Flight Mechanics, Stability and Control

Course Information

- **Instructor:**
  - Damian Toohey
  - The Aerospace Corporation
  - E-mail: dtoohey@g.ucla.com

- **Teaching Assistant:**
  - ??
  - E-mail: ??

- **Office Hours:**
  - Office Hours: TBD (either before or after class)
  - Other times by arrangement

- **Texts:**
  - McCormick, B.W.,Aerodynamics, Aeronautics and Flight Mechanics, 2nd edition, Wiley & Sons, 1995

- **Tentative Grading:**
  - Homework 20%
  - Midterm 30%
  - Final 50%

Course Objectives

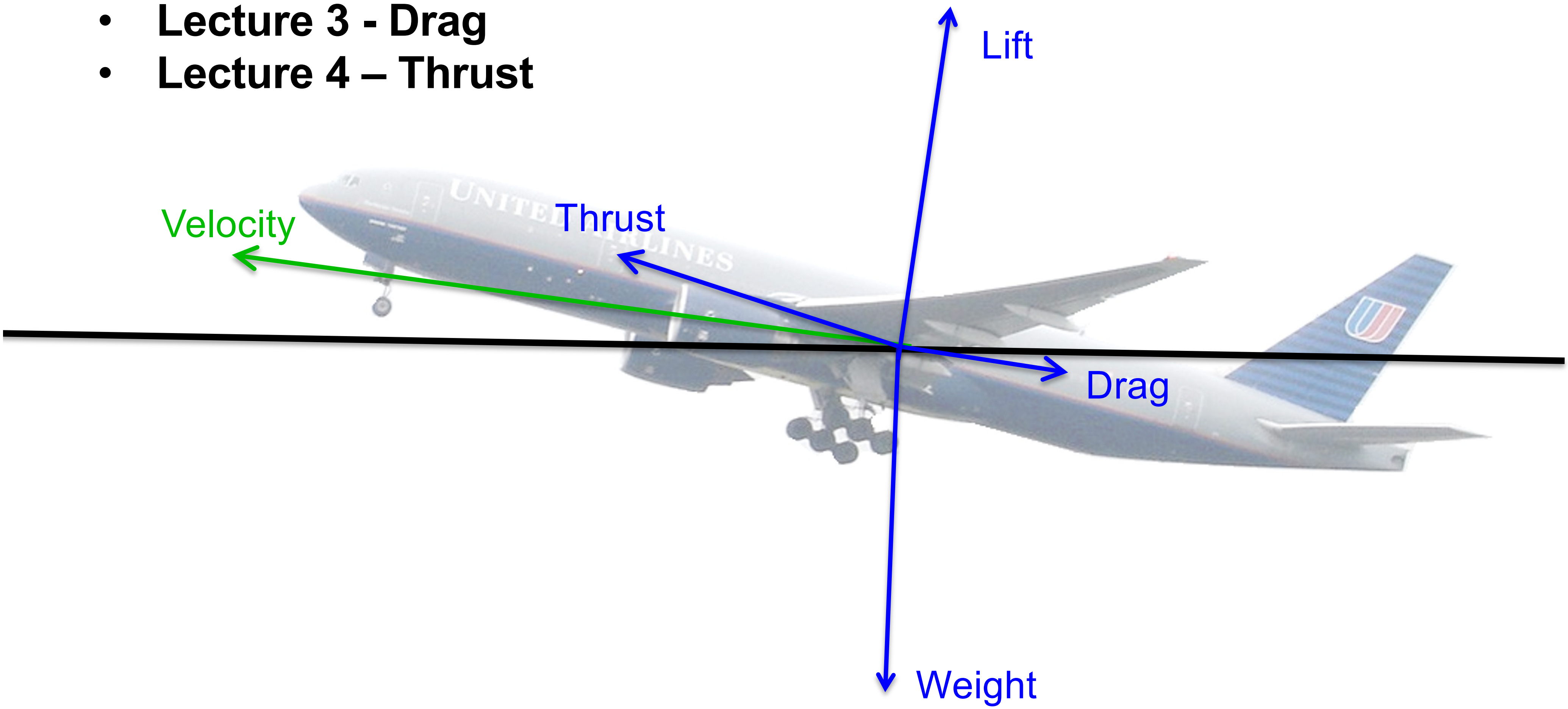
The goals of this course are to….

- **Develop an understanding of aircraft dynamics**
- **Examine how an aircraft's design impacts its performance and stability, and understand why there is a such a variety of different aircraft**
- **Demonstrate how aircraft dynamics can be modeled in a simulation**
- **Introduce aircraft guidance and control concepts**

B-2 Spirit - Image Courtesy of USAF

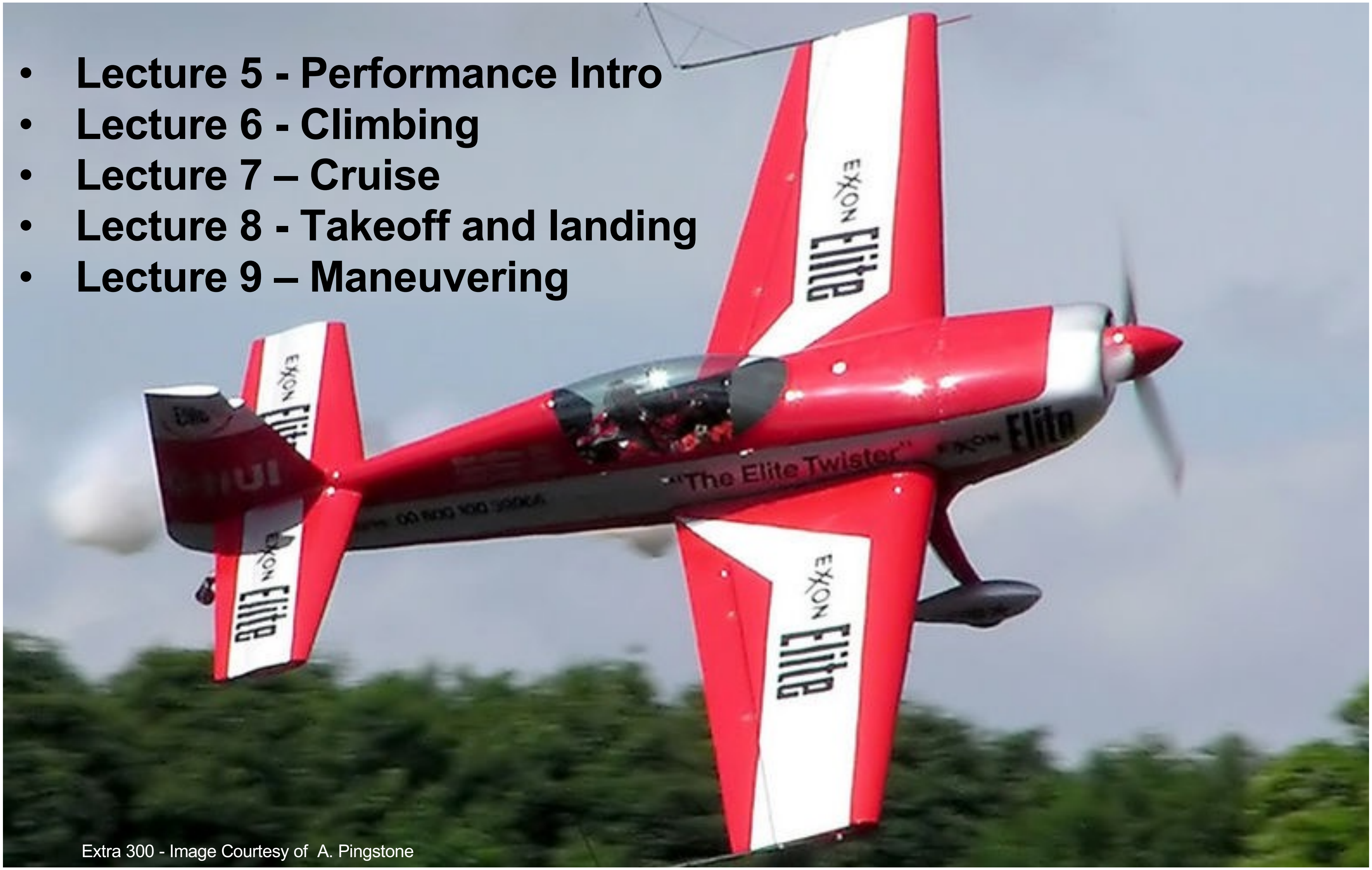
Part 1-Aircraft Basics

- **Lecture 1 - Brief History of Flight**
- **Lecture 2 - Lift**
- **Lecture 3 - Drag**
- **Lecture 4 – Thrust**



