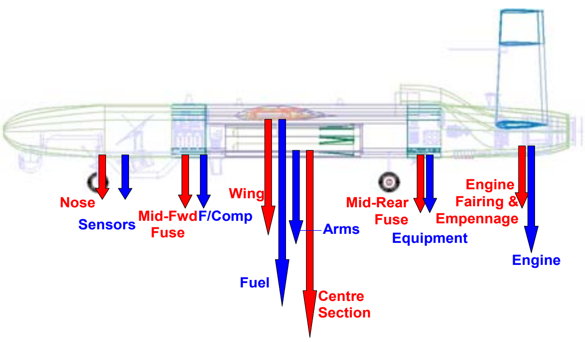


***Figure** 7: UCAV Balancing*

The investigated configuration is analysed regarding its flight mechanical stability defined by the following three criteria:

- $-\dfrac{x_{NP} - x_{CG}}{\bar{c}} \overset{!}{<} 0$ *Equation 1*
- $\dfrac{\partial c_m}{\partial c_l} = c_{m_\alpha} \overset{!}{<} 0$ *Equation 2*
- $c_m \overset{!}{<} 0$ *Equation 3*

where:

x_{NP}: x-value of neutral point (NP, measured from nose);

x_{CG}: x-value of CG (measured from nose);

$\bar{c}$: Mean aerodynamic chord (MAC);

c_m: Moment coefficient;

c_m: Lift coefficient; and

c_{m_α} : Pitch moment coefficient.

- *<u>Criterion 1:</u>* The first correlation describes the recommended position of the CG compared to the neutral point located at 25% MAC. Typically the CG is located between 10 to 20% MAC to obtain the flight mechanical stability of the configuration. A CG at 5 to 15% MAC in front of the NP creates a positive moment around the NP which is balanced by the negative lift of the empennage.
- *<u>Criterion 2:</u>* The changing of the moment coefficient c_m over the lift coefficient c_l describes the second static stability criterion which is identical to the pitch moment $c_{m_\alpha}\left(\dfrac{\partial c_m}{\partial c_\alpha}\right)$. This change has to be below zero to obtain the required stability.
- *<u>Criterion 3:</u>* The third stability criterion is summarising the first two in one requirement. The overall sum of moments has to be below zero to obtain a stable configuration. This is the negative moment (ascribing moment) that forces the nose down in a wind gust that pushes it up. This negative moment around the NP is caused by the CG in front of the NP. It is balanced by the

negative lift in the empennage. Hence, the overall sum of moments has to be below zero.

The CG of the UCAV is set at 17% MAC which makes it a stable configuration. To adjust the CG; the wing position and the engine position were shifted slightly. The wings position in the centre section has been set back compared to the preliminary design. The challenge in the payload modelling process is the requirement of a full re-configuration and easy replacement. Component groups have to be assembled in fuselage sections which are most likely to be employed in the specific mission where this payload is onboard. The mid-forward and-rear sections e.g. are certainly part of the combat mission due to the reduced capacity in the centre section carrying the weapons. Mission systems, which are mainly part of the combat mission like the chaff and flare dispenser or EW systems; were thus placed in these specific sections.

***Table 2**: Mission Matrix*

	Mission 1	Mission 2	Mission 3
1	UCAV Light Attack	HAME Surveillance	LAME Surveillance
2	UCAV Light Attack	HAME Surveillance	MAME Surveillance
3	UCAV Light Attack	LAME Surveillance	MAME Surveillance
4	LAME Surveillance	MAME Surveillance	HAME Surveillance
5	LAME Surveillance	UCAV Cargo Deployment	HAME Surveillance
6	MAME Surveillance	UCAV Cargo Deployment	HAME Surveillance
7	LAME Surveillance	UCAV Cargo Deployment	MAME Surveillance
8	LAME Surveillance	MAME Cargo Deployment	HAME Surveillance
9	LAME Surveillance	MAME Cargo Deployment	MAME Surveillance
10	HAME Surveillance	MAME Cargo Deployment	MAME Surveillance
11	UCAV Cargo Deployment	MAME Cargo Deployment	MAME Surveillance
12	UCAV Cargo Deployment	MAME Cargo Deployment	HAME Surveillance
13	UCAV Cargo Deployment	MAME Cargo Deployment	LAME Surveillance
14	UCAV Cargo Deployment	UCAV Light Attack	LAME Surveillance
15	UCAV Cargo Deployment	UCAV Light Attack	MAME Surveillance
16	UCAV Cargo Deployment	UCAV Light Attack	HAME Surveillance
17	MAME Cargo Deployment	UCAV Light Attack	HAME Surveillance
18	MAME Cargo Deployment	UCAV Light Attack	MAME Surveillance
19	MAME Cargo Deployment	UCAV Light Attack	LAME Surveillance
20	MAME Cargo Deployment	UCAV Light Attack	UCAV Cargo Deployment

