UAV Workshop

Introduction to UAS

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UAS: Outline

- **Classifications**
  - Based on Maximum Takeoff Weight (MTOW)
  - Based on type of platform
  - Based on Operational altitude
- **Make up of UAS**
  - Command & Control Elements
  - Communications Data Link
  - Launch and Recovery
    - Takeoff/Landing
  - Human Elements
    - Pilot
    - Observer
- **Payload**
  - Electro-Optical
  - Infrared
  - Laser
  - Radiowave
  - …

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UAS: Classifying Unmanned Aircraft System

- **Why? (for what purpose)**
  - To Regulate in order to:
    - Improve Safety
    - Generate Revenue
- **Who? (sovereign bodies)**
  - U.S. Department of Transportation - FAA
  - U.S. Department of Defense
- **How? (properties/attributes)**
  - Maximum Takeoff Weight (MTOW), Altitude, & Airspeed (primarily)

UAS: Classifying Unmanned Aircraft System

- **Different Classification Methods**
  - **Levels of autonomy**
    - Unmanned Aircraft (UA) or Remotely Piloted Aircraft (RPA) Types
  - **Maximum Takeoff Weight (MTOW)**
    - Heavier-than-air (Aerodyne)
    - Lighter-than-air (Aerostat)
  - **Operational Altitude**
  - **Operational Speed**

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UAS: Classifying Levels of Autonomy

Table 5.7 Autonomous control levels (Source: Clough (2002a))

ACL	Level descriptor
0	Remotely piloted vehicle
1	Execute preplanned mission
2	Changeable mission
3	Robust response to real-time faults/events
4	Fault/event adaptive vehicle
5	Real-time multi-vehicle coordination
6	Real-time multi-vehicle cooperation
7	Battlespace knowledge
8	Battlespace cognizance
9	Battlespace swarm cognizance
10	Fully autonomous

Important for:

- **ALL Pilots**
- **ALL applications**
  - **For Fun - Recreational**
  - **For Profit - Commercial**
- **Determines Regulation**
- **Command, Control, & Communications**

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UAS: Classifying Unmanned Aircraft System

- **U.S. Department of Defense category groups by :**
  - **MTOW, Altitude, & Airspeed**

UAS Category	Max Gross Takeoff Weight	Normal Operating Altitude (ft)	Airspeed
Group 1	<20 pounds	<1200 above ground level (AGL)	<100 knots
Group 2	21–55 pounds	<3500 AGL	< 250 knots
Group 3	<1320 pounds	<18,000 mean sea level (MSL)	
Group 4	>1320 pounds		Any airspeed
Group 5		>18,000 MSL	

Note: If a UAS has even one characteristic of the next higher level, it is classified in that level.

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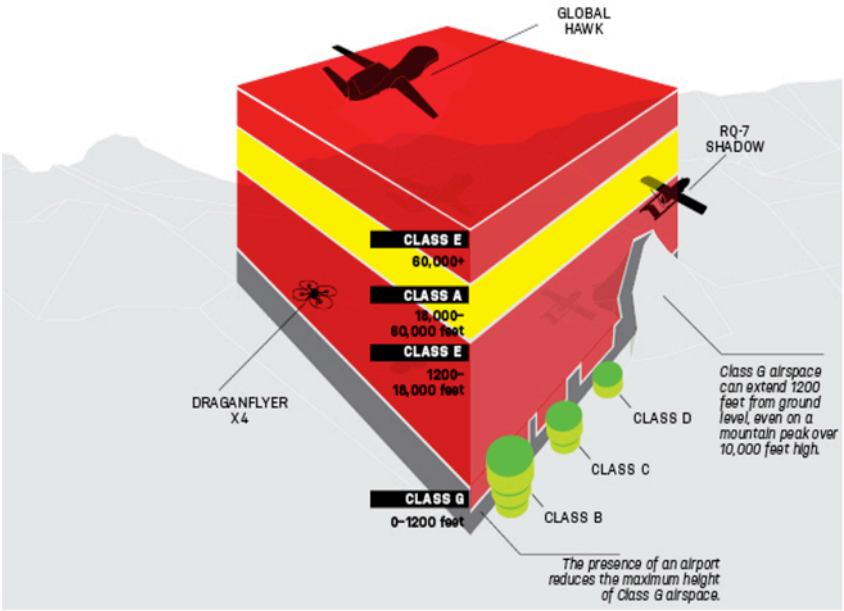
UAS: Classifying Operational Altitude

