Introduction to Multicopter Design and Control

Lesson 01 Introduction

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Preface

Why do people choose small multicopters eventually?

Outline

1. Concepts
2. Remote Control and Performance Evaluation
3. History
4. Objective and Structure of the Course

1. Concepts

□ Classification of Commonly Used Small Aircraft

(a) Fixed-wing aircraft　　(b) Helicopter　　(c) Multicopter

Figure 1.1 Commonly-used small drones

（1） Fixed-wing aircraft

Advantage： Longer distance while consuming less power

Disadvantage： Requirement of a runway or launcher for take-off and landing

1. Concepts

□ Classification of Commonly Used Small Aircraft

(a) Fixed-wing aircraft (b) Helicopter (c) Multicopter

Figure 1.1 Commonly-used small drones

（2） Single rotor blade helicopter

Advantage： Vertical Take-Off and Landing (VTOL)

Disadvantage： Hard to pilot, complex structure incurring a high maintenance cost.

1. Concepts

□ Classification of Commonly Used Small Aircraft

(a) Fixed-wing aircraft　　(b) Helicopter　　(c) Multicopter

Figure 1.1 Commonly-used small drones

（3） Multicopter

Advantage： VTOL, simple structure, ease of use

Disadvantage： payload capacity as well as the time of endurance are both compromised

1. Concepts

◻ Classification of Commonly Used Small Aircraft

（3） Multicopter

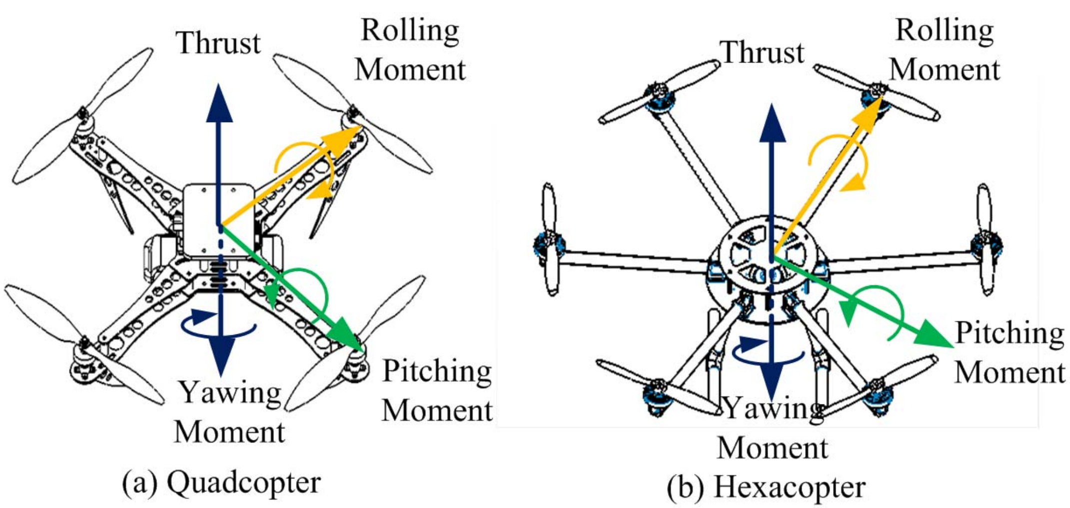


Fig 1.2 Thrust and moments of quadcopter and hexacopter

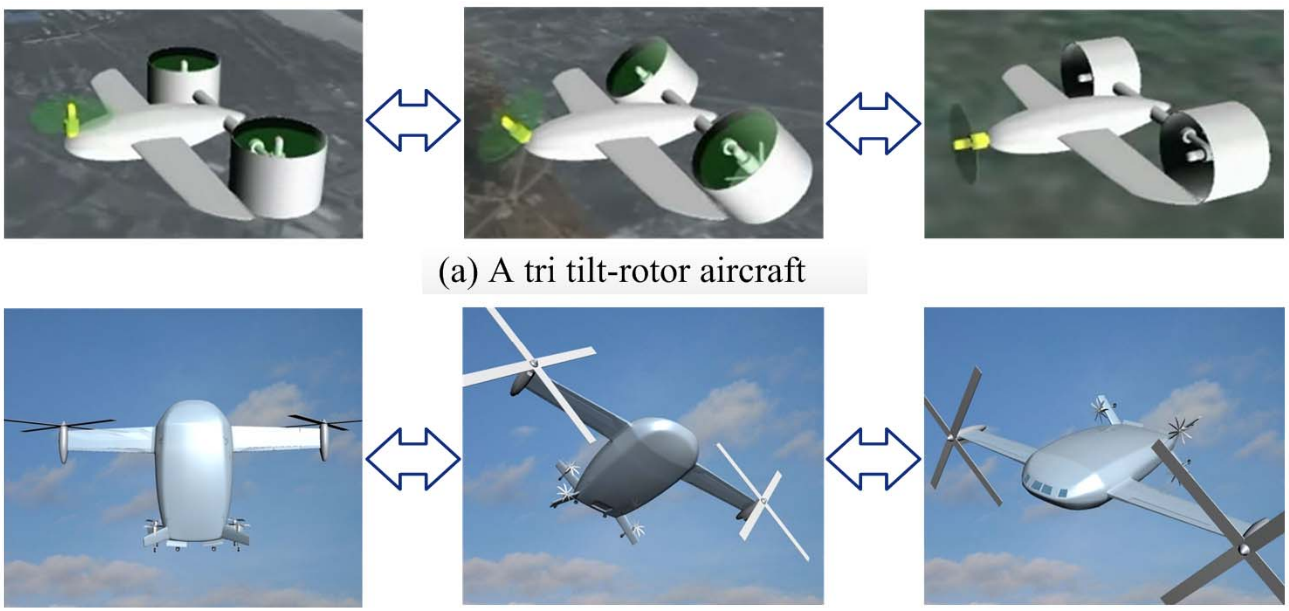
What are the differences between a quadcopter or a hexacopter ?

- Both generate one thrust, pitching moment, rolling moment and yawing moment.
- There are hardly any fundamental differences but allocation of the thrust and moments to these propellers.

1. Concepts

□ Classification of Commonly Used Small Aircraft

（4） Compound[1,2]



(a) A tri tilt-rotor aircraft

(b) A compound helicopter

Fig 1.3 Thrust and moments of quadcopter and hexacopter Transition of compound helicopters from the hover mode to the forward flight mode. (a) Rotors tilt to achieve mode transition; (b) Rotors are all fixed to the airframe, while the airframe tilts to achieve mode transition.

[1] Fan P H. Design and Control of Multi-rotor Aircraft[Master dissertation], Beihang University, China, 2010 (in Chinese)
[2] Zhang R F. A Study on Quadrotor Compound Helicopter Oriented to Reliable Flight Control [Ph.D dissertation], Beihang University, China, 2011 (in Chinese)

1. Concepts

□ Classification of Commonly Used Small Aircraft

（4） Compound[3]

Figure 1.4 A compound multicopter. The middle coaxial rotor with a slow dynamic response provides the main lift, while the surrounding quadcopter can change the propellers' angular velocities rapidly to improve the dynamic response of attitude.

[3] Quan Q, Fu J S, Cai K-Y. A Compound Multicopter, China. Patent 203005746U, June 2013 (in Chinese)

1. Concepts

□ Unmanned Aerial Vehicle and Model Aircraft

(1) Unmanned Aerial Vehicle or Uninhabited Aerial Vehicle (UAV). The flight of UAVs may be controlled either autonomously by onboard computers or by the remote control from a pilot on the ground or in another vehicle. UAVs are also called *drones*.

(2) Model Aircraft. "An aircraft of limited dimensions, with or without a propulsion device, not able to carry a human being and to be used for aerial competition, sport or recreational purposes" is called a model aircraft [4]. The statutory parameters of a model aircraft operation are outlined in [5], [6].

[4] FAI Aeromodelling Commission. F3-Radio Control Soaring[Online], available: http://www.fai.org/ciam-our-sport/f3-radio-control-soaring, February 28, 2016

[5] Palmer D. The FAA'S Interpretation of the Special Rule For Model Aircraft. Journal of Air Law & Commerce. 2015, 80: 567-749

[6] Federal Aviation Administration (FAA). Interpretation of the Special Rule for Model Aircraft. June 18, 2014

1. Concepts

□ Unmanned Aerial Vehicle and Model Aircraft

Table 1.1 Differences between drones and model aircraft

	Drones	Model Aircraft
Operation	Autonomous control and remote control	Remote control
Function	Military or special civil applications	Entertainment
Composition	Complex	Simple

- Semi-Autonomous Control (SAC) : used to stabilize the attitude of multicopters, and also can help to hold the altitude and position. Belong to *Model Aircraft*
- Full-Autonomous Control (FAC): can follow a pre-programmed mission script stored in the, and also can take off and land automatically. Belong to *Drones*

Why do people choose multicopters?

2. Remote Control and Performance Evaluation

☐ Remote Control of a Quadcopter

（1） Hover

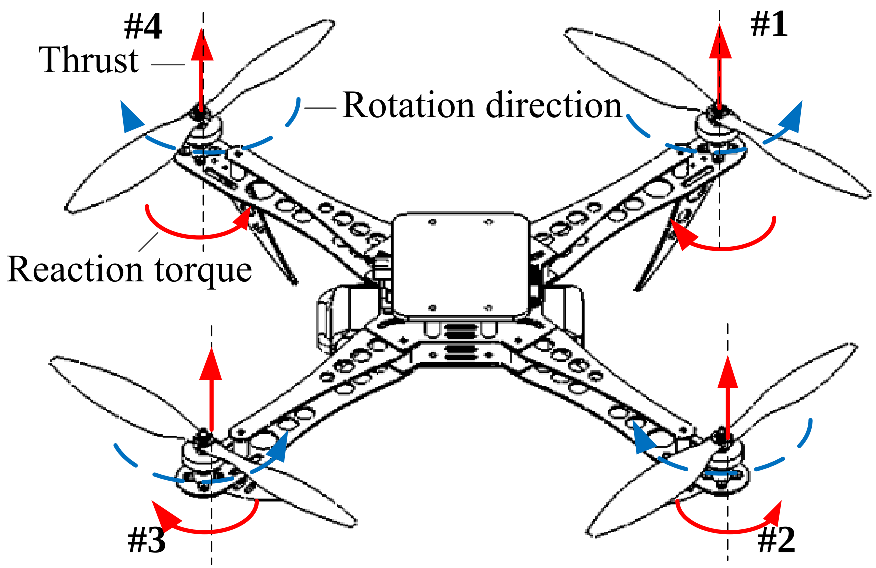
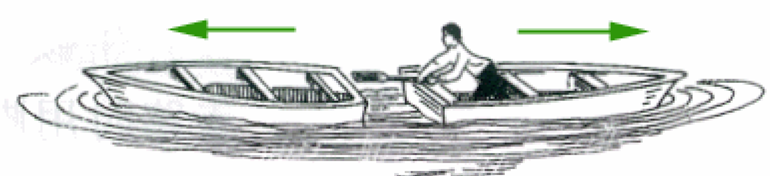


Figure 1.5 A quadcopter in hovering flight

At a hover position，

- Sum of the four produced thrusts compensates for the weight;
- Thrusts of four rotors are the same and the moments of four rotors sum to zero;
- About yaw moment. If the blades are spinning counterclockwise, then the airframe will start to rotate clockwise due to the torque reaction. This is due to *Newton's Third Law*.