Currently smaller adjustments are made to optimise the CG location and the accessibility to reduce maintenance efforts and to obtain a minimum system complexity for the re-configuration. A matrix (*Table 2*) of systems and components for each mission has been set up to facilitate the payload selection of the other category UAVs (*Figure 8*). This matrix provides the basis for further takeoff weight calculations and flight mechanical stability investigations.

7 Concluding Remarks

The re-configurable UAV design concept is in its preliminary design phase for further improvement of the 3D models. The implementation in CATIA V5 allows an enhanced design and flight mechanical investigations as well as a payload optimised fuselage. The RC-UAV concept that addresses operational and logistical challenges of the UAV technology is expected to pioneer and to revolutionise the UAV design philosophy to obtain a cost efficient design solution.

8 Acknowledgements

The authors acknowledge the contribution of Tom Nguyen and Adrian Stafford in their investigations on Windows®-based software for preliminary design of the RC-UAV. For support in the collaboration between Wackett Aerospace Centre, RMIT University, Melbourne and the Technical University in Munich (TUM), Germany, the authors like to thank Prof Horst Baier, Head of the Department of Aeronautical Engineering, TUM, for his support.

9 Glossary

AGM	Air to Ground
CG	Centre of Gravity
DGPS	Differential GPS
EO	Electro Optical
EW	Electronic Warfare
FADEC	Full Authority Digital Engine Control
FLIR	Forward looking IR
GPS	Global Positioning System
HAME	High Altitude Medium Endurance
IR	Infra Red
IFF	Identification Friend / Foe
LAME	Low Altitude Medium Endurance
LOS	Line of Sight
LVAD	Low Velocity Air Drop
MAC	Mean Aerodynamic Chord
MAME	Medium Altitude Medium Endurance