- **Very Low Altitude / Line-of-sight (VLA/LOS)**
  - Class G Airspace below 400 - 500 feet with operator always having visual contact
- **Very Low Altitude / Beyond Line-of-sight (VLA/BLOS)**
  - Class G Airspace below 400 - 500 feet with possibility of flying beyond the line of sight
- **Medium Altitude (MA)**
  - Class A - Class E Airspace
- **Very High Altitude (VHA)**
  - Class E Airspace above Flight Level 60,000 feet (**FL600**)



UAS: Classifying - Speed

- **U.S. Military UAV Categories**

Table 5.10 Military UAV categories and relevant UAV regulations (Source: U.S. Department of Defense, Office of the Secretary of Defense (2007)) **UPDATE: June 2016**

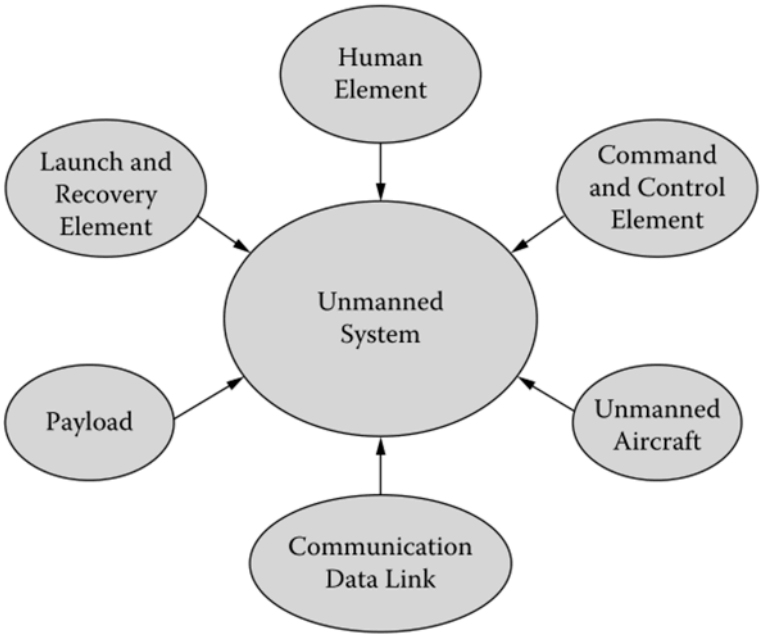
Category	FAA regulation	Airspace usage	Airspeed limit (KIAS)
Cat I – R/C model aircraft	**14 CFR Part 107**	Class G	100[a]
Cat II – Nonstandard aircraft	FAR Parts 91, 101, and 103	Class E,G, and non-joint-use D	250[a]
Cat III – Certified aircraft	FAR Part 91	All	None

[a]Proposed

Source: U.S. Department of Defense, Office of the Secretary of Defense, Unmanned systems roadmap 2007–2032. Report, 2007

UAS: What is an Unmanned Aircraft System

- **Collection of Elements make a system**
  - Aircraft
    - Manned (piloted)
    - Unmanned
  - Control Elements
    - Autopilot computer
  - Communications architecture
    - Radios (for control & telemetry)
  - Payload
    - Sensors
  - Human Elements
    - Pilot
    - Observer
  - Launch and Recovery (L&R)
    - Catapults
    - Parachutes
    - Takeoff/Landing procedures



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UAS: Unmanned Aircraft (Quadrotor)