Part 2 – Aircraft Performance

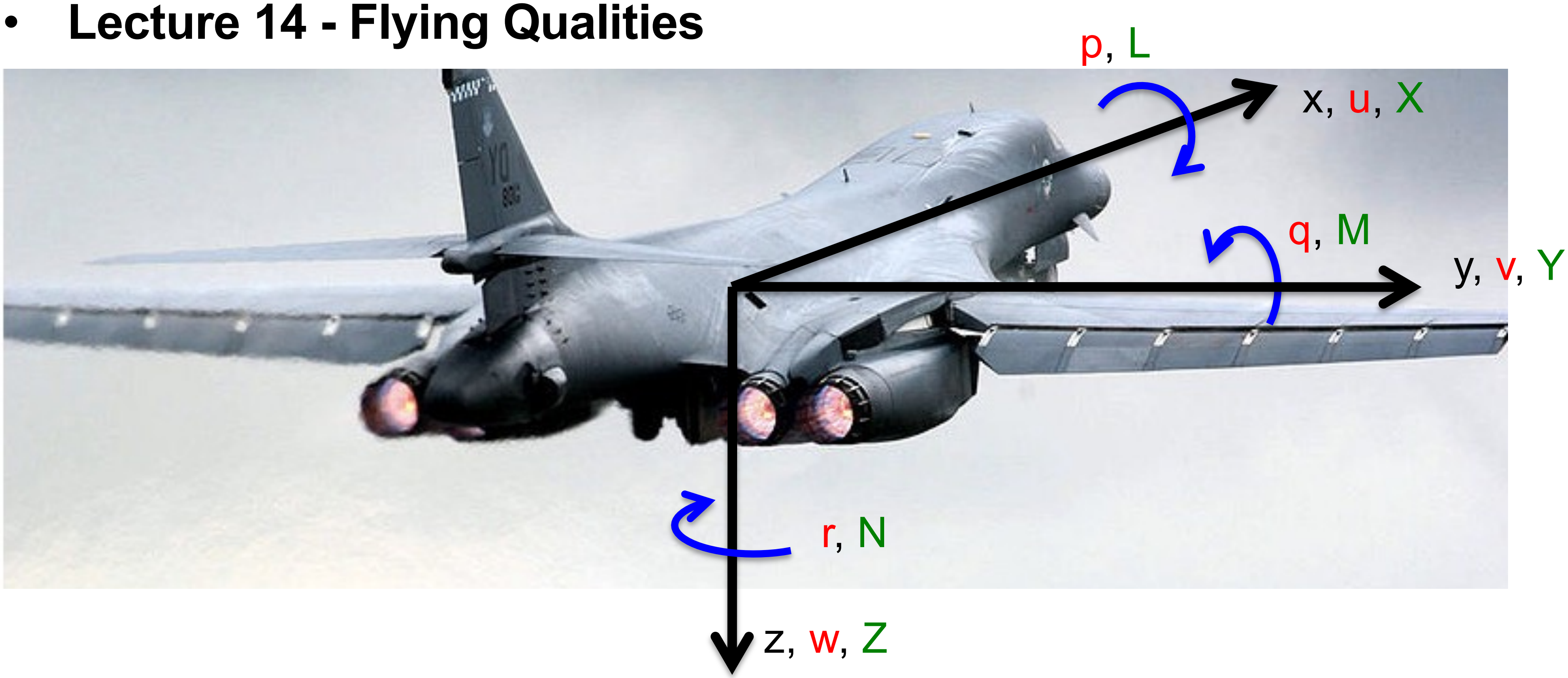
- **Lecture 5 - Performance Intro**
- **Lecture 6 - Climbing**
- **Lecture 7 – Cruise**
- **Lecture 8 - Takeoff and landing**
- **Lecture 9 – Maneuvering**