From http://www.hzjys.net/

2. Remote Control and Performance Evaluation

☐ Remote Control of a Quadcopter

(1) Hover

How is the opposite reaction compensated for in helicopters ?

- A small rotor placed vertically at the tail

- Coaxial propellers

2. Remote Control and Performance Evaluation

☐ Remote Control of a Quadcopter

（2） Upward and downward movement

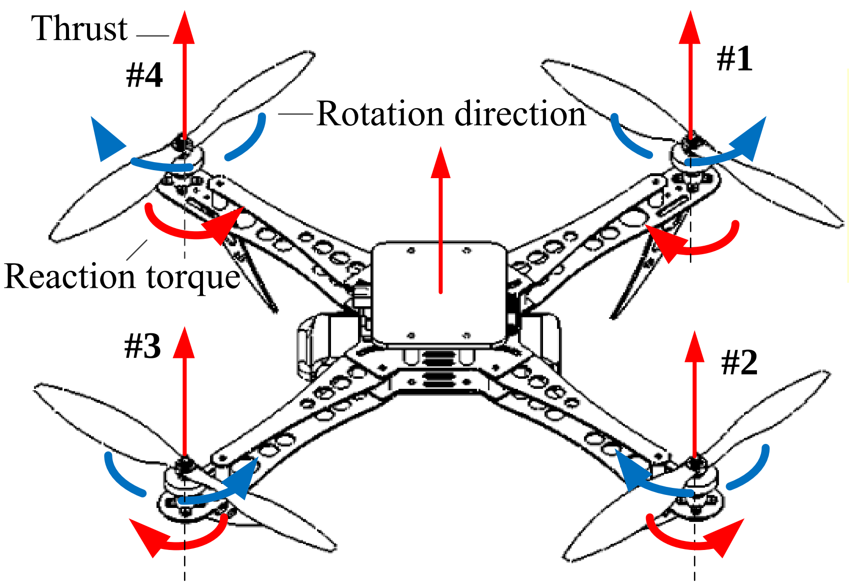


Figure 1.6 Upward movement of a quadcopter

Table 1.2 Change of propellers' angular velocities ("+"indicates increase, "-" indicates decrease)

	#1	#2	#3	#4
Thrust change	+1	+1	+1	+1

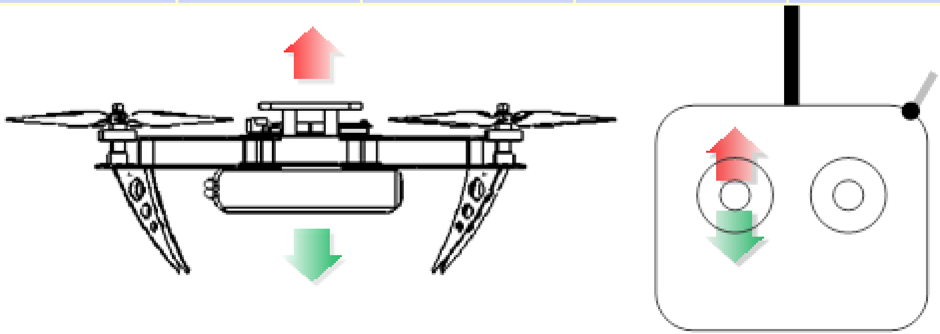


Figure 1.7 Operation of an RC transmitter for the upward and downward movement

2. Remote Control and Performance Evaluation

☐ Remote Control of a Quadcopter

（3） Forward and backward movement

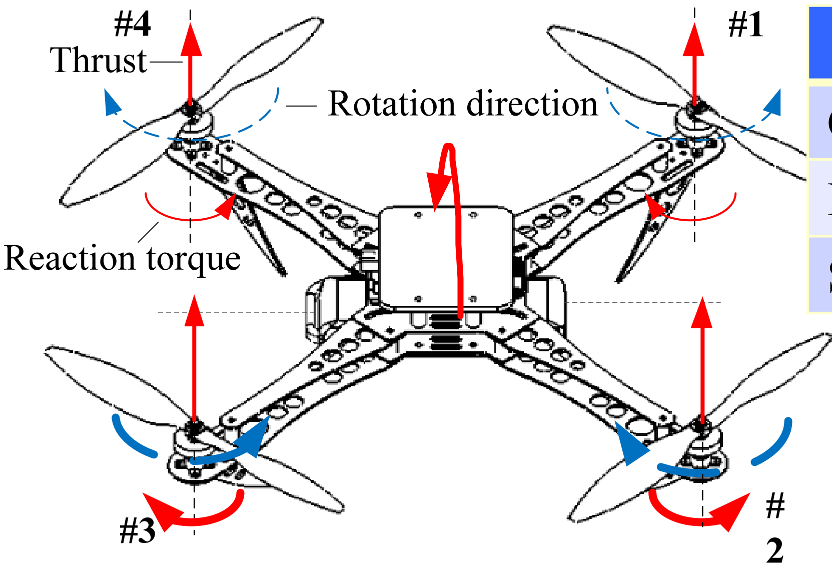


Figure 1.8 Forward movement of a quadcopter

Table 1.2 Change of propellers' angular velocities ("+"indicates increase, "-" indicates decrease)

	#1	#2	#3	#4
Change pitch angle	-1	+1	+1	-1
Increase thrust	+0.2	+0.2	+0.2	+0.2
Sum	-0.8	+1.2	+1.2	-0.8

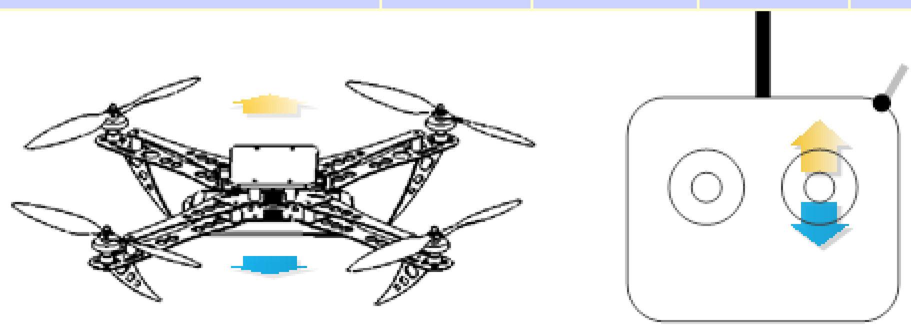
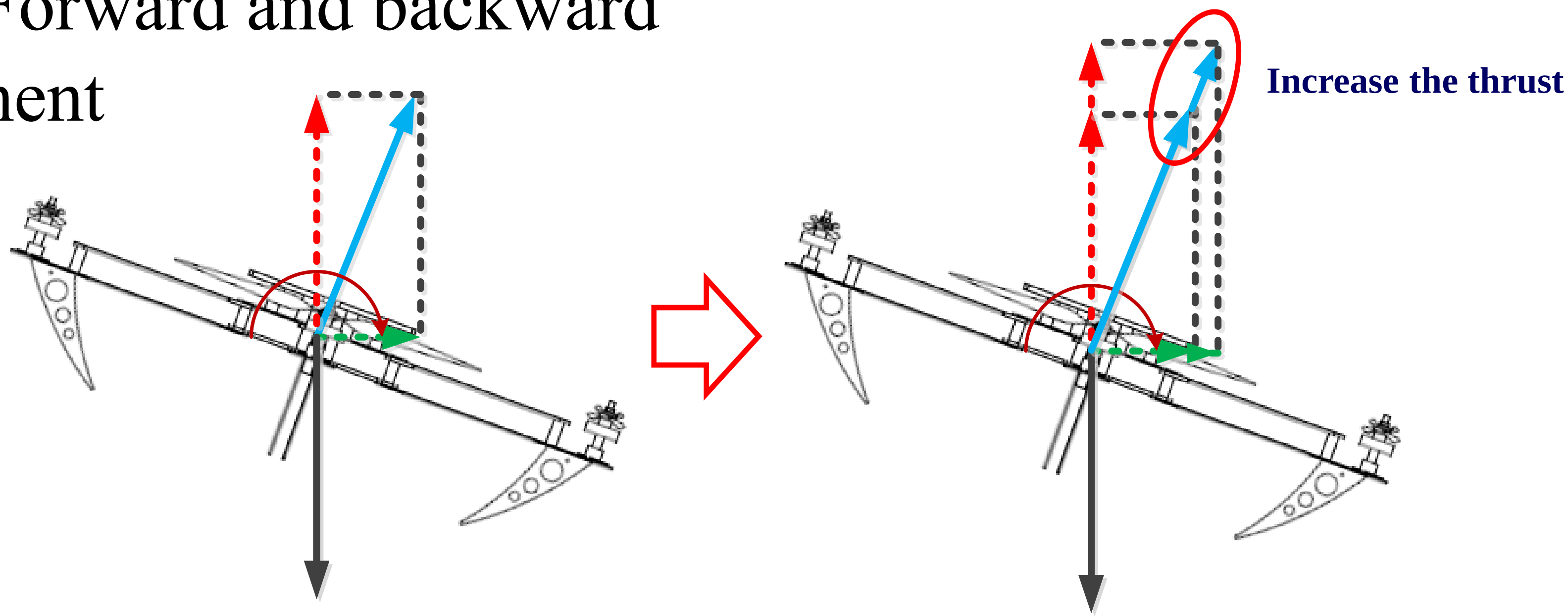


Figure 1.9 Operation of an RC transmitter for the forward and backward movement

2. Remote Control and Performance Evaluation

Remote Control of a Quadcopter

（3） Forward and backward movement



（a） Change pitch angle

（b） Increase thrust

After the pitch angle exists, four propellers' angular velocities should be further increased by the same amount to compensate for the weight.

