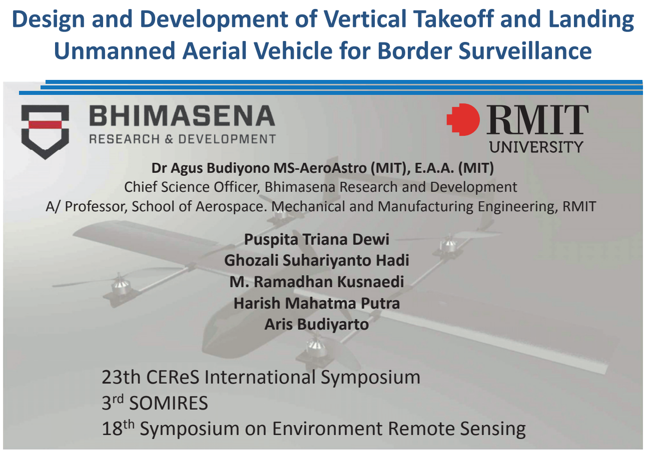


Design and Development of Vertical Takeoff and Landing Unmanned Aerial Vehicle for Border Surveillance

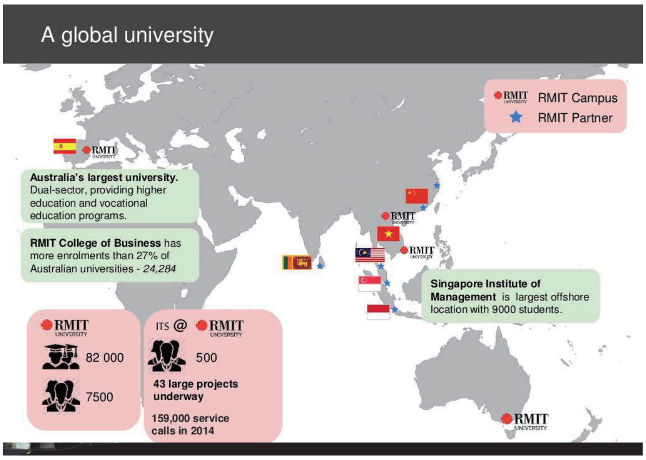
Dr Agus Budiyono MS-AeroAstro (MIT), E.A.A. (MIT)
Chief Science Officer, Bhimasena Research and Development
A/ Professor, School of Aerospace. Mechanical and Manufacturing Engineering, RMIT

Puspita Triana Dewi
Ghozali Suhariyanto Hadi
M. Ramadhan Kusnaedi
Harish Mahatma Putra
Aris Budiyarto

23th CEReS International Symposium
3rd SOMIRES
18th Symposium on Environment Remote Sensing

SAMME Facilities:

School of Aerospace, Mechanical and Manufacturing Engineering



A global university

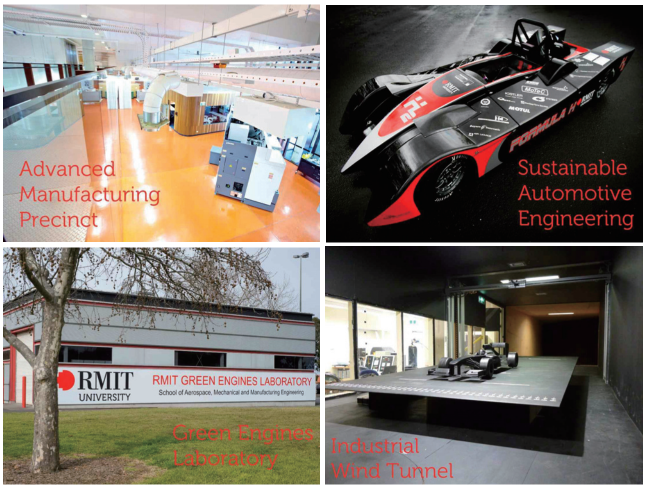
Australia's largest university. Dual-sector, providing higher education and vocational education programs.