Extra 300 - Image Courtesy of A. Pingstone

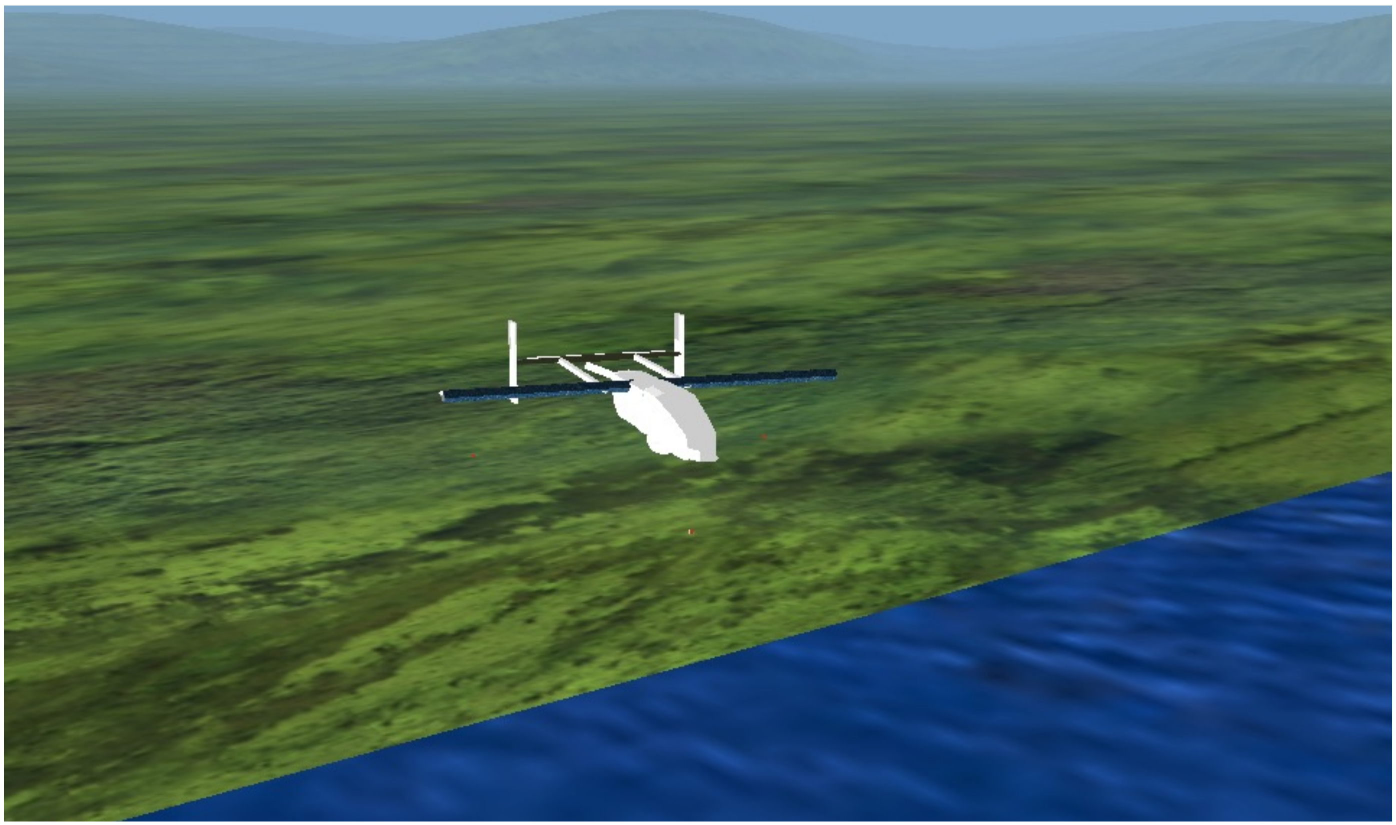
Part 3 – Stability and Control

- **Lecture 10 - Static Stability**
- **Lecture 11 – Stability Derivatives**
- **Lecture 12 - Longitudinal Motion**
- **Lecture 13 - Lateral-Directional Motion**
- **Lecture 14 - Flying Qualities**



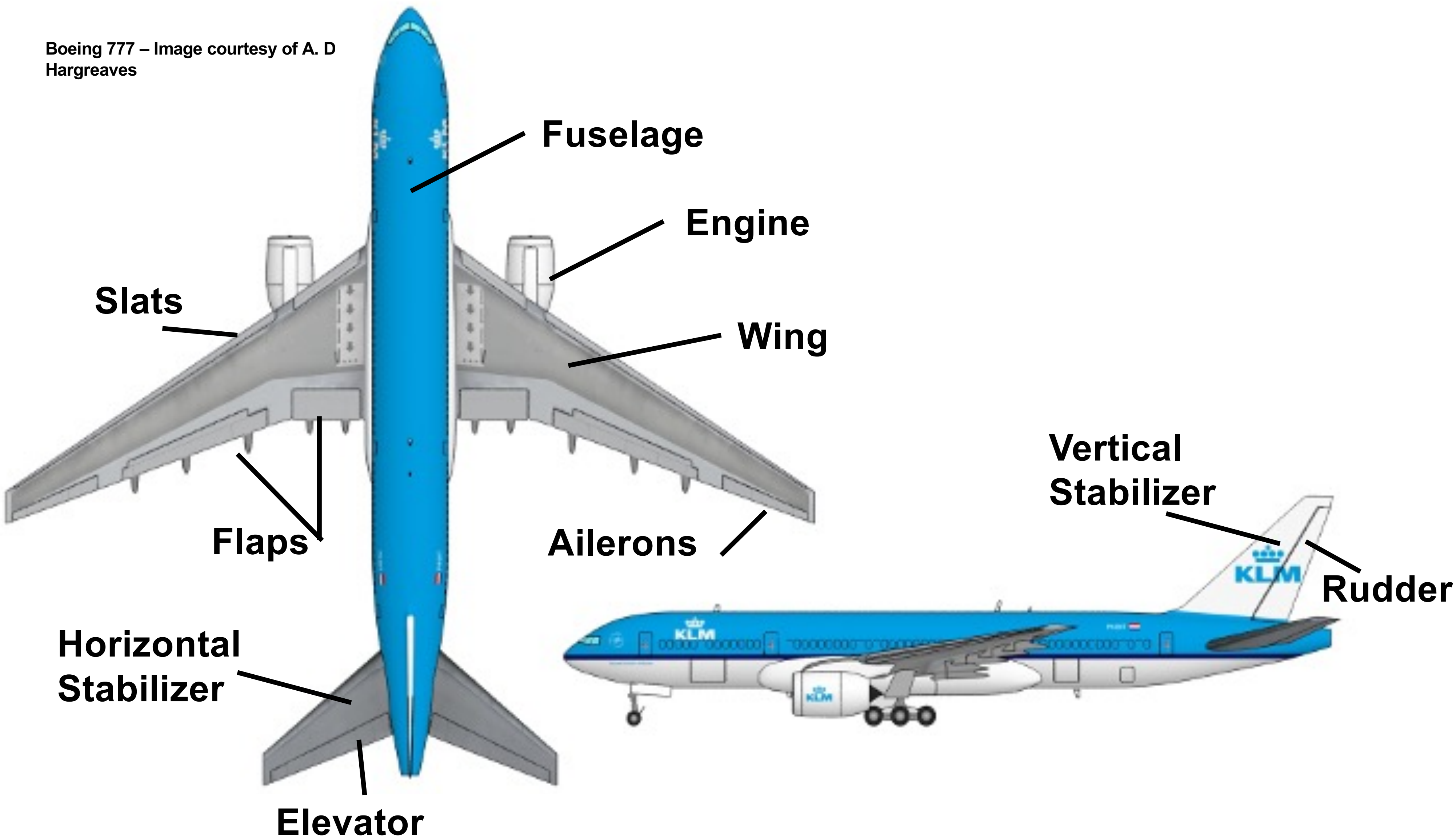
Part 4 – Aircraft Simulation, GN&C

- **Lecture 15 - Aircraft Simulation**
- **Lecture 16 - Automatic Control & GN&C Strategies**



Aircraft Basics

Boeing 777 – Image courtesy of A. D Hargreaves



Aircraft Control

- **Pitch Control**
  - **Pilot pulls back on the stick to deflect the elevator up. This decreases the lift on the tail and increases the pitch of the aircraft. Pushing stick forward deflects the elevator downward, leading to a negative pitching moment.**
  - **Pilot can control climb rate and airspeed with combinations of pitch attitude and throttle setting**
  - **Climbing with pitch control only (no increase in power) will lead to a decrease in airspeed**

- **Roll Control**
  - **Moving control stick to the left or right produces differential deflection of the ailerons**
  - **The down aileron increases the lift on that wing, while the up aileron spoils the lift on that wing**
  - **Aileron deflections produce a roll moment, as well as a yawing moment due to differential drag on both wings**

- **Yaw Control**
  - **Foot pedals control rudder deflection for yaw control**
  - **Rudder pedals normally not used by themselves, but are meant to to be used in combination with ailerons in a coordinated turn**