□ Remote Control of a Quadcopter

（4） Leftward and rightward movement

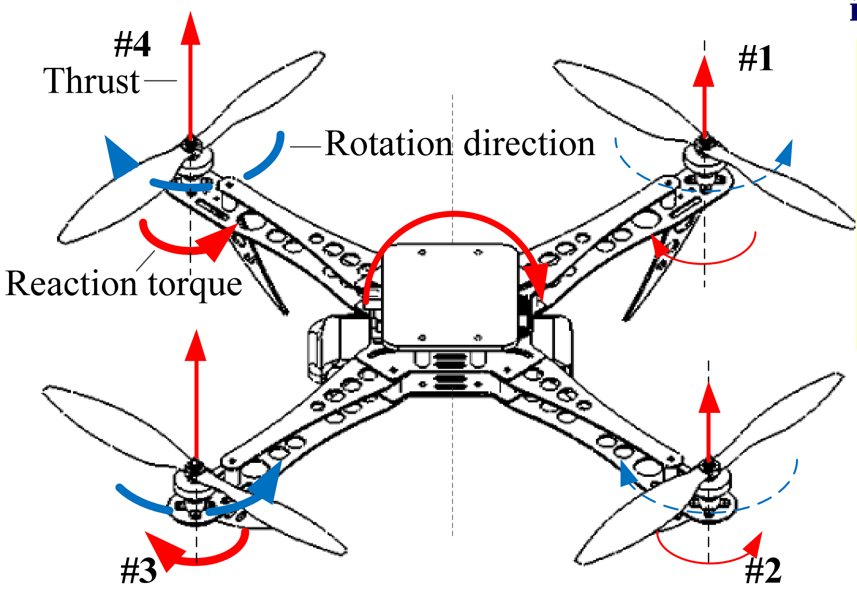


Figure 1.10 Rightward movement of a quadcopter

Table 1.3 Change of propellers' angular velocities ("+"indicates increase, "-" indicates decrease)

	#1	#2	#3	#4
Change roll angle	-1	-1	+1	+1
Increase thrust	+0.2	+0.2	+0.2	+0.2
Sum	-0.8	-0.8	+1.2	+1.2

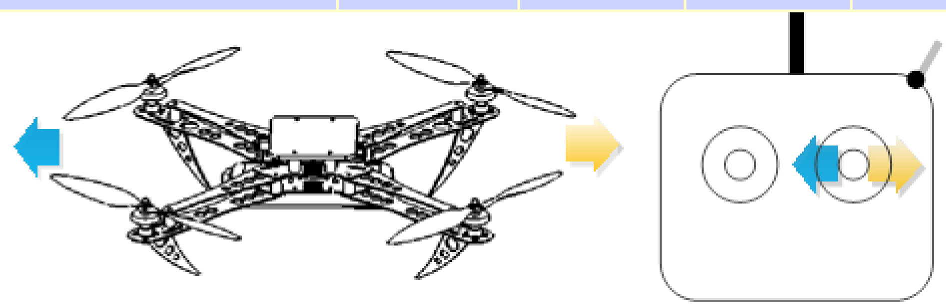


Figure 1.11 Operation of an RC transmitter for the leftward and rightward movement

2. Remote Control and Performance Evaluation

☐ Remote Control of a Quadcopter

（5） Yaw movement

Table 1.4 Change of propellers' angular velocities ("+"indicates increase, "-" indicates decrease)

	#1	#2	#3	#4
Change yaw angle	+1	-1	+1	-1

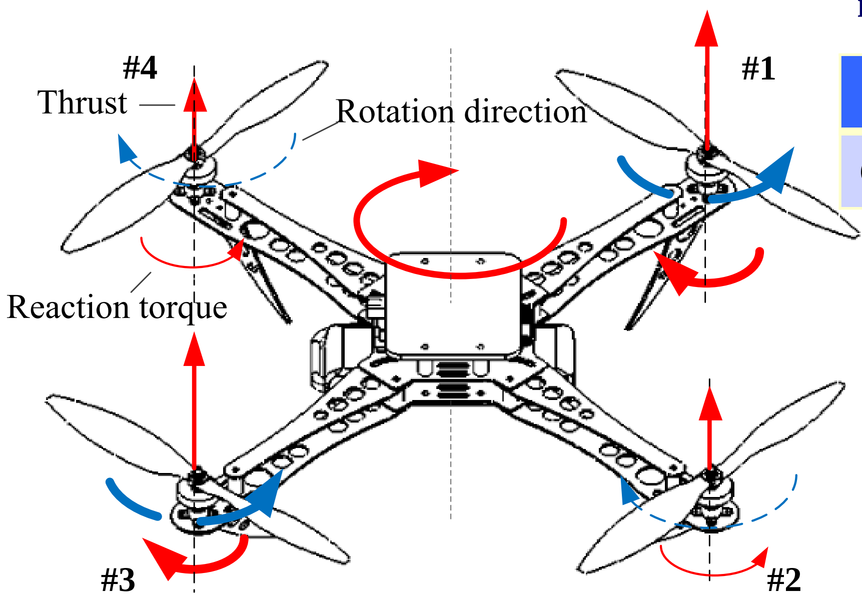


Figure 1.12 Clockwise yaw movement of a quadcopter

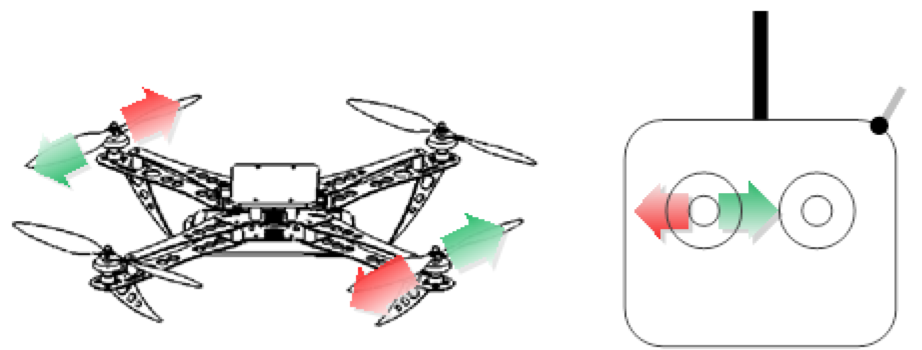


Figure 1.13 Operation of an RC transmitter for yaw movement

2. Remote Control and Performance Evaluation

Performance Evaluation

Table 1.5 Comparisons of user experiences of three types of small aircraft (More “+” implies better)

	Fixed-wing aircraft	Helicopters	Multicopters
Ease-of-use	++	+	+++
Reliability	++	+	+++
Maintainability	++	+	+++
Time of endurance	+++	++	+
Payload capacity	++	+++	+

- Ease-of-use： Movements are decoupled
- Reliability： There is hardly any mechanical wear
- Maintainability： Simple structure

These make people choose multicopters

2. Remote Control and Performance Evaluation

Bottleneck

（1） The longer the radius of a propeller is, the slower the dynamic response of propellers will be

$$M = \frac{1}{2\pi} C_{\mathrm{M}} \rho \varpi^2 \left(2r_{\mathrm{p}}\right) \Rightarrow \begin{matrix} M \sim \varpi^2 R^5 \\ J \sim R^5 \end{matrix} \Rightarrow \alpha = \frac{M}{J} \sim \frac{\varpi^2 R^5}{R^5} = \varpi^2$$

Linear velocity of the blade tip can be treated as a constant $\varpi \sim 1/r_{\mathrm{p}} \Rightarrow \varpi \sim 1/R$

$$\Rightarrow \boxed{\alpha \sim \frac{1}{R^2}}$$

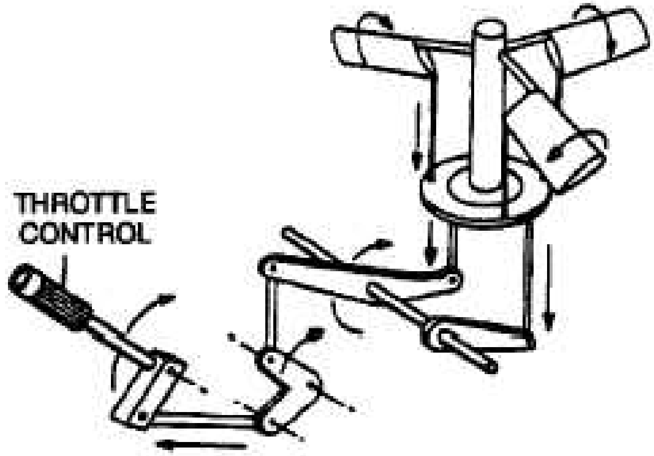
α is the acceleration of angular velocity

R is the airframe radius

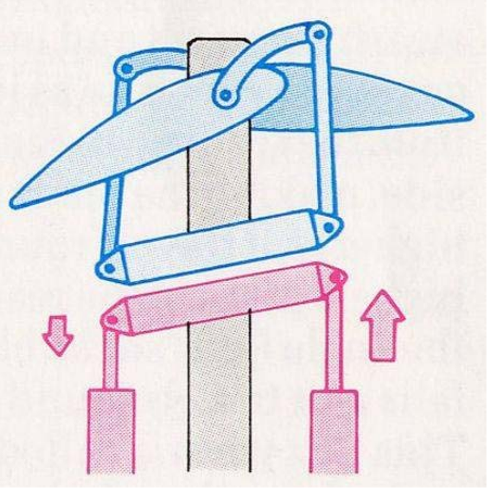
2. Remote Control and Performance Evaluation

Bottleneck

（1） The longer the radius of a propeller is, the slower the dynamic response of propellers will be



From http://aviationmaintenance.tpub.com/



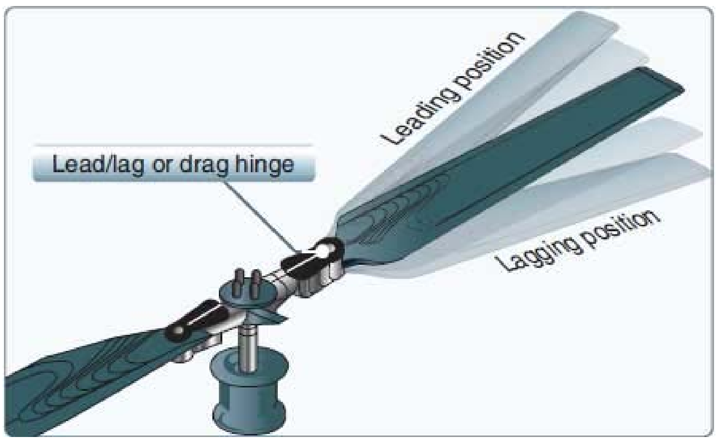
From http://www.aerospaceweb.org/

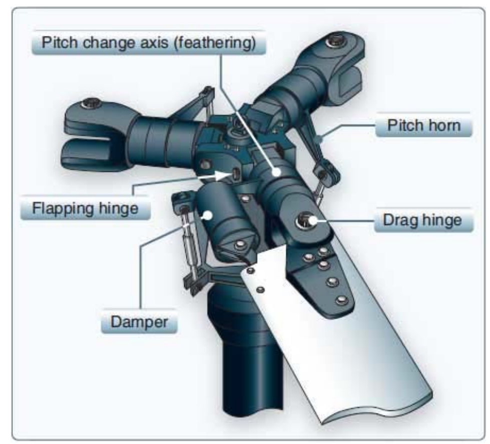
Helicopters increase or decrease overall lift by altering the angle of attack for all blades collectively by equal amounts at the same time, resulting in ascent and descent behavior.