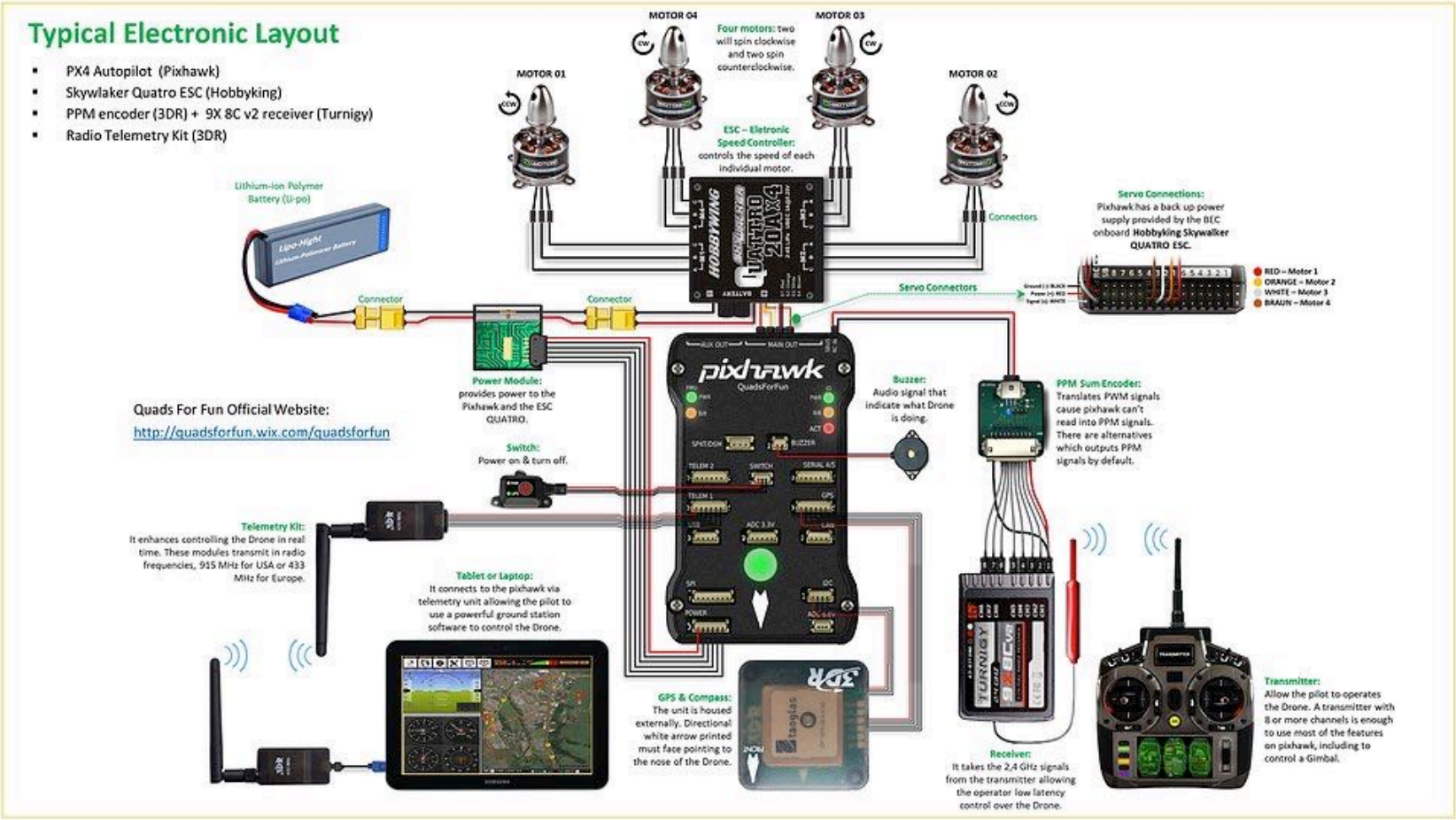
- **UA Hardware**
  - Motors
  - Propellers
  - Electronics
    - Avionics System
      - Control CPU (Autopilot Units)
      - Inertial Measurement Unit (IMU)
      - Electronic Speed Controller (ESC)
      - Radio-Frequency (RF) Receivers
    - Power Supply
      - Lithium-Polymer Battery (Li-Po)
        - In most Micro/Mini UAV's
    - Sensors (for mission)
      - Cameras (electro-optical or infrared)
      - Lasers (targeting or depth measure)

Table 11.5 Weight budget for quadrotor MAV

Components	Amount	Estimate weight (g)	Current weight (g)
Battery	1	10	9.8
Motor and propeller	4	3.5	3.59
Quadrotor arm	4	1	0.93
Quadrotor frame	1	4	2.13
Onboard system	1	10	7.32
Miscellaneous		2	1.7
Total		44	39.03

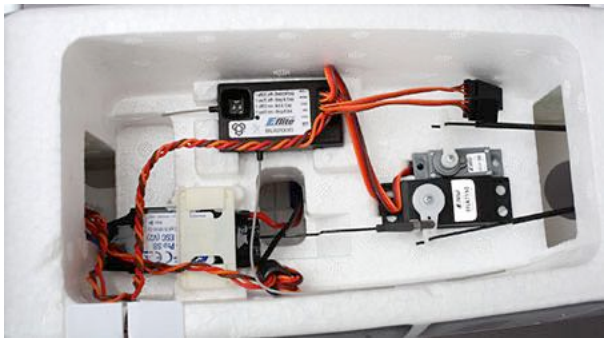
http://ardupilot.org/copter/docs/hoverthings-flip-sport-quadcopter.html

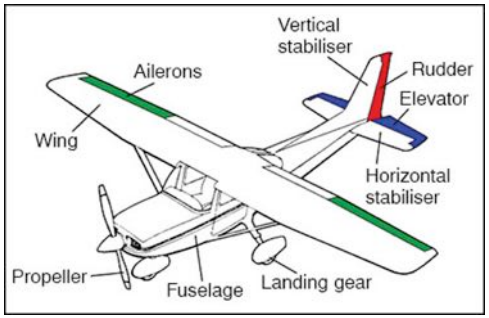
UAS: Unmanned Aircraft (Micro/Mini) Vehicle