Non-conventional Aircraft


Beechcraft Starship – Canard Pusher

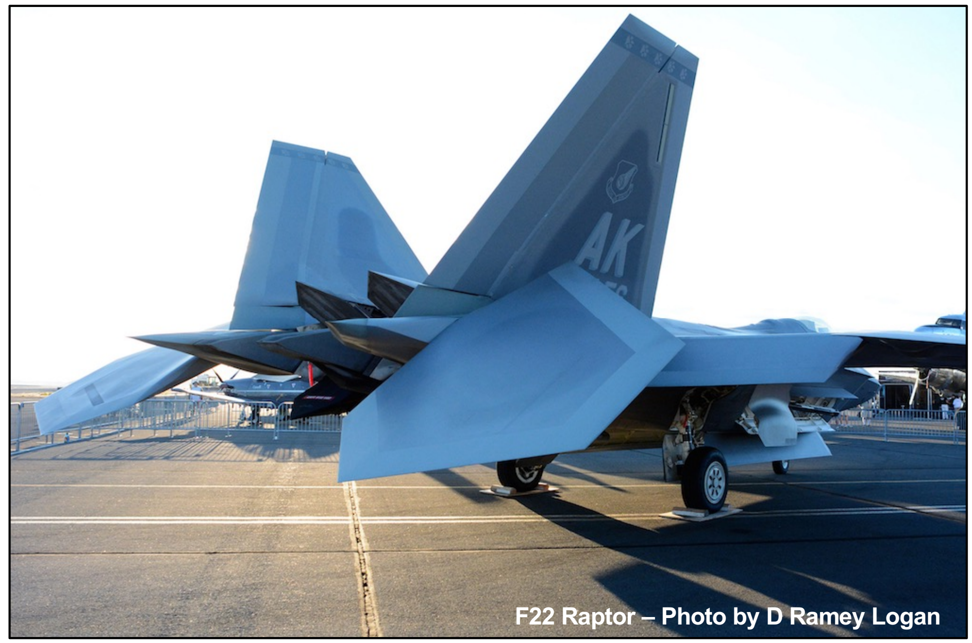
Robin ATL – V-tail configuration


PCUAV: Outboard Horizontal Stabilizers


B-2 Spirit - Image Courtesy of USAF

Non-conventional Control Methods

- **Stabilators:** horizontal stabilizer and elevator combined into one
- **Elevons**: combined elevator and aileron. Usually seen on tailless aircraft, delta wings
- **Flaperons:** Flaps that can also be actuated asymmetrically for additional roll control
- **Taileron**: when stabilators are used for aileron function as well
- **Spoilerons:** spoilers used also as ailerons
- **V-tail:** combines function of rudder and elevator (ruddervators)
- **Thrust Vector Control (TVC):** deflects engine exhaust for additional maneuvering



F22 Raptor – Photo by D Ramey Logan

Brief History of Flight

H-4 Hercules - Image Courtesy of FAA

"Of all the men who attacked the flying problem in the 19th century, ***Otto Lilienthal*** *was easily the most important. ... It is true that attempts at gliding had been made hundreds of years before him, and that in the nineteenth century… many others were reported to have made feeble attempts to glide, but their failures were so complete that nothing of value resulted."*