2. Remote Control and Performance Evaluation

□ Bottleneck

（2） The longer the radius of a propeller is, the more fatigue it is in the rotor hub due to the blade-flapping effects.





来源http://www.danubewings.com/fully-articulated-rotor-system/

Large helicopters adopt flapping hinges. With flapping hinges, none of the bending forces or rolling moments are transferred to the body of the helicopter.

2. Remote Control and Performance Evaluation

□ Bottleneck

（3）There is a way to increase the payload capacity, which is to use more small propellers to replace large rotors.

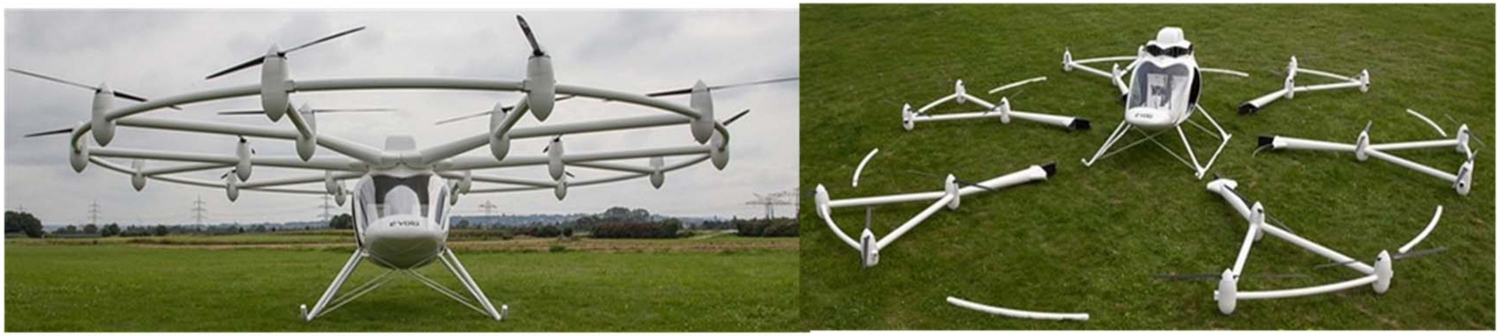
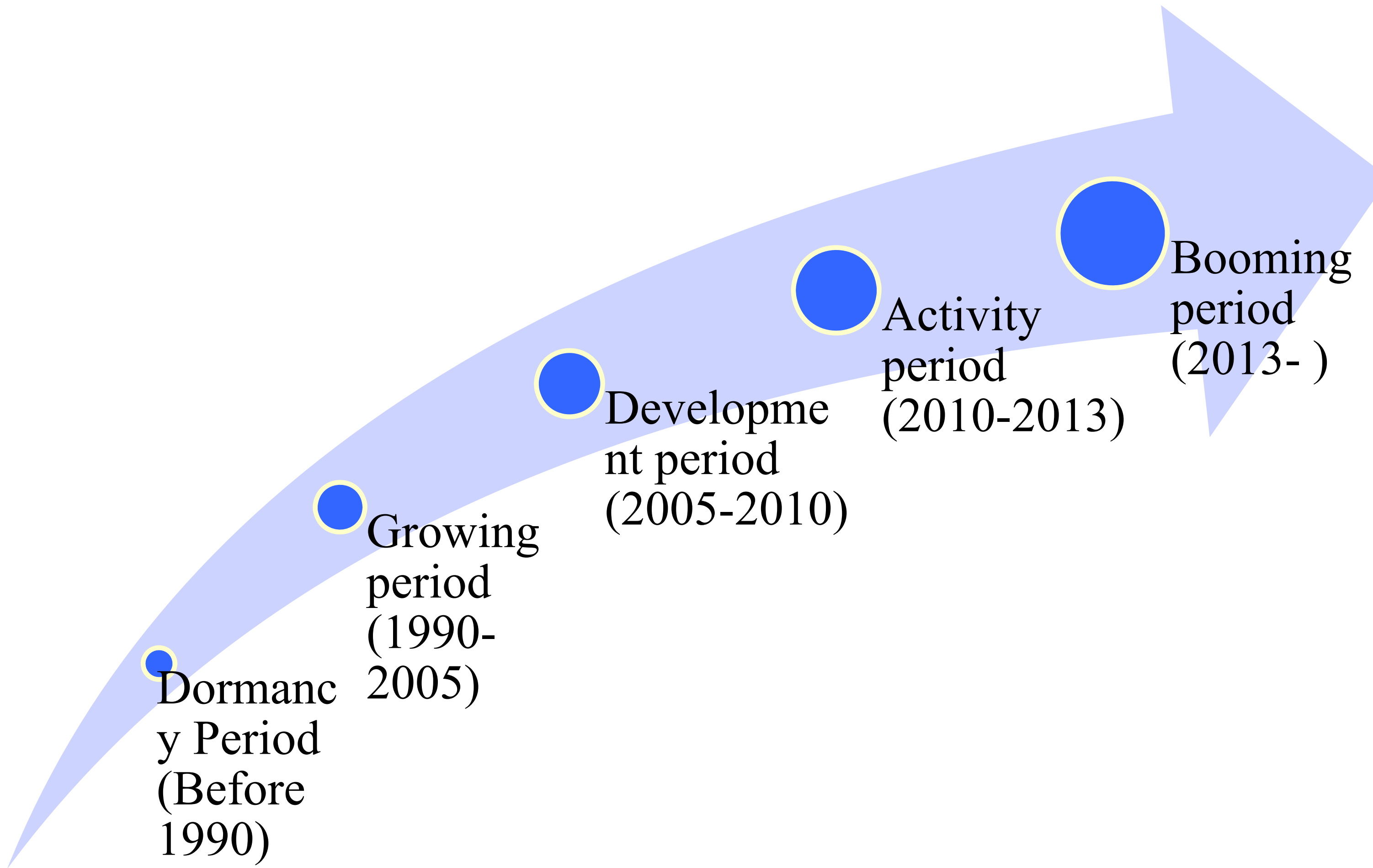


Figure 1.14 Volocopter VC200

Volocopter VC200 has eighteen motors, the failure rate of any single one is increased. However, there is much control redundancy. By some smart control allocation algorithms, the flight safety can be improved.

3. History


Dormancy Period (Before 1990)
Growing period (1990-2005)
Development period (2005-2010)
Activity period (2010-2013)
Booming period (2013-)

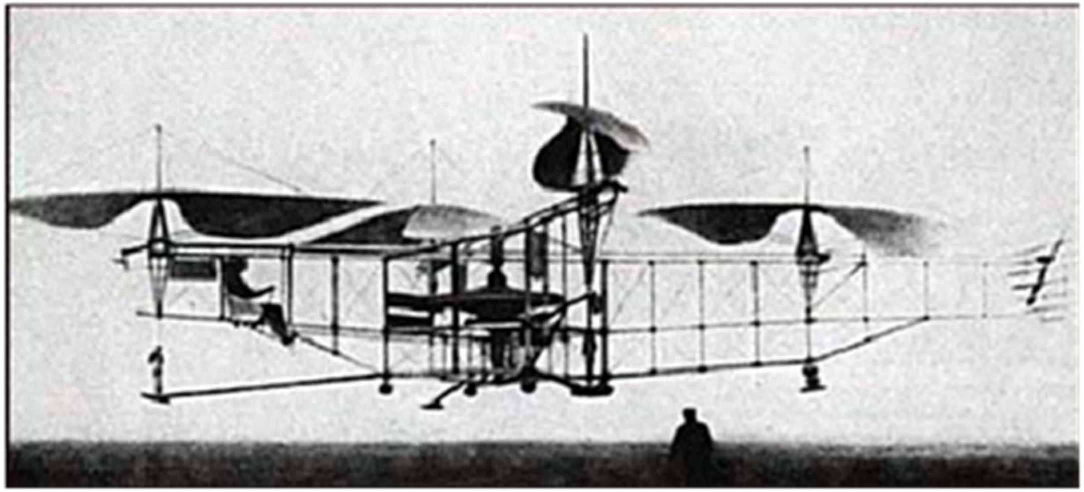
3. History

□ The First Stage (Before 1990): Dormancy Period

- As early as 1907 in France, guided by Charles Richet, the Breguet Brothers built their first human carrying helicopter—and they called it the Breguet-Richet Gyroplane No. 1, which was a quadcopter. The first attempt of flight was undertaken between August and September of 1907. The witnesses said they saw the quadcopter lifted 1.5 m into the air for a moments and landed soon after. This failure was caused by the impractical design.

3. History

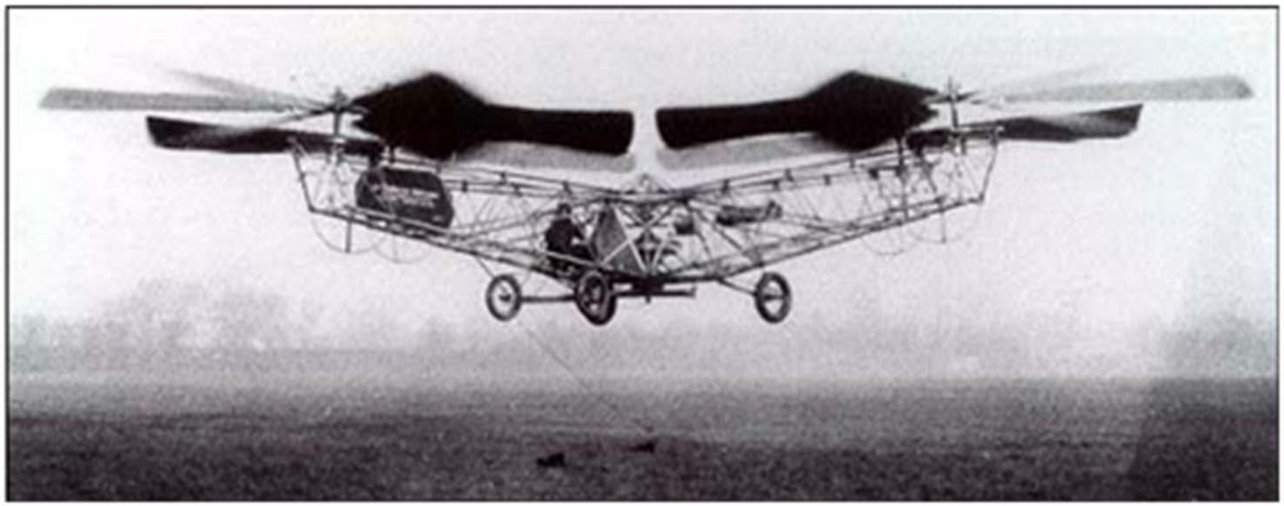
□ The First Stage (Before 1990): Dormancy Period



- Etienne Oemichen, another engineer, also began experimenting with rotating-wing designs in 1920. His first model failed to lift from the ground. However, after some calculations and redesigns, his second aircraft, the Oemichen No. 2, as shown in Figure 1.15 (b), established a world record for helicopters in 1923 by remaining airborne for up to fourteen minutes.