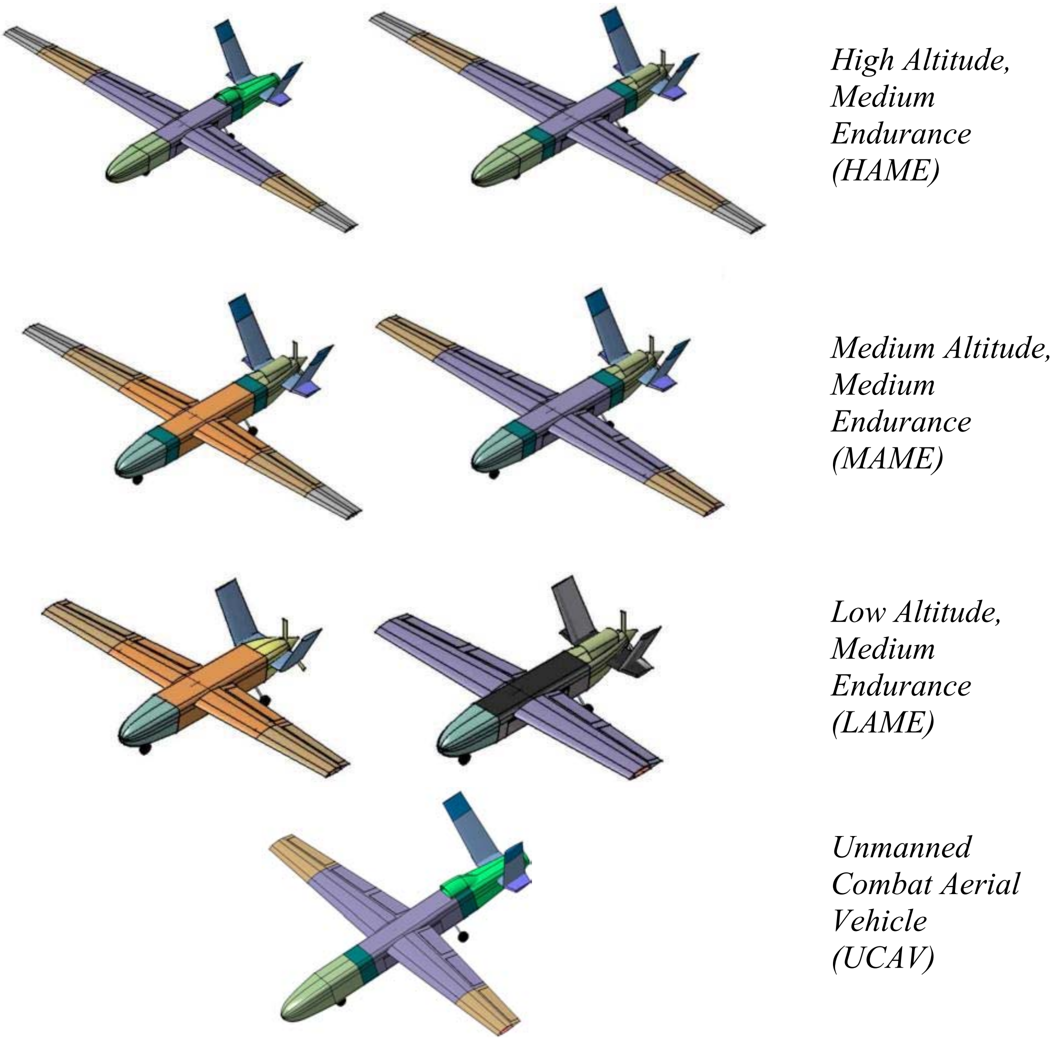


***Figure 8**: Four Spectrums of Re-configurable Unmanned Aerial Vehicles from Baseline Configuration*

MM-UAV	Multi Mission UAV
MTI	Moving Target Indicator
NP	Neutral Point
RC	Re-configurable
SATCOM	Satellite Communication
SAR	Synthetic Aperture Radar
UAV	Unmanned Aerial Vehicle
UCAV	Combat UAV
UHF	Ultra High Frequency

10 References

[1] Bender, B., Burger, K., & Koch, A., *"Afghanistan: First lessons"*, Jane's Defence Weekly, vol.36, no 25, pp. 18-21, Jane's Information Group Publication, UK, December 2001.

[2] Koch, A., *"US Intelligence Plays Key Role in Afghanistan"*, Jane's Defence Weekly, vol.36, no 25, pp. 21, Jane's Information Group Publication, UK, December 2001.

[3] Eshel, D., *"Tactical UAVs in Counter-Terror Warfare"*, Defence Reporter – Australia & Asia Pacific, vol. 29, no 6, pp. 51-53, Australian Public Affairs Information Service, Canberra, September 2003.

[4] Franchi, P.L. *"UAV"*, A Flight International Supplement, p. 3-5, Reed Business Information, UK, January 2001.

[5] Sinha, A.K. Kusumo, R., Scott, M.L., Bil, C. & Mohandas, P., *"A Systems Approach to the Issues and Challenges of UAV System"*, 16th Bristol International UAV Systems Conference, 3-8 April 2001a, Bristol, UK.

[6] Anon, *"Shephard's Unmanned Vehicles Handbook 2002",* The Shepherd Press, pp.6-94, England, 2002

[7] Sinha, A. K., Kam, B. H., Wood, L. A., Bil, C., & Mohandas, P., *'Design of Payloads to meet the Mission Expectations of Unmanned Aerial Vehicles'.* Proceedings of 14th International Conference on Unmanned Aerial Vehicles, Bristol, UK, April 1999.

[8] Sinha, A.K. Bil, C., Scott, M.L., & Mohandas, P., *'Design of Optimum Payloads to Meet the Mission Requirements of Unmanned Aerial Vehicles'.* Proceedings of the 22nd Congress of the International Council of Aeronautical Sciences, Harrogate, UK, 27 August - 02 September 2000.

[9] Nguyen, T., Sinha, A.K., Stafford, A., 2003 *"Conceptual Design Methodology for a Multi-mission Reconfigurable Unmanned Aerial Vehicle",* 10th Australian International Aerospace Congress, 29 July – 01 August, Brisbane, Australia