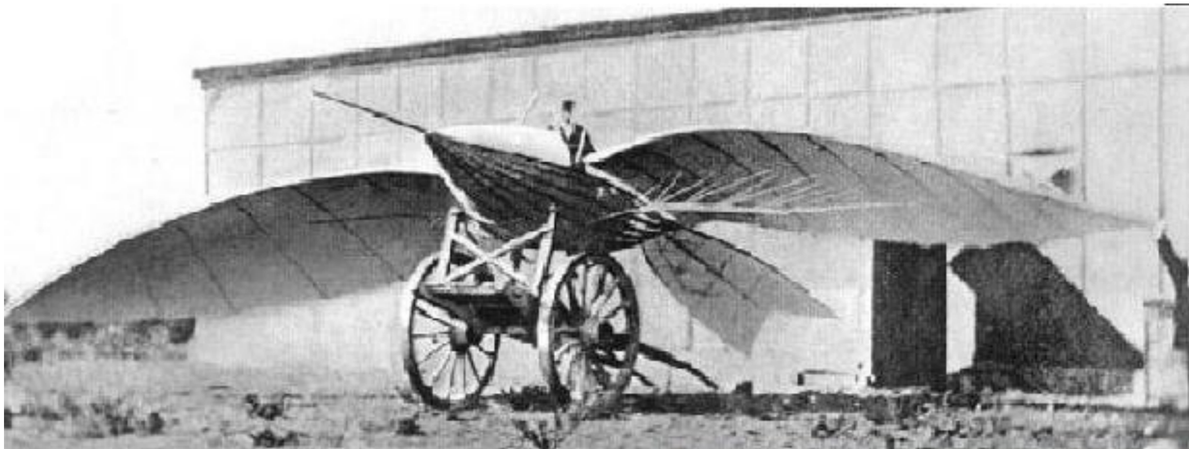
- Wilbur Wright

Bell X-1 - Image Courtesy of NASA

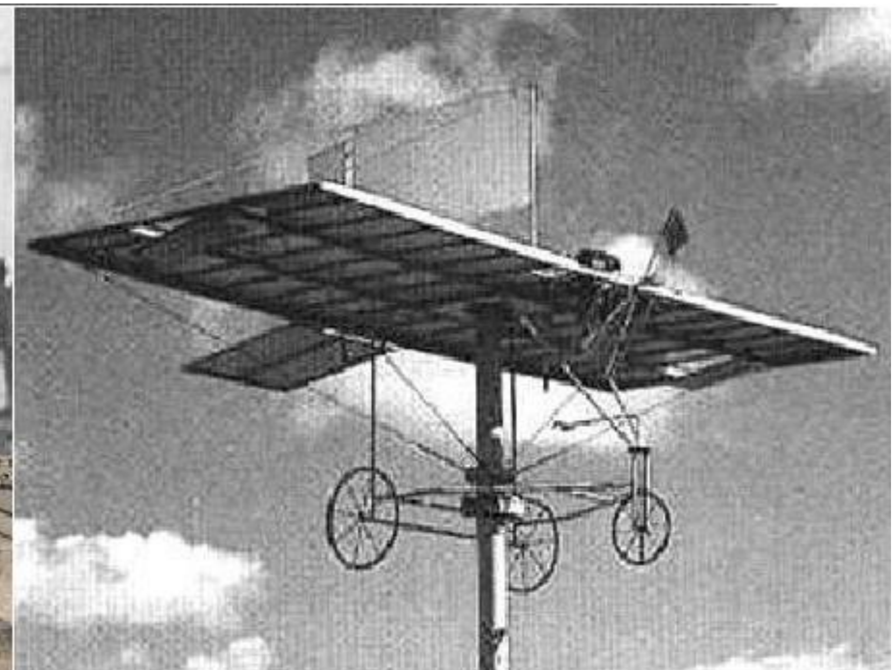
Daedalus - Image Courtesy of NASA

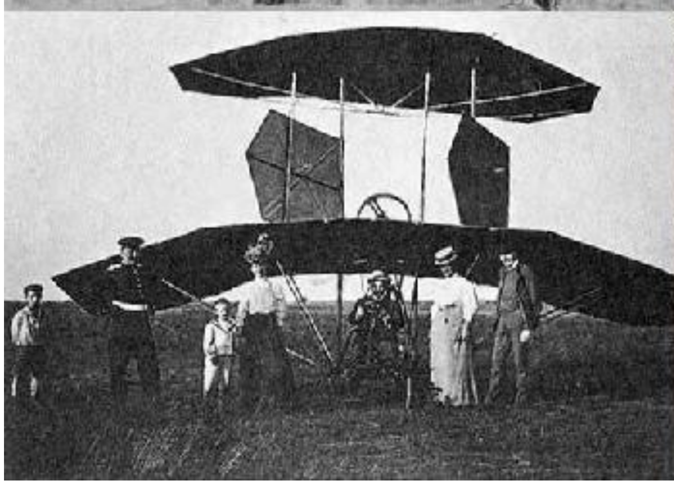
First attempts

Le Bris Albatross, 1857



Richard Pearse, March 1903



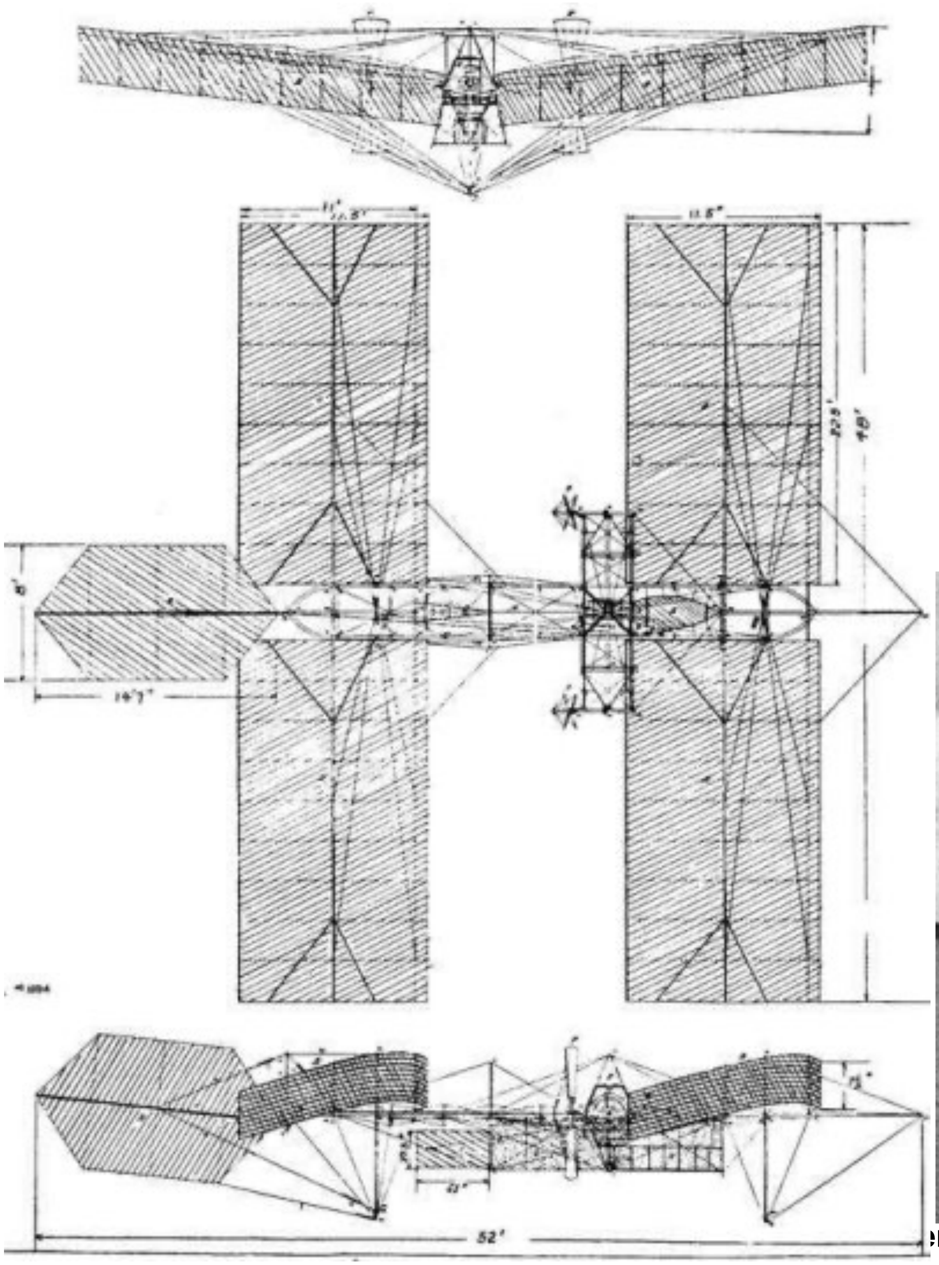


Jatho, Nov. 1903

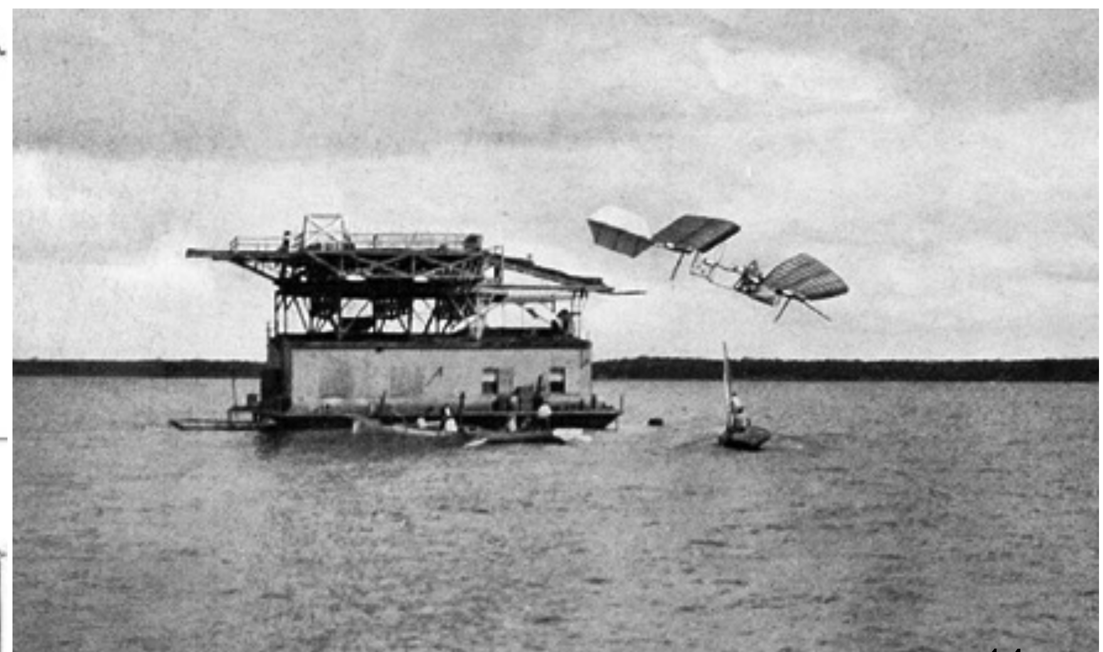
Flugan, 1897

Ader Avion, 1897

Langley Aerodrome (1903)



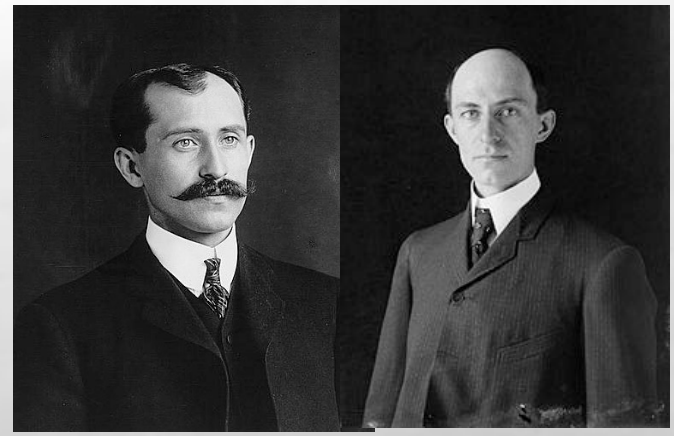
- **Tandem wing configuration**
- **9 days before the successful first flight of the Wright Flyer, the Langley Aerodrome failed**
  - **Broke apart upon take off and fell into the Potomac River**
  - **Structure was too flexible**
- **Eventually flew in 1914 after modifications were made to its design**



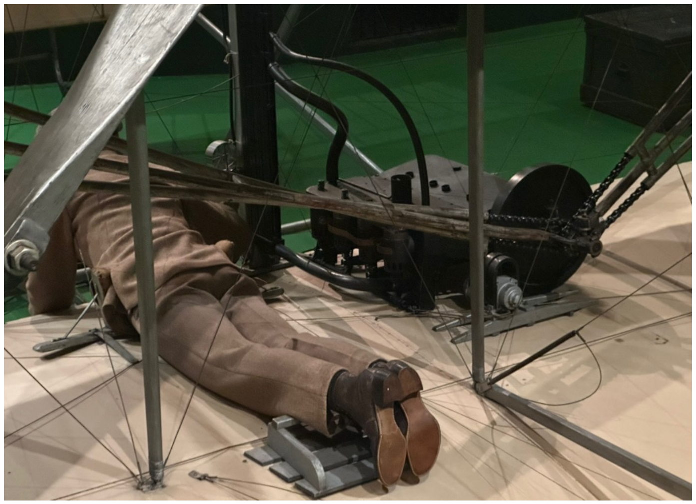
Birth of Flight: Wright Flyer (1903)