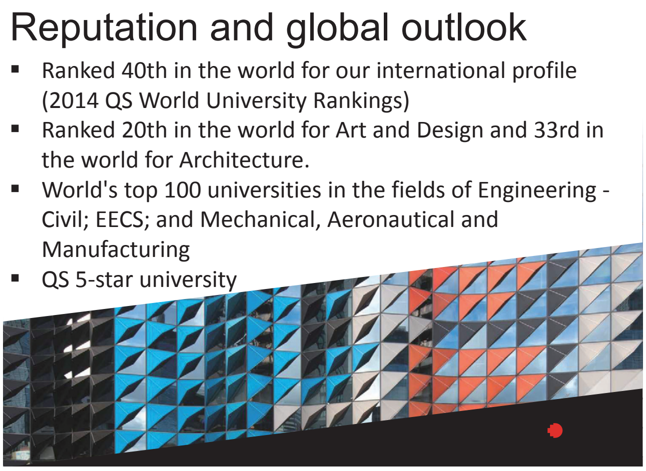
RMIT College of Business has more enrolments than 27% of Australian universities - *24,284*

Singapore Institute of Management is largest offshore location with 9000 students.

RMIT UNIVERSITY
82 000
7500

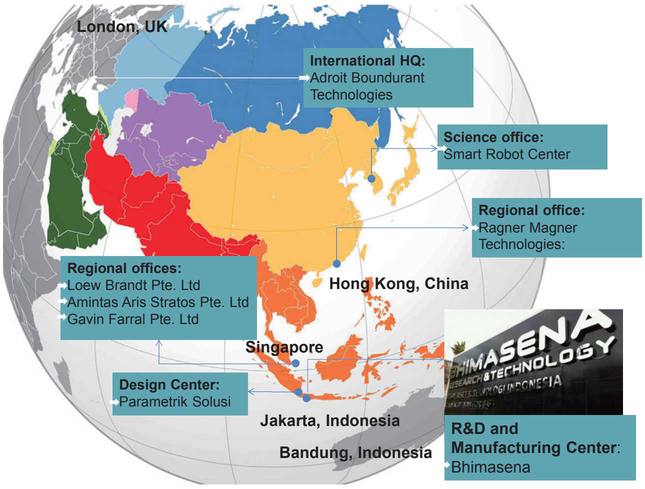
ITS @ RMIT UNIVERSITY
500
43 large projects underway
159,000 service calls in 2014





Reputation and global outlook

- Ranked 40th in the world for our international profile (2014 QS World University Rankings)
- Ranked 20th in the world for Art and Design and 33rd in the world for Architecture.
- World's top 100 universities in the fields of Engineering - Civil; EECS; and Mechanical, Aeronautical and Manufacturing
- QS 5-star university



London, UK

International HQ:
Adroit Boundurant Technologies

Science office:
Smart Robot Center

Regional office:
Ragner Magner Technologies:

Regional offices:
Loew Brandt Pte. Ltd
Amintas Aris Stratos Pte. Ltd
Gavin Farral Pte. Ltd

Hong Kong, China

Singapore

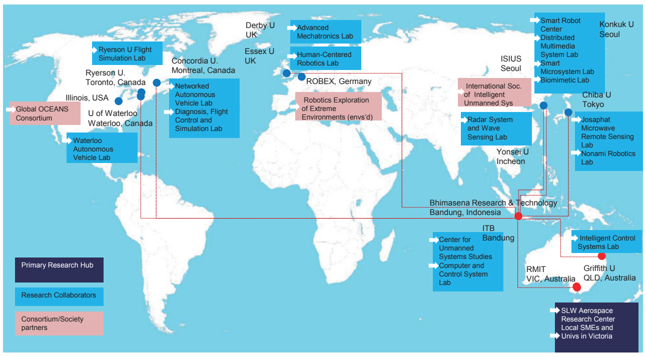
Design Center:
Parametrik Solusi

Jakarta, Indonesia

Bandung, Indonesia

R&D and Manufacturing Center:
Bhimasena

Global Research Network



Derby U
UK
- Advanced Mechatronics Lab

Essex U
UK
- Human-Centered Robotics Lab

Ryerson U.
Toronto, Canada
- Ryerson U Flight Simulation Lab

Concordia U.
Montreal, Canada
- Networked Autonomous Vehicle Lab
- Diagnosis, Flight Control and Simulation Lab