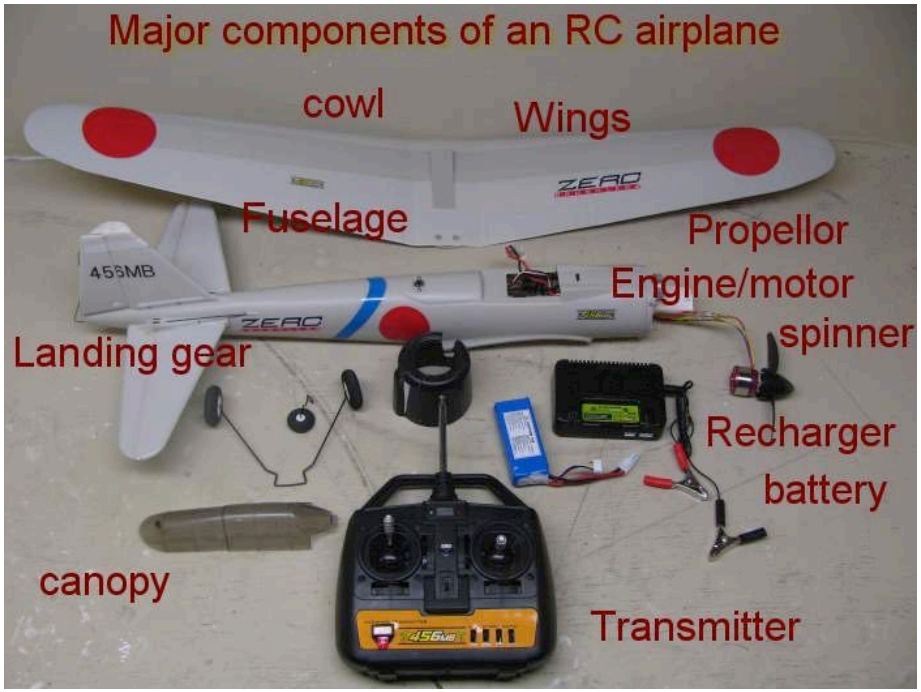


http://ardupilot.org/copter/docs/advanced-pixhawk-quadcopter-wiring-chart.html

UAS: Unmanned Aircraft (FWA)





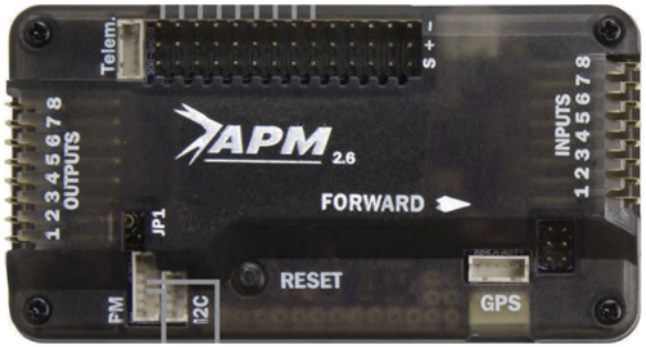


UAS: Autopilot

- **Autopilot**
  - Computing unit dedicated to controlling aspects of flight
    - Takeoff/Landing
    - Altitude
    - Stabilization/State Estimation
    - Flight path & speed
    - Preprogrammed missions
    - Safety features
      - Lost link procedures
  - Built-in sensors
    - Orientation/Acceleration
    - Heading
    - Altitude
  - Examples
    - Pixhawk
    - APM (defunct)
    - Piccolo
    - DJI Naza

http://www.cloudcaptech.com/products/detail/piccolo-SL1

http://www.dji.com/product/naza-m-lite/spec



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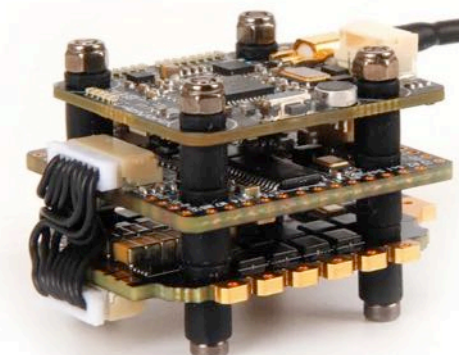
UAS: Autopilots