3. History

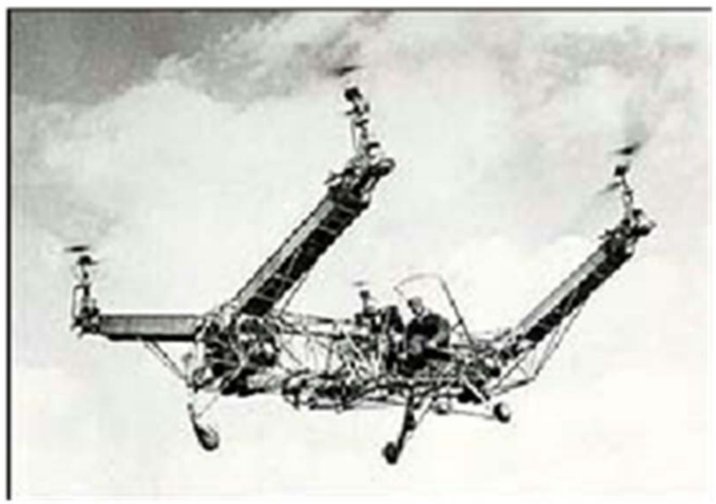
◻ The First Stage (Before 1990): Dormancy Period



- In 1921, George De Bothezat and Ivan Jerome were hired to develop one for the U.S. Army Air Corps. Their quadcopter was designed to take a payload of three people in addition to one pilot and was supposed to reach an altitude of one hundred meters, but the result was that it only managed to lift five meters.

3. History

□ The First Stage (Before 1990): Dormancy Period



- Until the mid-1950s, the first real quadcopter was flown, which was designed by Marc Adman Kaplan. His quadcopter design, Convertawings Model "A" was first flown in 1956 and proved to be a great success. The one ton heavy quadcopter was able to hover and maneuver with its two 90 horsepower engines.

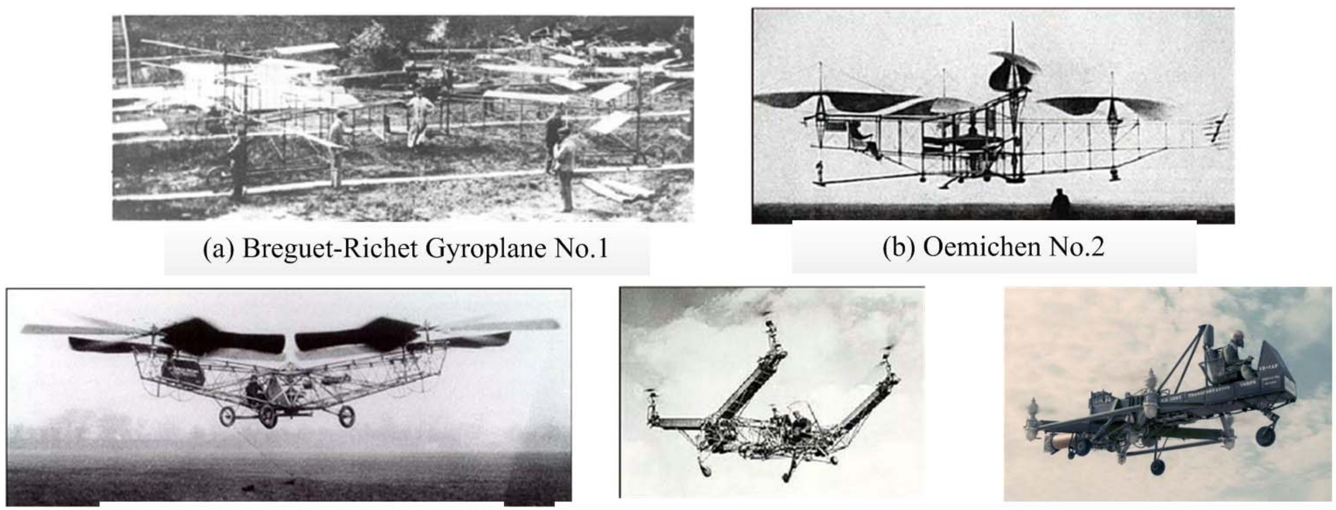
3. History

□ The First Stage (Before 1990): Dormancy Period

- In 1957, the Army contracted with Curtiss-Wright to develop VZ-7 as a prototype flying jeep, to carry small amounts of men and machinery over rough terrain. Curtiss-Wright produced two VZ-7 prototypes in 1958. The machines were proved to be very easy to handle and maneuver. However, they were not able to meet the altitude and speed requirements specified in the Army’s contract.

3. History

◻ The First Stage (Before 1990): Dormancy Period



(a) Breguet-Richet Gyroplane No.1

(b) Oemichen No.2

(c) De Bothezat helicopter

(d) Convertawings Model “A”

(e) Curtiss-Wright VZ-7

Figure 1.15 Some multicopters in the Dormancy Period, from http://www.aviastar.org/

- Full-scale multicopters did NOT have advantages over full-scale single rotor helicopters. That is why U.S. Army cancelled these projects in 1960s. Since then, multicopters were nearly abandoned.

3. History

□ The Second Stage (1990-2005): Growing Period

(1) Research

- Until 1990s, with the development of Micro-Electro-Mechanical System (MEMS), Inertial Measurement Unit (IMU) weighting several grams emerged. The research started to receive more and more attention on how to get rid of the noise in the attitude measurement of MEMS IMUs.
- The researchers at universities started to build models and design control algorithms [7]-[11].
- Some pioneers started to build their own real multicopters, such as Mesicopter by Stanford University

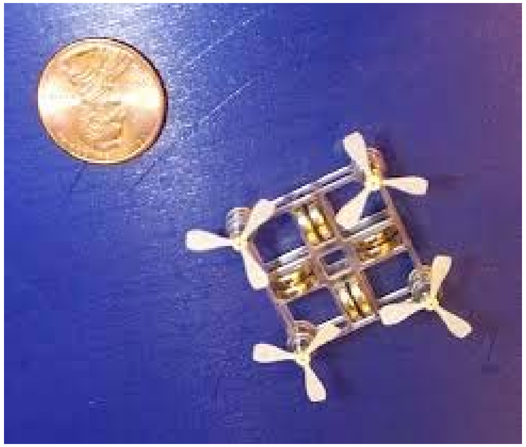


Figure 1.16 Mesicopter

[7] Hamel T, Mahony R, Chriette A. IEEE ICRA, 2002

[8] Altug E. Ph.D. dissertation, University of Pennsylvania, 2003

[9] Kroo I, Printz F. Mesicopter Project[Online], available: http://aero.stanford.edu/mesicopter,

[10] Borenstein J. The Hoverbot-An Electrically Powered Flying Robot[Online], available:http://www-personal.umich.edu/~johannb/hoverbot.htm

[11] Bouabdallah S, Murrieri P, Siegwart R. IEEE ICRA, 2004.

3. History

□ The Second Stage (1990-2005): Growing Period

(2) Products

- During the early 1990s, a mini quadcopters, called Keyence Gyrosaucer, was marketed in Japan.
- During the early 1990s, engineer Mike Dammar developed his own battery-powered quadcopter.
- In 2002, the Silverlit X-UFO was invented and developed in the Jugend forscht (young researchers) competition in Germany.

(a) Gyro Saucer 1 (b) Roswell Flyer (c) Silverlit X-UFO

Figure 1.17 Some multicopters in the growing period

3. History

□ The Third Stage (2005-2010): Development Period

(1) Research

- Since 2005, more and more researchers paid attention to multicopters and published a large amount of papers and started to build their own multicopters to test corresponding algorithms, especially the attitude control algorithms.
- Some researchers utilized the existing reliable commercial quadcopters and the optical motion-capture system to build testing environments. Based on the testing environments, some high-level tasks were completed indoor.

3. History

□ The Third Stage (2005-2010): Development Period

(1) Research

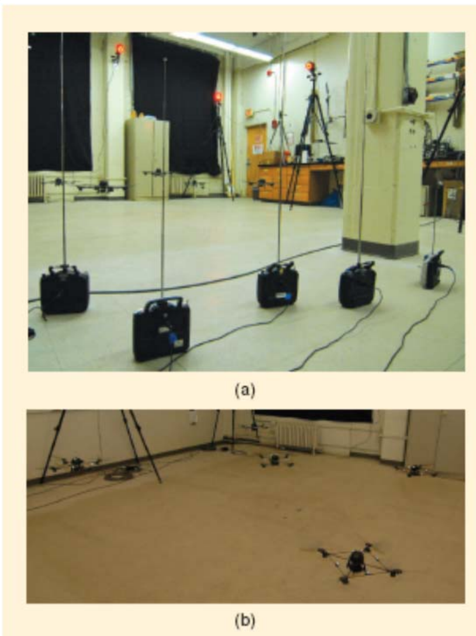


Figure 1.18. Real-Time Indoor Autonomous Vehicle Test Environment，MIT [12]

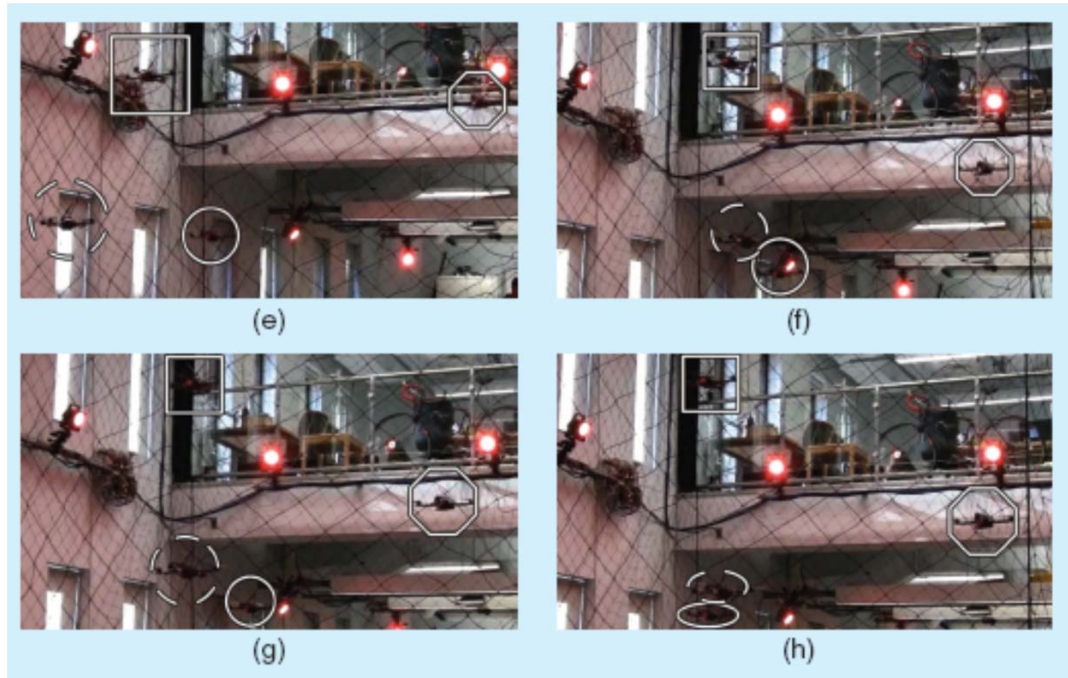


Figure 1.19. The Grasp Multiple Micro-UAV Test Bed，UPENN [13]

[12] How J P, et al. Real-time indoor autonomous vehicle test environment. IEEE TCS, 2008, 28(2): 51-64.