Illinois, USA
- Global OCEANS Consortium

U of Waterloo
Waterloo, Canada
- Waterloo Autonomous Vehicle Lab

ROBEX, Germany
- Robotics Exploration of Extreme Environments (envs'd)

ISIUS
Seoul
- International Soc. of Intelligent Unmanned Sys

Konkuk U
Seoul
- Smart Robot Center
- Distributed Multimedia System Lab
- Smart Microsystem Lab
- Biomimetic Lab

Yonsei U
Incheon
- Radar System and Wave Sensing Lab

Chiba U
Tokyo
- Josaphat Microwave Remote Sensing Lab
- Nonami Robotics Lab

Bhimasena Research & Technology
Bandung, Indonesia

ITB
Bandung
- Center for Unmanned Systems Studies
- Computer and Control System Lab

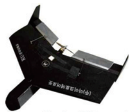
Griffith U
QLD, Australia
- Intelligent Control Systems Lab

RMIT
VIC, Australia
- SLW Aerospace Research Center
- Local SMEs and Univs in Victoria

Primary Research Hub

Research Collaborators

Consortium/Society partners



BHIMASENA
RESEARCH & DEVELOPMENT

Bhimasena's Core capabilities

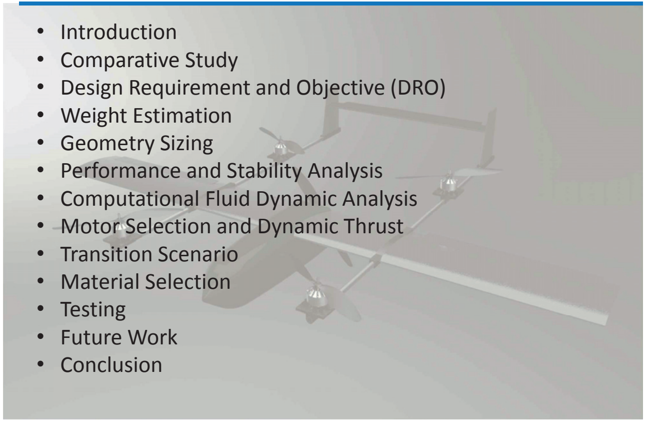
Intelligent Vehicular Systems
- Advanced Ground Vehicle :
  - EOD Vehicle
  - CBRN Vehicle
- Aerial Vehicles:
  - UAV Backpack
  - Multirotor/VTOL UAV
  - High Altitude Long Endurance (HALE) UAV
- Underwater/Marine Vehicles
- Synthetic Aperture Radar (SAR)

Smart Energy Generation

Telecommunications: Micro Satellite

Outline

BHIMASENA
RESEARCH & DEVELOPMENT



- Introduction
- Comparative Study
- Design Requirement and Objective (DRO)
- Weight Estimation
- Geometry Sizing
- Performance and Stability Analysis
- Computational Fluid Dynamic Analysis
- Motor Selection and Dynamic Thrust
- Transition Scenario
- Material Selection
- Testing
- Future Work
- Conclusion