pixhawk



Kakute F7 V1.5 Stacks

Pixhawk 2

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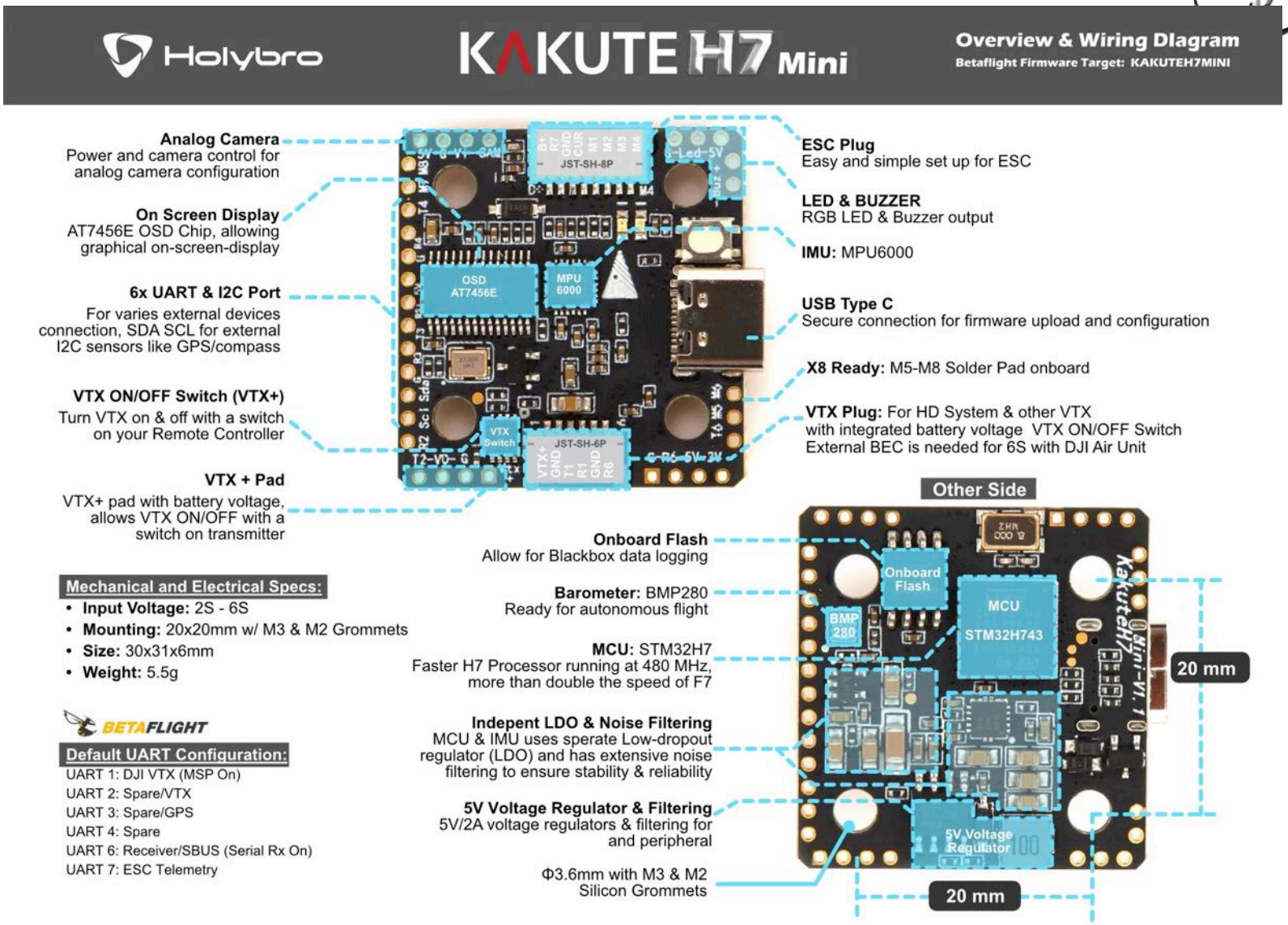
UAS: Inside the Autopilot



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UAS: Command & Control

- **Ground Control Station (GCS)**
  - Location, equipment, and software
  - Provides human control of UA
  - Vary is size
    - Handheld device
    - Self-contained facility
  - Provides
    - Sensor/Telemetry Data
    - GPS
    - Commands for Controlling UA
  - Examples
    - Mission Planner
    - QGroundControl
    - DJI GroundStation
    - MQ-1 GCS trailer

Handheld GCS (Copyright AeroVironment)

MQ-1 Predator GCS

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UAS: Communications Elements

- **Data Link**
  - Term used to describe how UAS Command and Control information is sent
  - 2 Categories
    - Line-of-sight (LOS)
      - Operate via direct radio waves
      - Limited delay (0 sec - 1 sec)
      - Unlicensed
        - 915 MHz
        - 2.45 GHz
        - 5.8 GHz
      - Licensed
        - 310-390 MHz
        - 405-425 MHz
        - 1350-1390 MHz
    - Beyond Line-of-sight (BLOS)
      - Relayed connection
        - Satellite (Iridium Sat System for civilian on Ku band)
        - Significant delay (1 sec - 10+ sec)