- Developed 3-axis control system for their aircraft after
  - Performed numerous glider experiments and wind tunnel tests
  - Pitch control with forward elevator (canard configuration)
  - Wing warping for lateral-directional control
  - Movable rudder
- Pratt truss construction
  - Wooden struts and spars
  - Steel wire for diagonal bracing
- Cotton fabric used for wing skin
- Wright Flyer Specs
  - Wingspan: 40 ft
  - Weight: 625 lbs
  - 12 hp engine

Orville   Wilbur



Wright Flyer III (1905)

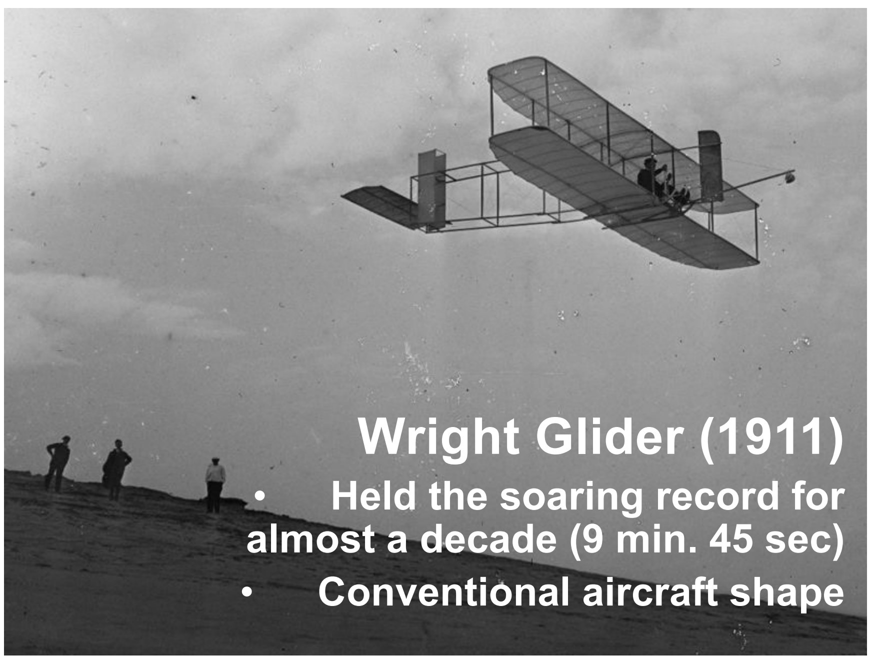


Conventional Aircraft takes Shape

Bleriot XI (1909)

- First to fly across English Channel
- Truss fuselage
- Monoplane design with external cable supports

Bleriot XI - Image Courtesy of Kogo



Wright Glider (1911)

- Held the soaring record for almost a decade (9 min. 45 sec)
- Conventional aircraft shape

June Bug (1908)

- Designed by Glenn Curtiss
- First aircraft in US to use ailerons

Aircraft Innovations During WWI

- **Cantilever wings**
  - Thicker wings made room for structural bracing to take place inside the wings
  - Drag improvements
- **Engine power increased**
  - Engines capable of 150 hp were produced
  - By the end of the war, aircraft could exceed 120 mph and achieve altitudes above 20,000 ft.

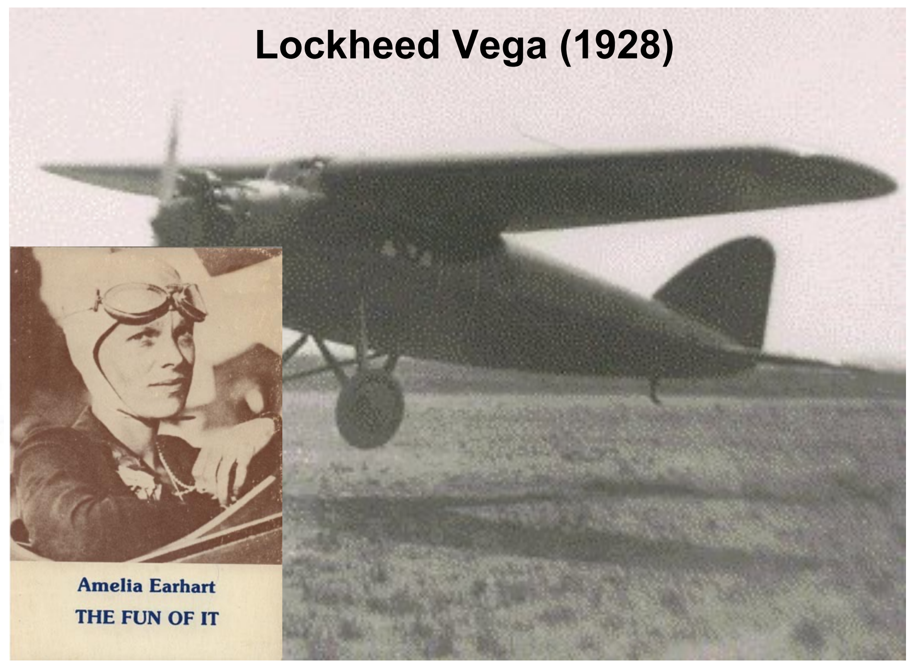
Fokker DVIII (1918)

Fokker Dr-I (1917)

Between the Wars

- **Significant aircraft advances were made in the years after the 1st World War**
- **Pilots came back from the war looking to show off their skills**
- **Air shows, races, challenge prizes, commercial aviation help spur advances in technology**
  - Engine advancements: Air cooled radial engines began to replace water-cooled in-line engines.
  - Advanced construction techniques: stressed skin to carry shear stresses, monocoque construction, metal airframes
- **Charles Lindbergh, Amelia Earhart owed their successes to state-of-the-art aircraft**

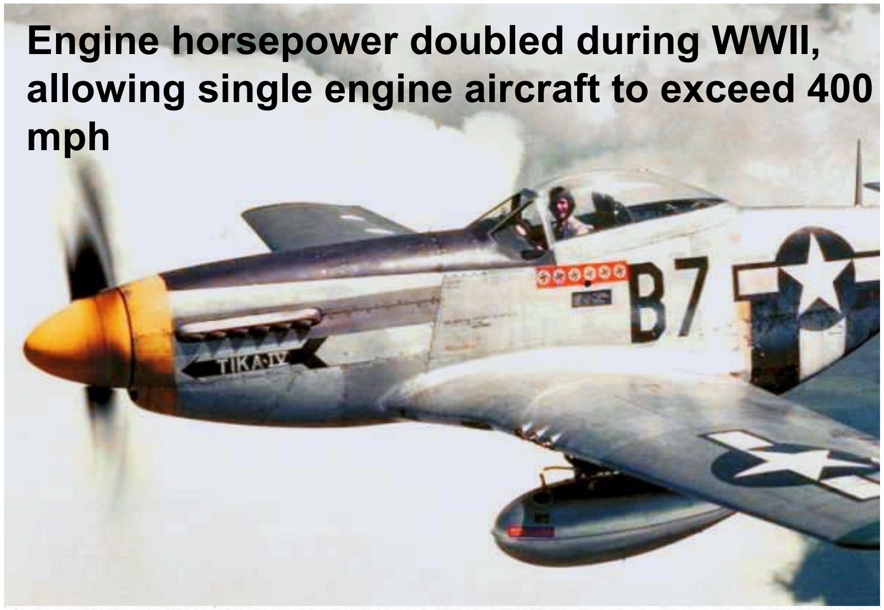
Douglas DC-3 (1935)