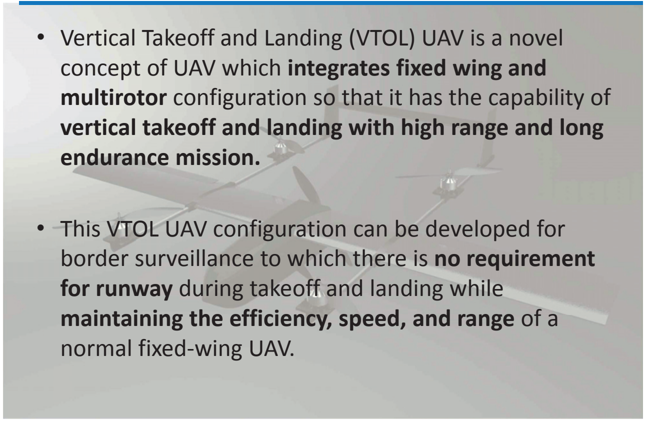
Bhimasena's R&D Areas

BHIMASENA
RESEARCH & DEVELOPMENT

Control System and Automation:
Model-based autonomous control
Visual SLAM
Multi-rotor perception and control in winds
Laser scan registration for 3D mapping
Underwater guidance and navigation
Remote Sensing Technologies
UAV-based L/C Band CP Synthetic Aperture Radar
Microsatellite-based C/X Band CP SAR
Advanced Manufacturing
Advanced composite manufacturing
Rapid prototyping
Additive manufacturing
Smart Energy Generation
Hybrid PV-Wind Energy Technology
Smart energy storage

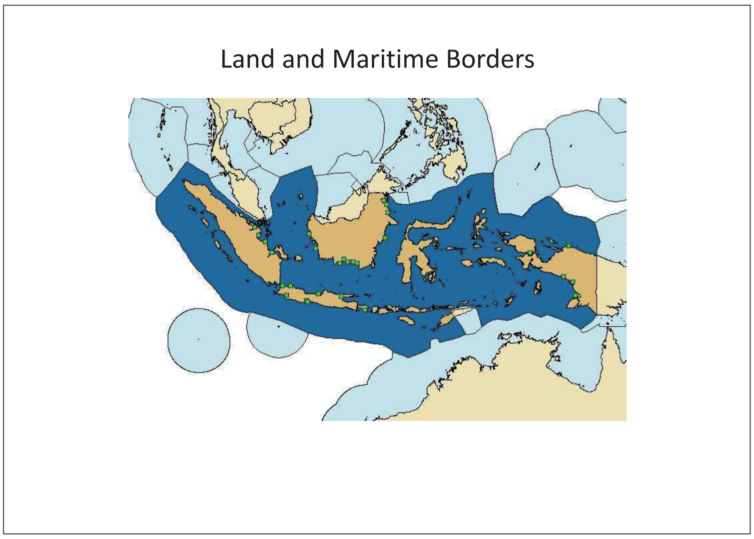
Introduction

BHIMASENA
RESEARCH & DEVELOPMENT

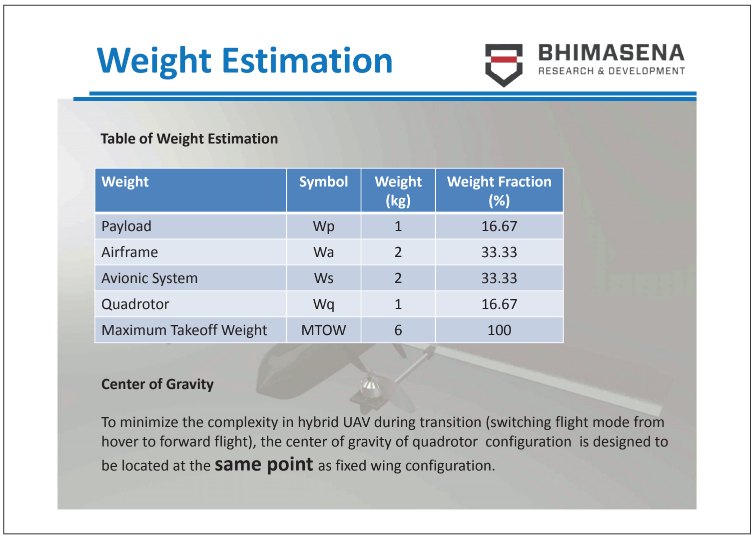


- Vertical Takeoff and Landing (VTOL) UAV is a novel concept of UAV which **integrates fixed wing and multirotor** configuration so that it has the capability of **vertical takeoff and landing with high range and long endurance mission.**

- This VTOL UAV configuration can be developed for border surveillance to which there is **no requirement for runway** during takeoff and landing while **maintaining the efficiency, speed, and range** of a normal fixed-wing UAV.