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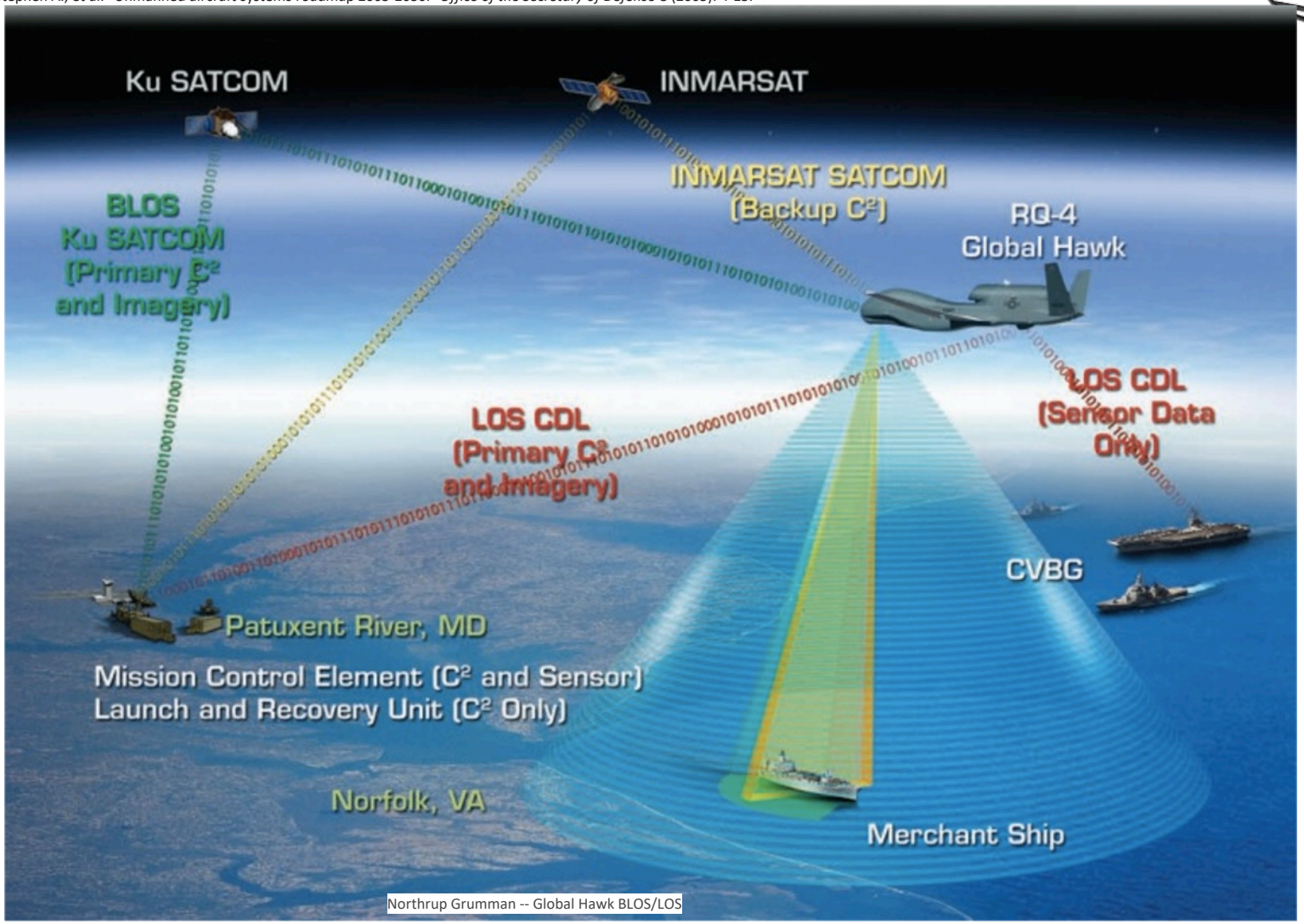
UAS: Communications Element

Cambone, Stephen A., et al. "Unmanned aircraft systems roadmap 2005-2030." *Office of the Secretary of Defense* 8 (2005): 4-15.