[13] Michael N, et al. The grasp multiple micro-uav test bed. IEEE TRAM, 2010, 17(3): 56-65.

3. History

□ The Third Stage (2005-2010): Development Period

(1) Research

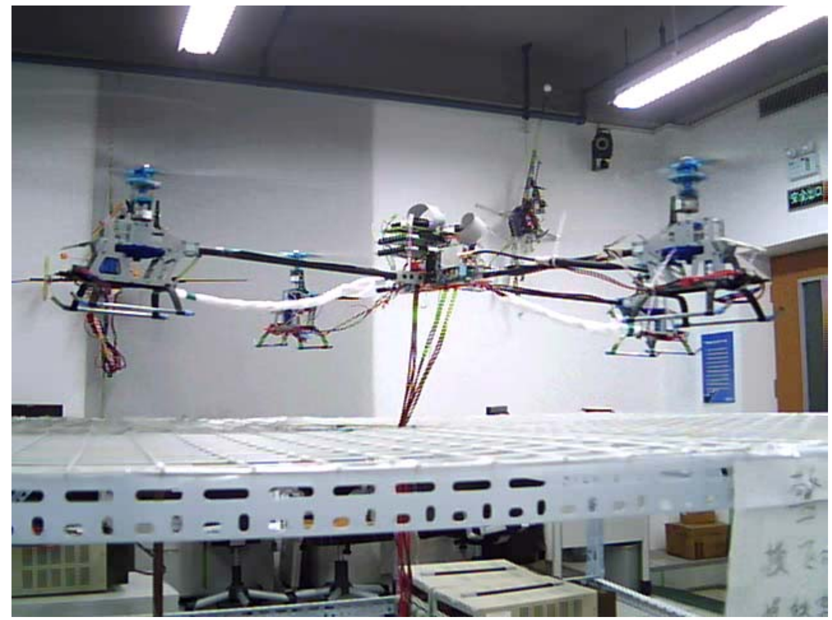


Figure 1.20. Some quadcopters of our lab during 2007-2009

- Our lab started the research on quadcopter since 2007

3. History

□ The Third Stage (2005-2010): Development Period

(2) Products

- Microdrones GmbH was founded in October 2005. The first product, namely MD4-200 as shown in Figure 1.20 (a), was launched in April 2006.
- In October 2006, open source MikroKopter autopilot was created by Holger Buss and Ingo Busker.
- In 2007, the two inventers of the Silverlit X-UFO started Ascending Technologies GmbH in Germany.
- In 2008, Draganflyer designed a Draganflyer X6 as shown in Figure 1.20 (b).
- In 2007, in the business column of *Nature*, an article was published to discuss the commercialization time line of drones [14].

[14] Stafford N. Spy in the sky. Nature, 2007, 445(22): 808-809

(a) Md4-200

(b) Draganflyer X6

Figure 1.20 Some products in the development period

3. History

□ The Fourth Stage (2010-2013): Activity Period

(1) Research

- In February 2012, Vijay Kumar at the University of Pennsylvania made a speech at TED conference. Several videos demonstrated that fleets of tiny flying robots performed a series of intricate maneuvers, working together on tasks.
- In 2012, IEEE Robotics and Automation Magazine published a special issue on aerial robotics and the quadcopter platform, which summarized and demonstrated some state-of-the-art technologies [15,16,17].
- At this stage, many open source autopilots about multicopters emerged, which lowered the threshold of building multicopters.

[16] Mahony R, Kumar V, Corke P. Multirotor aerial vehicles: Modeling, estimation, and control of quadrotor. IEEE Robotics & Automation Magazine, 2012 (19): 20-32.

[17] Lim H, Park J, Lee D, et al. Build your own quadrotor: Open-source projects on unmanned aerial vehicles. IEEE Robotics & Automation Magazine, 2012, 19(3): 33-45.

[18]Tomic T, Schmid K, Lutz P, et al. Toward a fully autonomous UAV: research platform for indoor and outdoor urban search and rescue. IEEE Robotics & Automation Magazine, 2012 (19): 46-56.

3. History

□ The Fourth Stage (2010-2013): Activity Period

Table 1.6 Major open source Projects

Open-Source Projects	Web site URL
Ardupilot	http://ardupilot.com
Openpilot	http://www.openpilot.org/
Paparazzi	http://paparazziuav.org
Pixhawk	https://pixhawk.ethz.ch/
Mikrokopter	http://www.mikrokopter.de
KKmulticopter	http://www.kkmulticopter.kr/
Multiwii	http://www.multiwii.com/
Aeroquad	http://www.aeroquadstore.com/
Crazyflie	https://www.bitcraze.io/category/crazyflie/
CrazePony	http://www.crazepony.com/
DR. R&D	http://www.etootle.com/
ANO	http://www.anotc.com/
Autoquad	http://autoquad.org/
MegaPirate	http://megapiratex.com/index.php
Erlerobot	http://erlerobotics.com/
MegaPirateNG	http://code.google.com/p/megapirateng

Open-Source Projects	Web site URL
Taulabs	http://forum.taulabs.org/
Flexbot	http://www.flexbot.cc/
Dronecode	https://www.dronecode.org/
Percepto	http://www.percepto.co/
Parrot API(SDK)	https://projects.ardrone.org/embedded/ardrone-api/index.html
3DR DRONEKIT(SDK)	http://www.dronekit.io/
DJI DEVELOPER(SDK)	http://dev.dji.com/cn
DJI MATRICE 100+ DJI Guidance	https://developer.dji.com/cn/matrice-100/
SDK for XMission(SDK)	http://www.xaircraft.cn/en/xmission/developer
EHANG GHOST SDK(SDK)	http://dev.ehang.com/

□ The Fourth Stage (2010-2013): Activity Period

（2） Products

- On August 18th, 2010, the AR. Drone was released into the market, as shown in Fig. 1.18(a). It was very successful in the toy market. Its technology and concept were also very advanced : 1) velocity estimation improves ease-of-use ; 2) light in weight and indoor hull made from foam improves safety ; 3) can be controlled by a smart phone or a tablet; 4) offered a Software Development Kit (SDK) to researchers.
- At the end of 2012, DJI released all-in-one solution, ready-to-fly "Phantom" quadcopter, as shown in Fig. 1.20(b)

(a) AR. Drone 1.0

(b) Phantom

Figure 1.21 Some products in the activity period

3. History

◻ The fifth Period (2013-): Booming period

（1） Research

- At this stage, the research on multicopters tended to make them more autonomous and cooperative.
- Raffaello D'Andrea at ETH Zurich made two speechs at TED in 2013 and 2016 mainly about multicopters.
- In June 2015, a special section about Machine Intelligence of the magazine *Nature* published an article on"Science, technology and the future of small autonomous drones" [19].

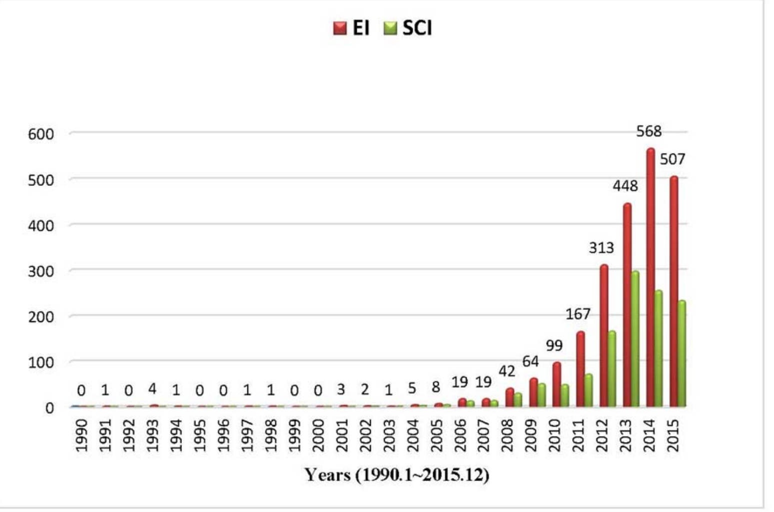


Figure 1.22 The trend of the number of publications about multicopters, from databases "Engineering Village" and "Web of Science"

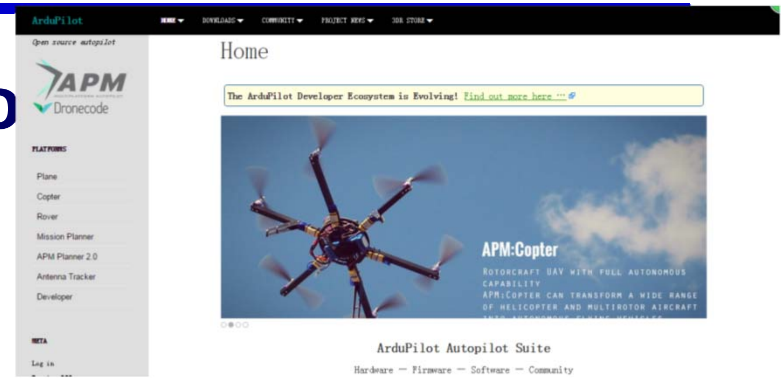
- The amount of publications reached a climax in 2013 with the delay occurred in the review process considered.

[19] Floreano D,Wood R J. Science, technology and the future of small autonomous drones. Nature,2015, 521(7553):460-466

3. History

□ The fifth Period (2013-): Boo

（2） Products



- Phantom mounted with GoPro spurted into popularity in the field of aerial photography.
- By 2012, Chris Anderson, the former editor-in-chief of Wired magazine, joined 3D Robotics as new CEO. Under his stewardship, 3DR's global neurosystem of volunteers soon created a world-class universal open source flight autopilot, called APM.

- In July, 2012, the PX4 team maintained by Lorenz Meier with ETH Zurich, announced availability of the PX4 autopilot platform.
- At the end of 2013, a video was released that Amazon.com hoped to deliver small packages by multicopters.