Land and Maritime Borders



Weight Estimation

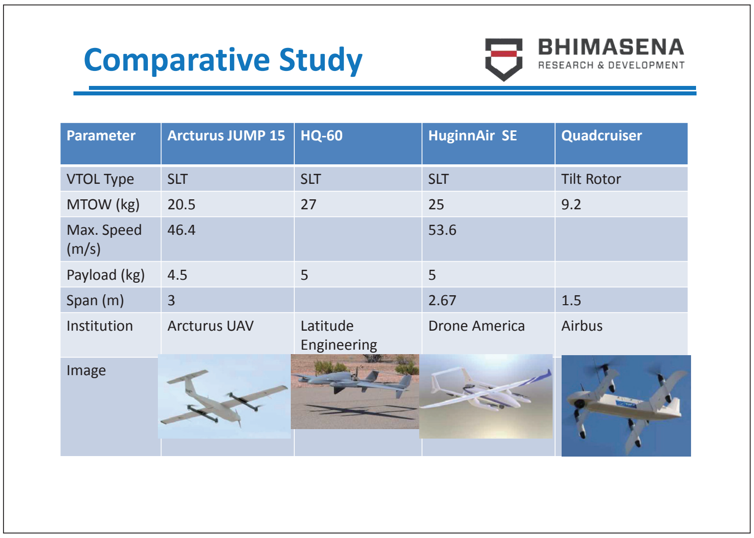
BHIMASENA
RESEARCH & DEVELOPMENT

Table of Weight Estimation

Weight	Symbol	Weight (kg)	Weight Fraction (%)
Payload	Wp	1	16.67
Airframe	Wa	2	33.33
Avionic System	Ws	2	33.33
Quadrotor	Wq	1	16.67
Maximum Takeoff Weight	MTOW	6	100

Center of Gravity

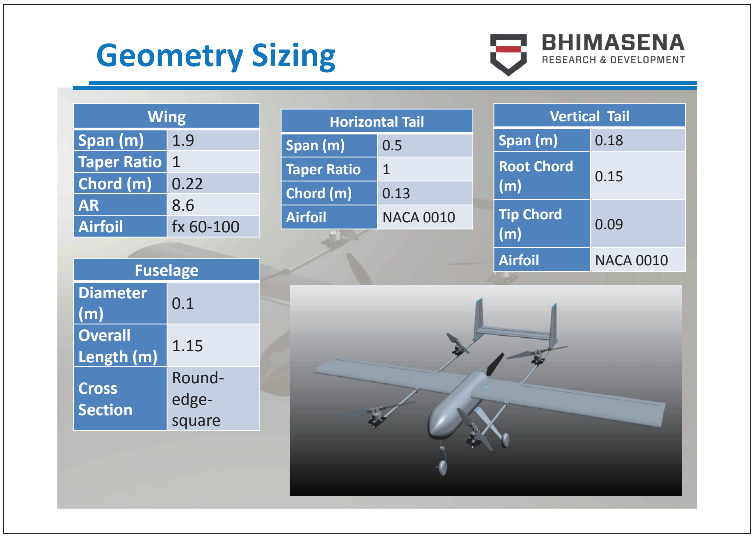
To minimize the complexity in hybrid UAV during transition (switching flight mode from hover to forward flight), the center of gravity of quadrotor configuration is designed to be located at the **same point** as fixed wing configuration.