Northrup Grumman -- Global Hawk BLOS/LOS

UAS: Sensors

- **Sensing for Flight**
  - IMU
    - Gyroscope
    - Accelerometer
    - Pressure sensor
  - GPS
    - Satellite Position data
  - Compass
    - Heading
  - Ultrasonic (altitude)
- **Sensing for mission**
  - Electro-optical cameras (pan-tilt-zoor
  - IR cameras (thermal imaging)
  - Synthetic Aperture Radars (SAR)
  - Laser Range Finder/Designator

Fig. 20.2 Typical infrared image with 10 cm spatial resolution taken from an aircraft onboard camera (image courtesy of Ergon Energy and the Cooperative Research Centre for Spatial Information (CRCSI))

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UAS: Navigators

- **Sensing for Flight**
  - IMU
    - Gyroscope
    - Accelerometer
    - Pressure sensor
    - Ultrasonic (altitude)
  - GPS
    - Satellite Position data
  - Compass
    - Heading
- **Sensing for mission**
  - Electro-optical cameras (pan-tilt-zoom)
  - IR cameras (thermal imaging)
  - Synthetic Aperture Radars (SAR)
  - Laser Range Finder/Designator

IMU **GPS**

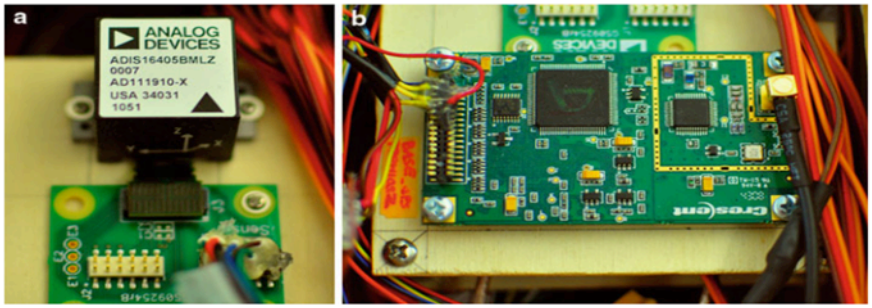

Fig. 18.4 Navigation sensor of UMN UAV: ADIS16405 (**a**) and Hemisphere Crescent OEM GPS receiver (**b**)

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UAS: Computing Unit

- **Stand Alone Computer**
  - For advanced automation tasks
    - Computer Vision
      - Image processing
    - Advanced Flight Dynamics
      - Turbulent conditions
    - Sensor Data Fusion
      - Combining and interpreting input from multiple sensors
    - Advanced path planning for obstacle avoidance

Table 9.6 Example of aircraft software budget table

Priority	Component	CPU allocation (%)
1	Image capture	10
2	Planning and control	10
3	Image processing	45
4	Data fusion	15
5	Housekeeping	10
	Total	100

UAS: UAS: Payloads: Power

- **Requirements based**
  - Mission Minimum Requirements determine power requirements
  - For Micro/Mini UAV (short duration)
    - Chargeable battery
      - Li-Po (Lithium-Polymer)
      - Lion (Lithium-Ion)
      - NiCd (Nickel-Cadmium)
  - For Short Range - Mid Range (and beyond)
    - Combustion engine
      - Gasoline
    - Turbojet
      - Jet fuel
    - Example
      - Global Hawk

	RQ-4A (Block 10)		RQ-4A (Block 10)
Length	44.4 ft	Wing Span	116.2 ft
Gross Weight	26,750 lb	Payload Capacity	1950 lb
Fuel Capacity	14,700 lb	Fuel Type	JP-8
Engine Make	Rolls Royce AE-3007H	Power, SLS	7600 lb
Data Link(s)	LOS	Frequency	UHF
	LOS		X-band CDL
	BLOS (SATCOM		Ku-band INMARSAT

Performance:

Endurance	32 hr	Maximum/Loiter Speeds	350/340 kt
Ceiling	65,000 ft	Radius	5400 nm
Takeoff Means	Runway	Landing Means	Runway
Sensor	EO/IR	Sensor Make	Northrop Grumman
	SAR/MTI		Raytheon

Source: U.S. Department of Defense, Office of the Secretary of Defense, Unmanned systems roadmap 2007–2032. Report, 2007

UAS: Launch & Recovery

- **Dependent on system size**
  - Mini/Micro
    - Fixed-wing
      - Hand launch
      - Low labor requirement
    - Rotary-Wing
      - Vertical-Takeoff-Landing (VTOL)
    - Airship
      - Pre-flight preparations
      - VTOL
  - Large systems
    - Dedicated crew
    - Runway of up to 10,000 feet

UAS: Human Element

- **Mandatory Requirement**
  - For Safety
    - Manual Override
    - Advanced operations
    - Complex flight maneuvering
    - Manual Sensor Data Fusion
      - Combining and interpreting input from multiple computers
    - Advanced path planning for obstacle avoidance
  - Demand by Law
    - Autonomy still requires assessment and regulation

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Fig. 4.28 The WASP is a MAV that can carry an EO payload and has an endurance of over 1 h (Photo Credit: NIST)

UAS: Flight Simulators

- *Simulation* – an computer application that imitate or mimic real systems
- Why?
  - Study the system – measure, improve, design, control
  - Lower Cost, training, safety
- *What do you need to develop one?*
  - *Model* – set of assumptions/approximations about how the system works
  - Flexibility to model things as they are (even if messy and complicated)
  - Allows uncertainty, non-stationarity in modeling
- Advances in computing/cost ratios
  - Parallel Processing (GPUs), Faster Processors and Graphic Engines
- Advances in simulation software
  - More realistic environment, graphic processing, realistic controls, models, simulation, hardware control (4D).