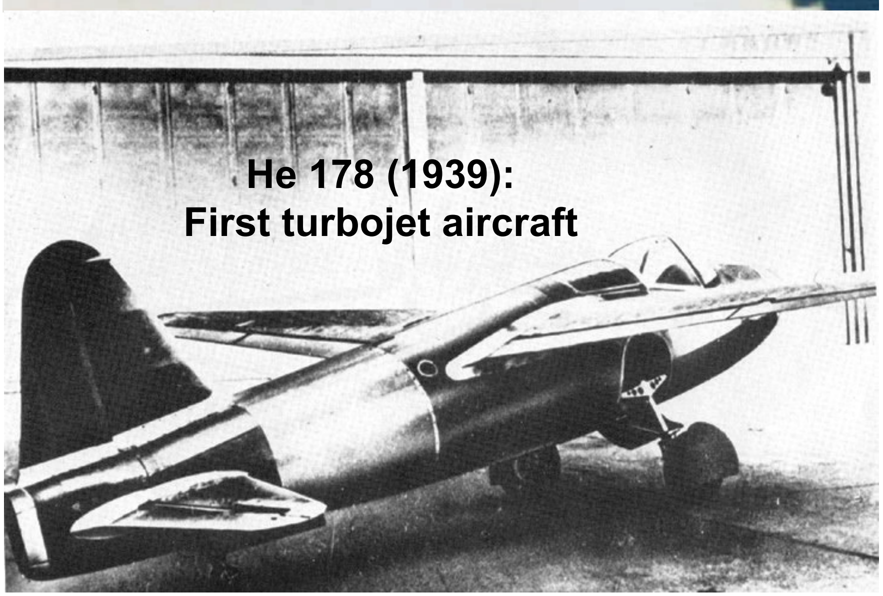
Lockheed Vega (1928)

Spirit of St. Louis (1927)

WWII Advances



Engine horsepower doubled during WWII, allowing single engine aircraft to exceed 400 mph



He 178 (1939): First turbojet aircraft

Aerodynamic advances: elliptical wing planform, tip washout, wing dihedral

By the end of the war, bombers could carry 40,000 lbs of ordinance, with a range of 3200 nmi

Jet Age

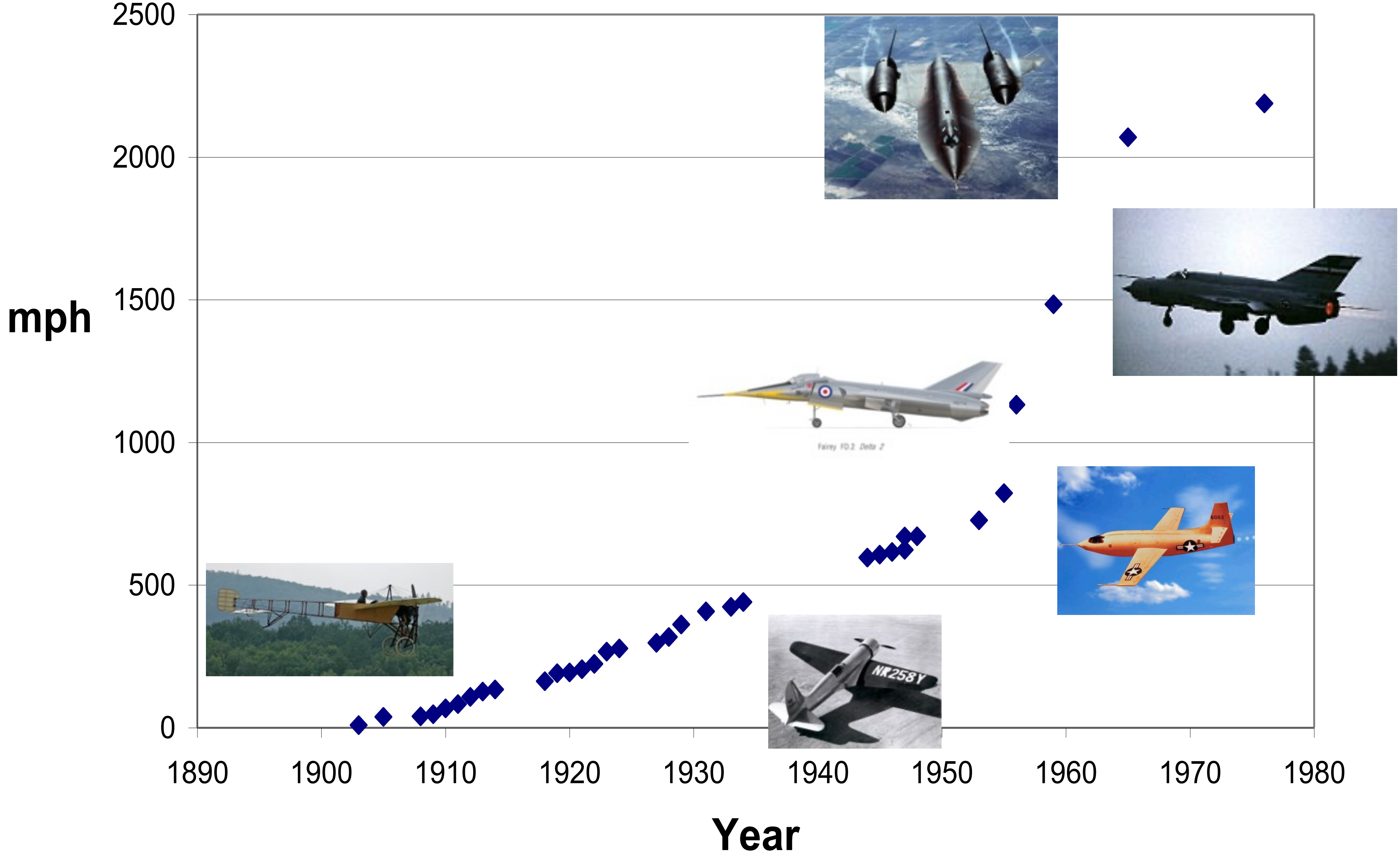
Me 262 (1944)

Me 163 Rocket Plane (1943)

- Me 262 first operational jet aircraft
- With early jets capable of speeds in excess of 500 mph, new aerodynamic issues started to appear
- Swept wings became the norm to reduce drag
- Wing divergence and aileron reversal became a problem

P80 Shooting Star (1945)

History of Airspeed



XB-70 Valkyrie (1964-69)

- **Mach 3 Bomber**

- **Aerodynamic heating**
  - **Temperatures could reach 640°F**
  - **Steel honeycomb structure**
  - **Titanium very costly for a mass-produced aircraft, so its use was limited to the most critical areas**
  - **Fuel tanks were used as heat sinks**

- **Wings drooped down as much as 65 deg for compression lift**

- **XB-70 never went into production, but its radical design led to many important studies in aerodynamics, aero heating, composite manufacturing**

Image Courtesy of NASA

SR-71Blackbird (1964)

- **Mach 3.3+, > 80,000 ft**
- **85% titanium, 15% composite to handle the almost 900° F skin temperature. Thermal expansion issues**
- **2 P&W J58 engines each capable of delivering over 32,000 lbs of thrust**
- **No aircraft was ever shot down despite several attempts to do so**