Comparative Study

BHIMASENA
RESEARCH & DEVELOPMENT

Parameter	Arcturus JUMP 15	HQ-60	HuginnAir SE	Quadcruiser
VTOL Type	SLT	SLT	SLT	Tilt Rotor
MTOW (kg)	20.5	27	25	9.2
Max. Speed (m/s)	46.4		53.6	
Payload (kg)	4.5	5	5	
Span (m)	3		2.67	1.5
Institution	Arcturus UAV	Latitude Engineering	Drone America	Airbus
Image				



Geometry Sizing

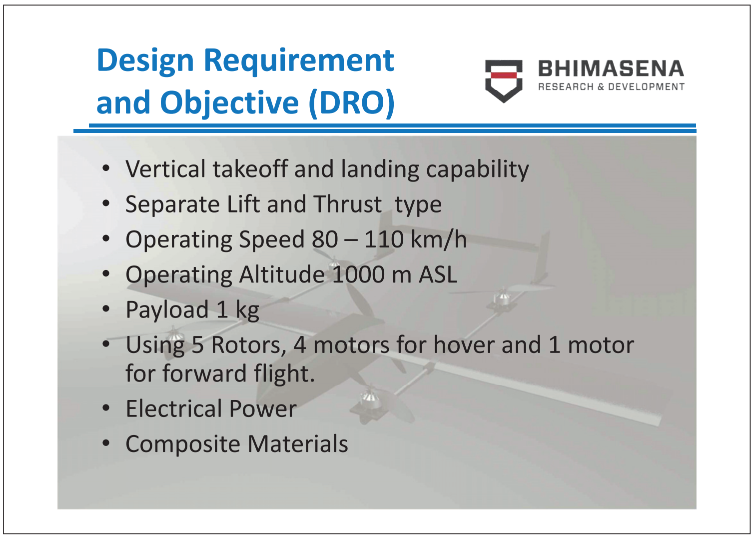
BHIMASENA
RESEARCH & DEVELOPMENT

Wing	
Span (m)	1.9
Taper Ratio	1
Chord (m)	0.22
AR	8.6
Airfoil	fx 60-100

Horizontal Tail	
Span (m)	0.5
Taper Ratio	1
Chord (m)	0.13
Airfoil	NACA 0010

Vertical Tail	
Span (m)	0.18
Root Chord (m)	0.15
Tip Chord (m)	0.09
Airfoil	NACA 0010

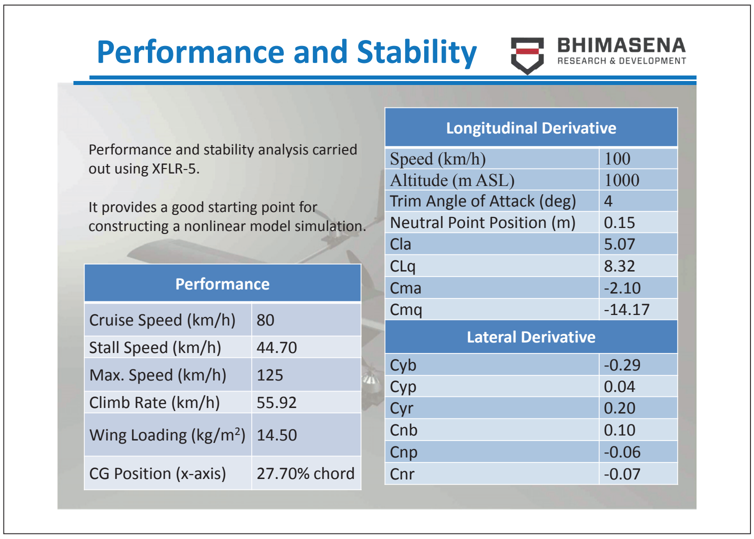
Fuselage	
Diameter (m)	0.1
Overall Length (m)	1.15
Cross Section	Round-edge-square



Design Requirement and Objective (DRO)

BHIMASENA
RESEARCH & DEVELOPMENT

- Vertical takeoff and landing capability
- Separate Lift and Thrust type
- Operating Speed 80 – 110 km/h
- Operating Altitude 1000 m ASL
- Payload 1 kg
- Using 5 Rotors, 4 motors for hover and 1 motor for forward flight.
- Electrical Power
- Composite Materials



Performance and Stability

BHIMASENA
RESEARCH & DEVELOPMENT

Performance and stability analysis carried out using XFLR-5.