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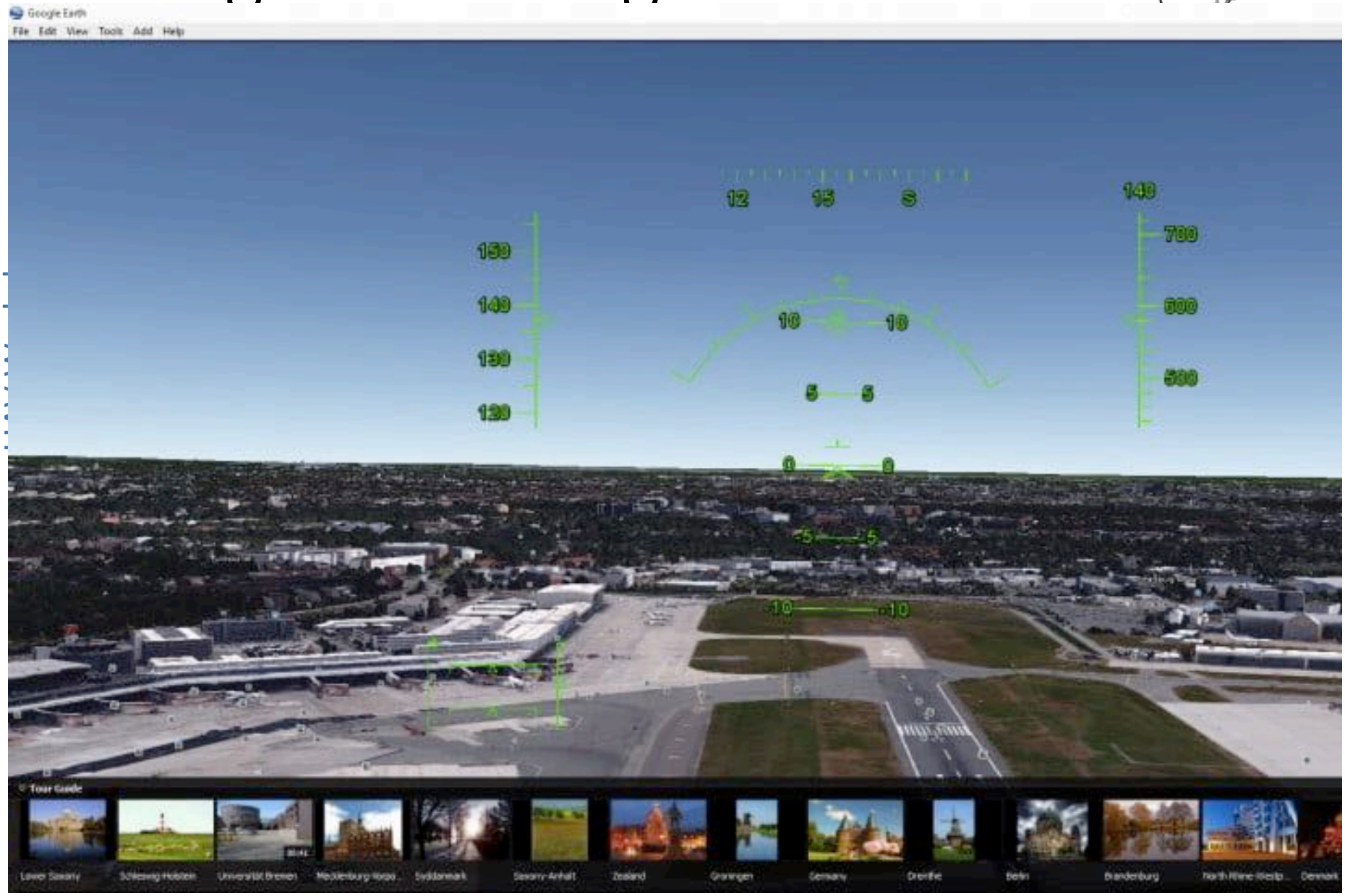
Google Earth Flight Simulator



YSFlight

>>GUN:3000<<
A-AAM:6 (Short-Range)
AAM:2 (Mid-Range)
AGM:6
FLR:30
FUEL:1 (800)
FLAP
SPOILER

FlightGear — Windows, MacOS, Linux

X-Plane — Windows, MacOS, Linux, Android, iOS