3. History

□ The fifth Period (2013-): Booming period

（2） Products (from August 2013 to September 2015)

Name	Company	Released Time	Country	Features
Spiri	Patrick Edwards-Daugherty	2013.8	Canada	Autonomous, fully programmable
Stingray500	Curtis Young Blood	2013.12	United States	Full collective pitch 3D quadcopter
AR.Drone 2.0	Parrot	2013.12	France	APP controlled, extreme precise control and automatic stabilization without GPS
AirDog	Helico Aerospace Industies	2014.6	Latvia	Rotor-arms able to fold away for easy storage, auto-follow
Rolling Spider	Parrot	2014.7	France	Small enough to fit in the palm of your hand, wheels enable the Rolling Spider to zip around the floor and up walls and ceilings
IRIS+	3D Robotics	2014.9	United States	The ‘Geofence’, follow the leader mode
Nixie	Fly nexie	2014.11	United States	A small camera-equipped drone that can be worn as a wrist band
GHOST 1.0	EHANG	2014.11	China	Control is through one-one click commands on your phone, auto-follow mode
Mind4	AirMind	2014.11	China	Precise and autonomous following and filming, Android based smart drone
Inspire 1	DJI	2014.11	China	Vision positioning system, transforming design, 4K camera full-featured APP, optional dual-operator control
Bebop	Parrot	2014.12	France	A comprehensive update based on AR. Drone 2.0
Vertex VTOL	ComQuestVentures	2015.1	Puerto Rico	Drone is a hybrid aircraft that combines the hover and VTOL capabilities of a quadcopter
Skydio	Skydio	2015.1	United States	Autonomously navigate around obstacles, flew using intuitive gestures with a mobile device
Steadidrone Flare	Steadidrone	2015.1	Czech	Highest quality carbon fiber and aluminum constructed ‘Rapid Deploy’ folding airframe
Airborg H61500	Top Flight Technologies	2015.3	United States	A hybrid gas-electric multicopter UAV

3. History

◻ The fifth Period (2013-): Booming period

(2) Products (from August 2013 to September 2015)

Name	Company	Released Time	Country	Features
Splash Drone	Urban Drones	2015.3	United States	Waterproof quadcopter
SOLO	3D Robotics	2015.4	United States	Powered by twin computers intelligent flight and can define its own flight
Phantom 3	DJI	2015.4	China	Vision sensor for indoor flight, gimbal stabilized 4K camera
XPlanet	XAIRCRAFT	2015.4	China	Agricultural UAV system, automatically Set the spraying route
Phenox2	Hongo Aerospace	2015.4	Japan	Intelligent, interactive and programmable drone
CyPhy LVL1	CyPhy Works	2015.4	United States	Six-rotor design with the exact angle of each rotor and the drone can fly completely horizontally even when making turns
Lily	Lily	2015.5	United States	Throw-and-shoot camera, waterproofing
PhoneDrone	xCraft	2015.5	New Zealand	Utilizes its user's smartphone as its brains
Yeair！	airstier	2015.6	Germany	A quadcopter powered by a combustion engine
Tayzu	Tayzu Robotics	2015.7	United States	Fully autonomous drones, large scale data collection
Fotokite Phi	Perspective Robotics AG	2015.8	Switzerland	A selfie quadcopter on a leash
Unicorn	FPVStyle	2015.8	China	A racer drone, with a high forward flight speed
Micro Drone3.0	Extreme Fliers	2015.8	United Kingdom	It’s small, smart and streams HD footage to your phone
Feibot	Feibot	2015.9	China	Smartphone-based drone controller
Snap	Vantage Robotics	2015.9	United States	The fuselage can be connected to the rotors and battery by pressing together magnetic strips and a tiny gimbal and camera that are housed inside the body of the drone
Flybi	Advance Robotix Corporation	2015.9	United States	Drone with virtual reality head-tracker goggles a kind rapid charging system. The sensor will detect any object in tis flight path and re-route itself safely.

3. History

□ Conclusion Remark

(1) The multicopter is the product of the time

- As the smart devices are emerging, AR. Drone has social networks are popular, multicopters are getting known by the world rapidly.
- The development of multicopters is also driven by the relevant techniques, like those of the sensors, motors, chips, and materials.
- It is expected that multicopters will dominate the mass market in quite a long time.

(2) Compared with pure autopilots, all-in-one solution and ready-to-fly multicopters arethe future trend

- The performance can be tested intensively in advance. So, the ease-of-use and reliability are guaranteed.
- The essential issue is to change the user.

4. Objective and Structure of the Course

□ Objective

An *introductory* course for beginners :

(1) Basic and practical

- Self-contained for students with the background of Electronic Engineering (EE).
- Most of the given methods are basic and practical.

(2) Comprehensive and systematic

- A complete picture of multicopter system given rather than a single method or technique, covering design, modeling, perception, control and decision.

4. Objective and Structure of the Course

□ Structure

(1) Design part

- Lesson 2. Basic composition

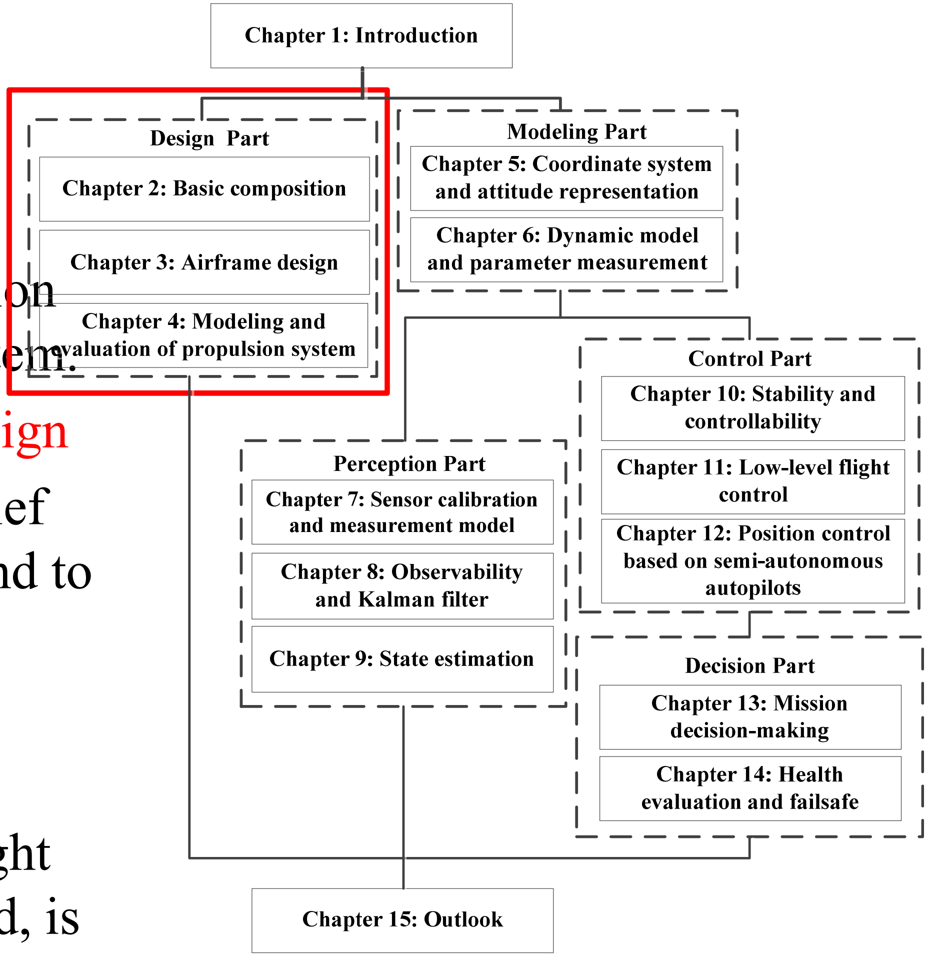
Includes three parts: the fuselage, the propulsion system, and the command and navigation system.

- Lesson 3. Configuration and structural design

Introduces the basic configuration, and the brief consideration on how to attenuate vibration and to reduce the noise.

- Lesson 4. Modeling and evaluation of propulsion system

Flight performance, such as the maximum flight time in hover mode and the maximum payload, is evaluated.



4. Objective and Structure of the Course

□ Structure

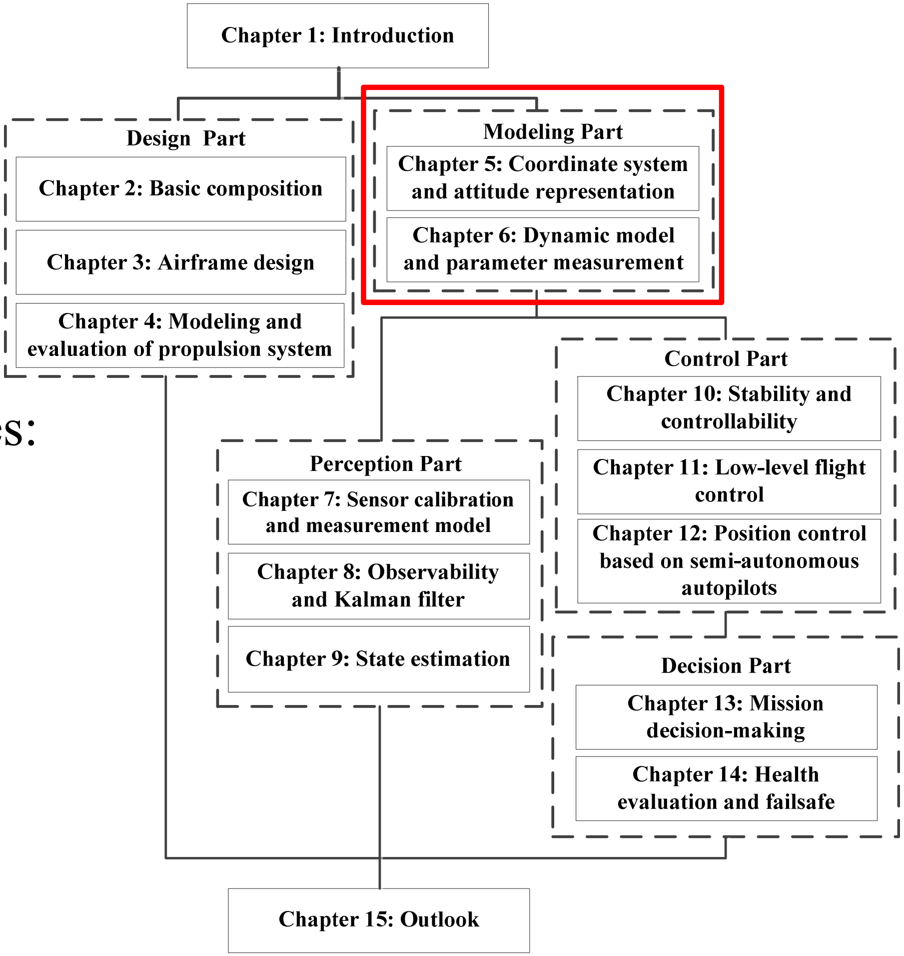
(2) Modeling part

- Lesson 5. Coordinate system and attitude representation

Introduces Coordinate Frames. Then, the attitude is represented in the form of three types: Euler angle, rotation matrix, andquaternion.