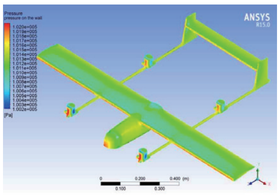
It provides a good starting point for constructing a nonlinear model simulation.

Performance	
Cruise Speed (km/h)	80
Stall Speed (km/h)	44.70
Max. Speed (km/h)	125
Climb Rate (km/h)	55.92
Wing Loading (kg/m^2)	14.50
CG Position (x-axis)	27.70% chord

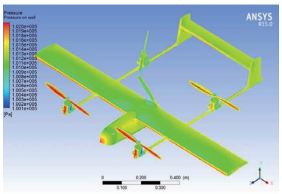
Longitudinal Derivative	
Speed (km/h)	100
Altitude (m ASL)	1000
Trim Angle of Attack (deg)	4
Neutral Point Position (m)	0.15
Cla	5.07
CLq	8.32
Cma	-2.10
Cmq	-14.17
Lateral Derivative	
Cyb	-0.29
Cyp	0.04
Cyr	0.20
Cnb	0.10
Cnp	-0.06
Cnr	-0.07

Computational Fluid Dynamic Analysis

Case 1: Without Propeller



Case 2: With Propellers



Forces at 34 m/s	Case 1	Case 2
Side Force (N)	0.21	1.70
Lift (N)	50.66	45.57
Drag (N)	8.401	33.45

Drag at vertical velocity 9 m/s = 24 N

Dynamic Thrust and Motor Selection (3)

Specification of motor for Hover

- Kv: **420 rpm/v**
- Max current: **29A**
- Max Power: **650w**
- Weight: **154r**
- Cell count: **6s**
- Propeller : **16 x 5”**

Static thrust test has been done for the motor and propeller chosen above. It produces a maximum thrust of 3.3 kg

For conventional multirotor:

$$\frac{Thrust}{W\ eight} = \frac{3.3\ kg\ x\ 4}{6\ kg} = 2.26$$

For VTOL UAV:

$$\frac{Thrust}{W\ eight} = \frac{3.3\ kg\ x\ 4}{6\ kg + 2.4\ kg} = 1.62$$

Outdoor hover experiment test has been done and our UAV can hover 104 m ASL for around 83% throttle

---

Dynamic Thrust and Motor Selection

Dynamic Thrust Calculation

$$F = 1.225\frac{\pi(0.0254\cdot d)^2}{4}\left[\left(RPM_{prop}\cdot 0.0254\cdot pitch\cdot\frac{1min}{60sec}\right)^2 - \left(RPM_{prop}\cdot 0.0254\cdot pitch\cdot\frac{1min}{60sec}\right)V_0\right]\left(\frac{d}{3.29546\cdot pitch}\right)^{1.5}$$

Gabriel Staples, 2013. http://electricrcaircraftguy.blogspot.com/

Motor for Forward Flight (FF)

- Kv: **1450 rpm/v**
- Max current: **80A**
- Max Power: **1770w**
- Weight: **244g**
- Cell count: **6s**
- Propeller : **8 x 6”**

Motor for FF

Propeller 8x6

Its hard to find the best combination of propeller and motor for forward flight due to very high drag dan structural problem in VTOL UAV.

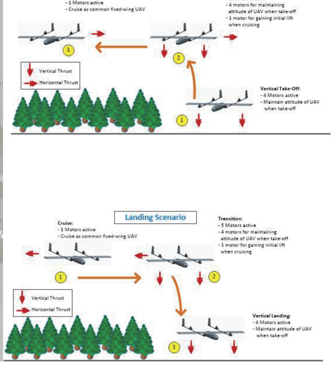
Transition Scenario

Transition is the most critical stage in VTOL UAV.