Image Courtesy of NASA

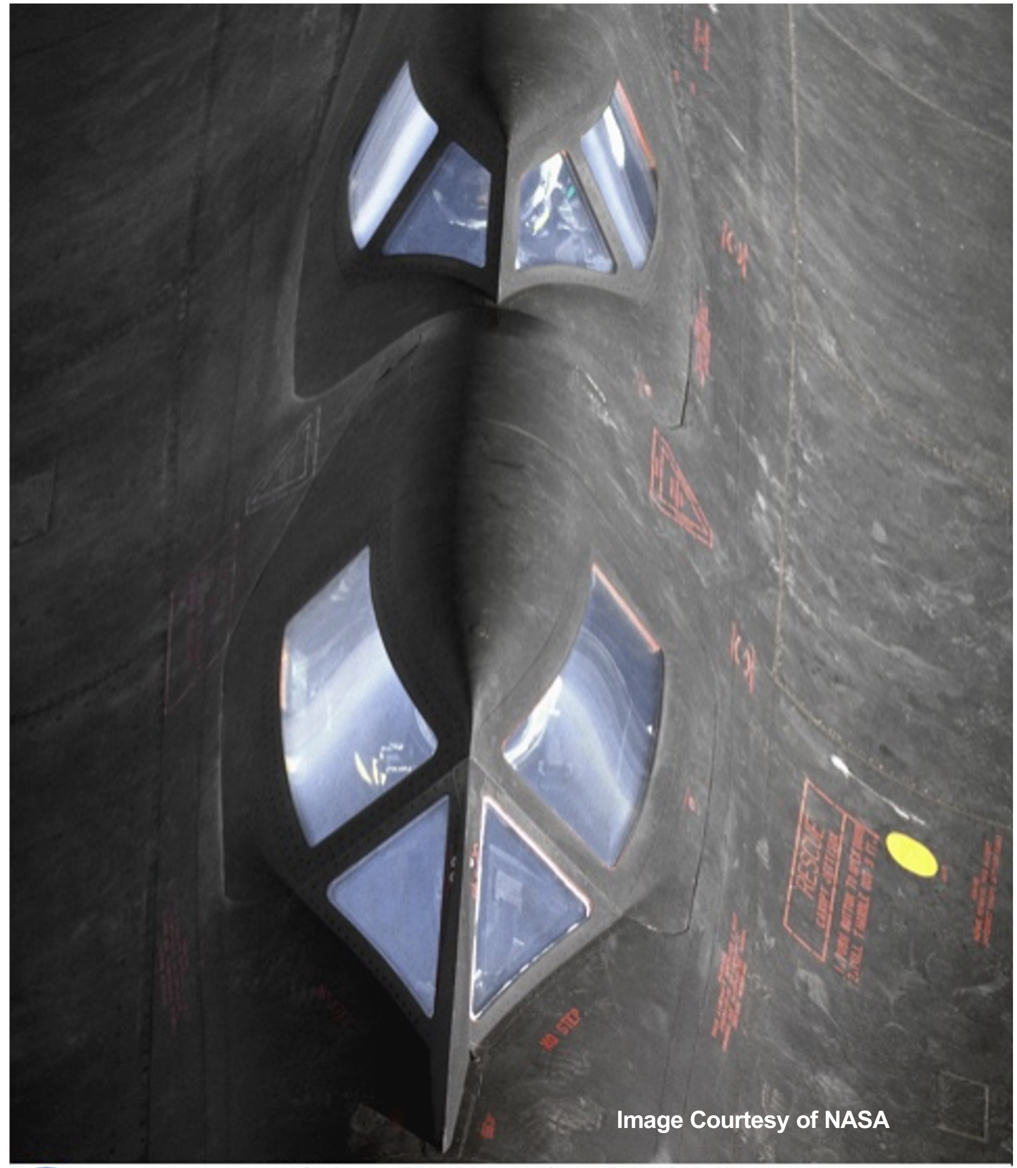


Image Courtesy of NASA

X-29 (1984)

X-29 in Flight from Above

- Forward swept wing, canard configuration
  - Forward wings deflect flow inward preventing the outer tips from stalling
  - Could maneuver at excess of 45 deg AoA
- Advanced composite construction
  - Very thin supercritical wings
  - Aeroelastic tailoring

Commercial Airliners

- **Douglas DC-3 (1935)**
  - **One of the first metal aircraft**
- **De Havilland Comet (1952)**
  - **Pressurized cabins**
  - **By 1953, three crashes**
  - **Metal fatigue, crack propagation in skin**
- **Boeing 707 (1958)**
  - **Considered the first modern airliner**
  - **Rounded windows. Fail-safe construction, new and improved aluminum alloys to combat fatigue led to life of millions of cycles**
  - **No real major changes to airlines since 707**
- **Boeing 787 (2009)**
  - **First airliner to use composite materials for most of its construction.**
  - **Light weight and fuel efficiency promises 20% fuel savings compared to similar-sized 767**
  - **First production aircraft delivered 9/25/11**

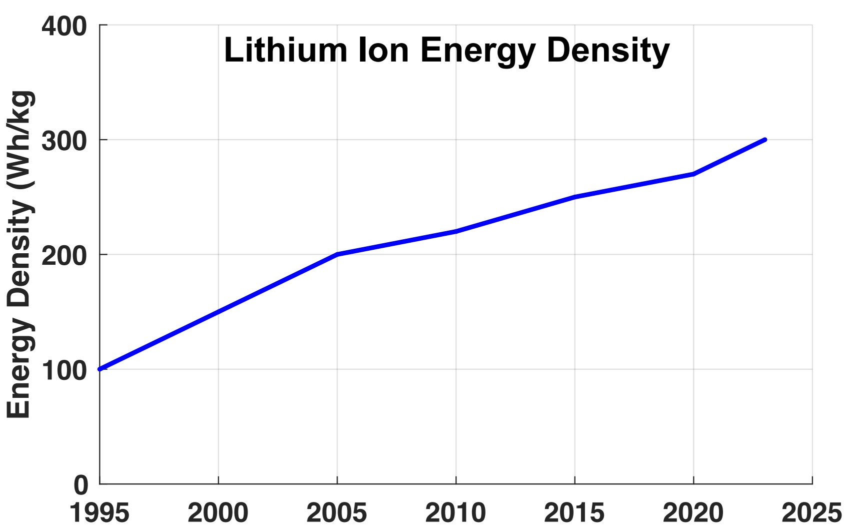
Unmanned Aircraft

B-21 Raider (2022)

- Next generation long range strategic bomber, intended to replace the B-1 and B-2 stealth bomber
- B-21 was unveiled to the public in December of 2022 and made its maiden flight on 10 November 2023
- Not many details are known, but it is expected to have:
  - Next generation stealth technology
  - Long range and endurance capabilities
  - Both conventional and nuclear payloads
  - Manned and unmanned capabilities
- Goal is to be significantly less expensive than the B-2 bomber and easier to maintain

eVTOLs

- Several electric vertical take-off and landing (EVTOL) aircraft are in development
- Energy density in batteries has improved significantly, making battery-powered aircraft more viable
- With ranges between 50-200 miles, eVTOLs are planned to be used as taxi services



References

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3. Crouch, Tom D. Blériot XI: The Story of a Classic Aircraft. Washington D.C.: Smithsonian Institution Press, 1982
4. Dennis R. Jenkins and Tony R. Landis - Valkyrie: North American's Mach 3 Superbomber, 2002
5. "SR71 Blackbird." PBS documentary, Aired: 15 November 2006
6. Pamadi, Bandu N. "Performance, Stability, Dynamics, and Control of Airplanes. 2nd Ed., Section 1.11." *AIAA, 2004*
7. Report of the Public Inquiry into the causes and circumstances of the accident which occurred on the 10 January 1954, to the Comet aircraft G-ALYP, Part XI (a. 69)