- Lesson 6. Dynamic model and parameter measurement

First, the multicopter control model is introduced. Secondly, the aerodynamics model is further introduced. Finally, methods are proposed to identify the parameters of a multicopter model.



4. Objective and Structure of the Course

□ Structure

(3) Perception Part

- Lesson 7. Sensor calibration and measurement model

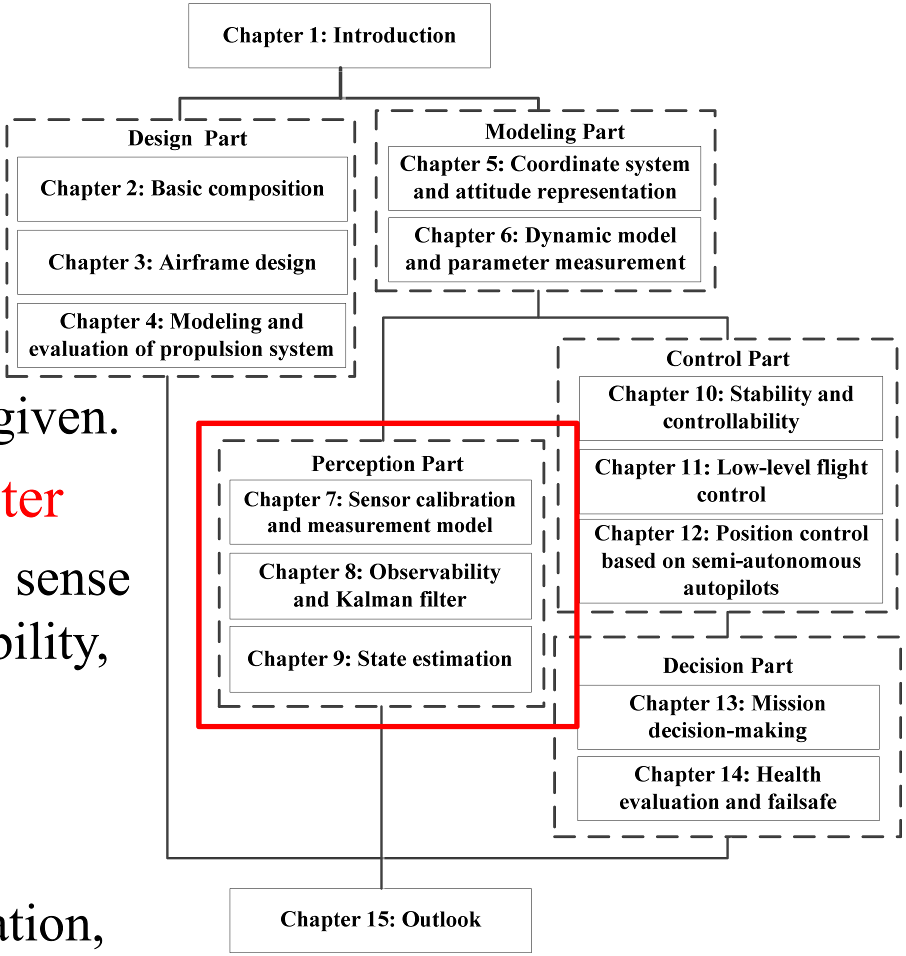
The calibration methods are introduced first. Then, the measurement models of sensors are given.

- Lesson 8. Observability and Kalman filter

If the system is unobservable, then it makes no sense to design filters. After introducing the observability, a widely-used filter, namely Kalman filter, is introduced.

- Lesson 9. State estimation

Contain the attitude estimation, position estimation, velocity estimation, and obstacle estimation.



4. Objective and Structure of the Course

□ Structure

(4) Control Part

- Lesson 10. Stability and controllability

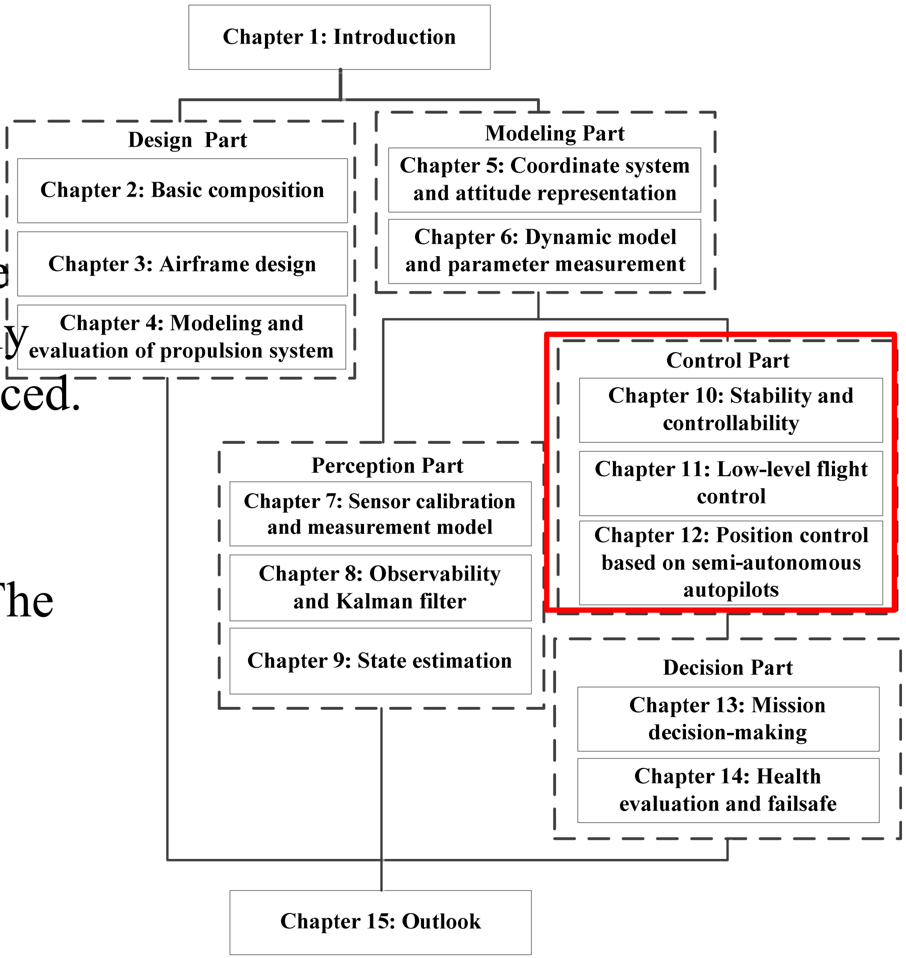
The stability of a multicopter is defined and some simple stability criteria have to be given. Secondly, the controllability of a multicopter is also introduced.

- Lesson 11. Low-level position control

Introduce how to design a motor controller that drives a multicopter to fly to a desired position. The process includes the position control, attitude control, control allocation and motor control.

- Lesson 12. Position control based on Semi-Autonomous Autopilot

The system identification and controller design process.



4. Objective and Structure of the Course

□ Structure

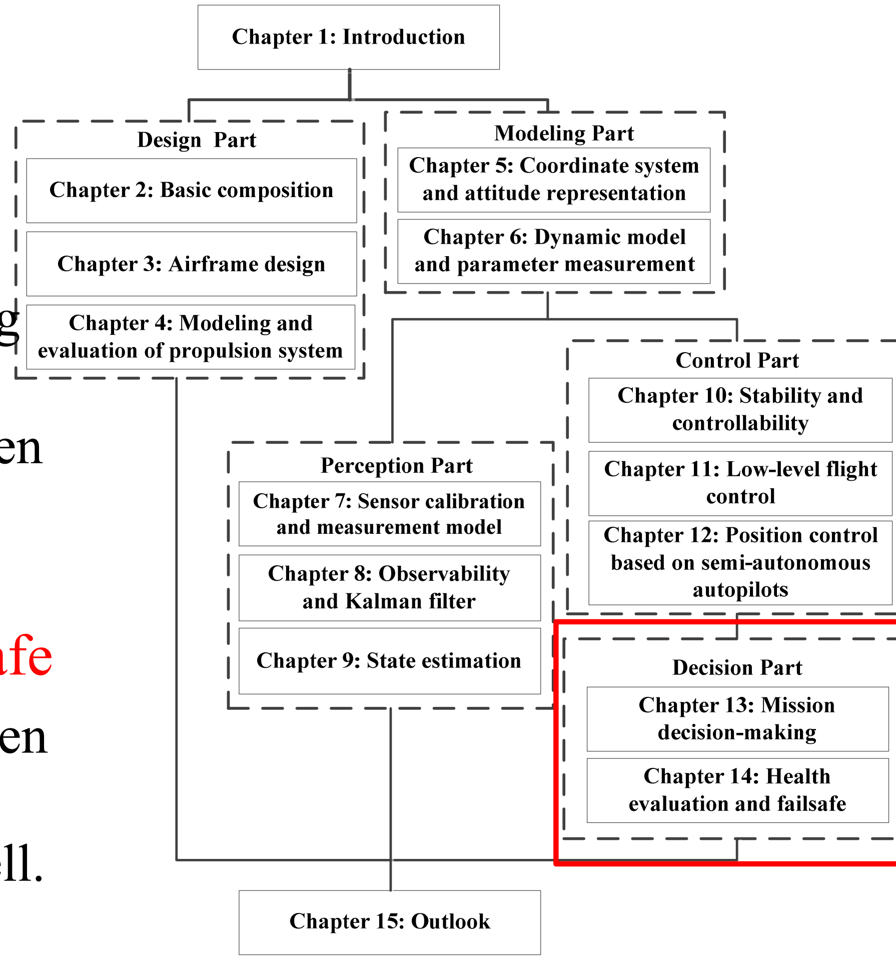
(5) Decision part

- Lesson 13. Mission decision-making

Consists of the task planning and path planning in Full-Autonomous Control . For Semi-Autonomous Control, a switching logic between the autonomous hover and the remote control will be introduced.

- Lesson 14. Health evaluation and failsafe

Some failure problems are introduced first. Then some methods of health evaluation are given. Moreover, failsafe suggestions are listed as well. Finally, a failsafe mechanism as a case is designed by using the Finite-State-Machine.



Acknowledgement

Deep thanks go to all students

for material preparation.

Thank you!

All course PPTs and resources can be downloaded at
http://rfly.buaa.edu.cn/course

For more detailed content, please refer to the textbook:

Quan, Quan. Introduction to Multicopter Design and Control. Springer, 2017. ISBN: 978-981-10-3382-7.

It is available now, please visit http://www.springer.com/us/book/9789811033810