Some aspects to be considered during transition are:

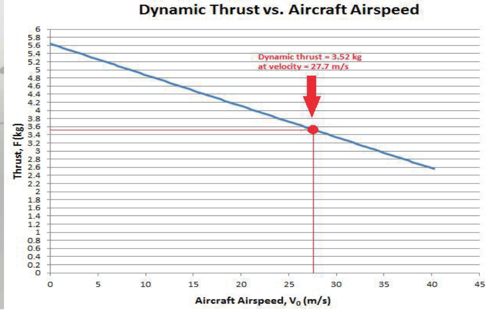
1. Overlapping thrust (vertical and horizontal thrust).
2. Transition speed.
3. Transition attitude.

Illustration of Transition Stage

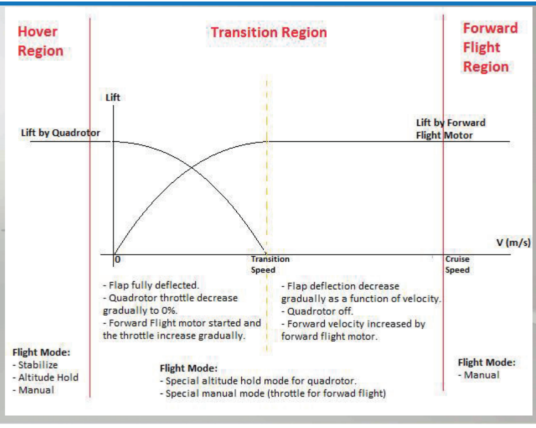


Dynamic Thrust and Motor Selection (2)

Graphic below is the plot of dynamic thrust vs airspeed using Gabriel Staples approach (see previous page). This graph shows that the combination of chosen motor and propeller produce sufficient thrust as CFD analysis result.



Transition Scenario (2)



- Flap fully deflected.
- Quadrotor throttle decrease gradually to 0%.
- Forward Flight motor started and the throttle increase gradually.

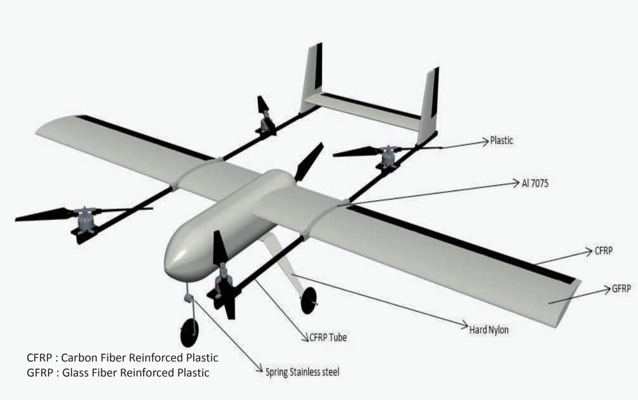
- Flap deflection decrease gradually as a function of velocity.
- Quadrotor off.
- Forward velocity increased by forward flight motor.

Flight Mode:
- Stabilize
- Altitude Hold
- Manual

Flight Mode:
- Special altitude hold mode for quadrotor.
- Special manual mode (throttle for forwad flight)

Flight Mode:
- Manual

Material Selection



CFRP : Carbon Fiber Reinforced Plastic
GFRP : Glass Fiber Reinforced Plastic

Future Work

- The result of this research will be optimized and applied into a full-scale hybrid UAV which carries 20 kg payload, both airframe and control design.
- Adding damping for stability and developing fully autonomous system for VTOL UAV.
- For the full scale UAV, we are going to design and manufacture the propellers in-house.

Testing

The test divided into two major part:

1. Ground test:
   - Validating static thrust
   - Inspection of structural integrity
   - Verification of weight and balance
   - Loading test
2. Flight Test:
   - Indoor hover test
   - Outdoor Hover Test
   - Forward Flight Test using conventional takeoff and landing
   - Hover-to-forward flight transition

Conclusion

- VTOL UAV is a very potential technology solution for surveillance in the remote areas where runway infrastructure is nonexistent.
- Issues related to weight, vibration, energy consumption and aerodynamics characteristic must be addressed to fully harvest the benefit of VTOL-UAV.

Testing (2)

Testing.mp4

THANK YOU

BHIMASENA
RESEARCH & DEVELOPMENT