Introduction to Helicopters

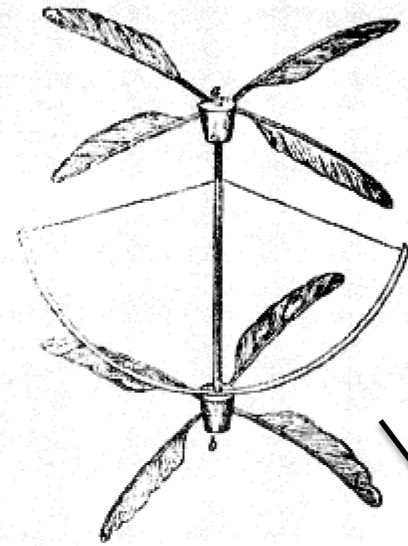
Abhishek

Overview

- **Brief history of rotorcraft**
- **Types of rotorcraft**
- **Physics of helicopter flight**

Early Ideas

I I T K A N P U R

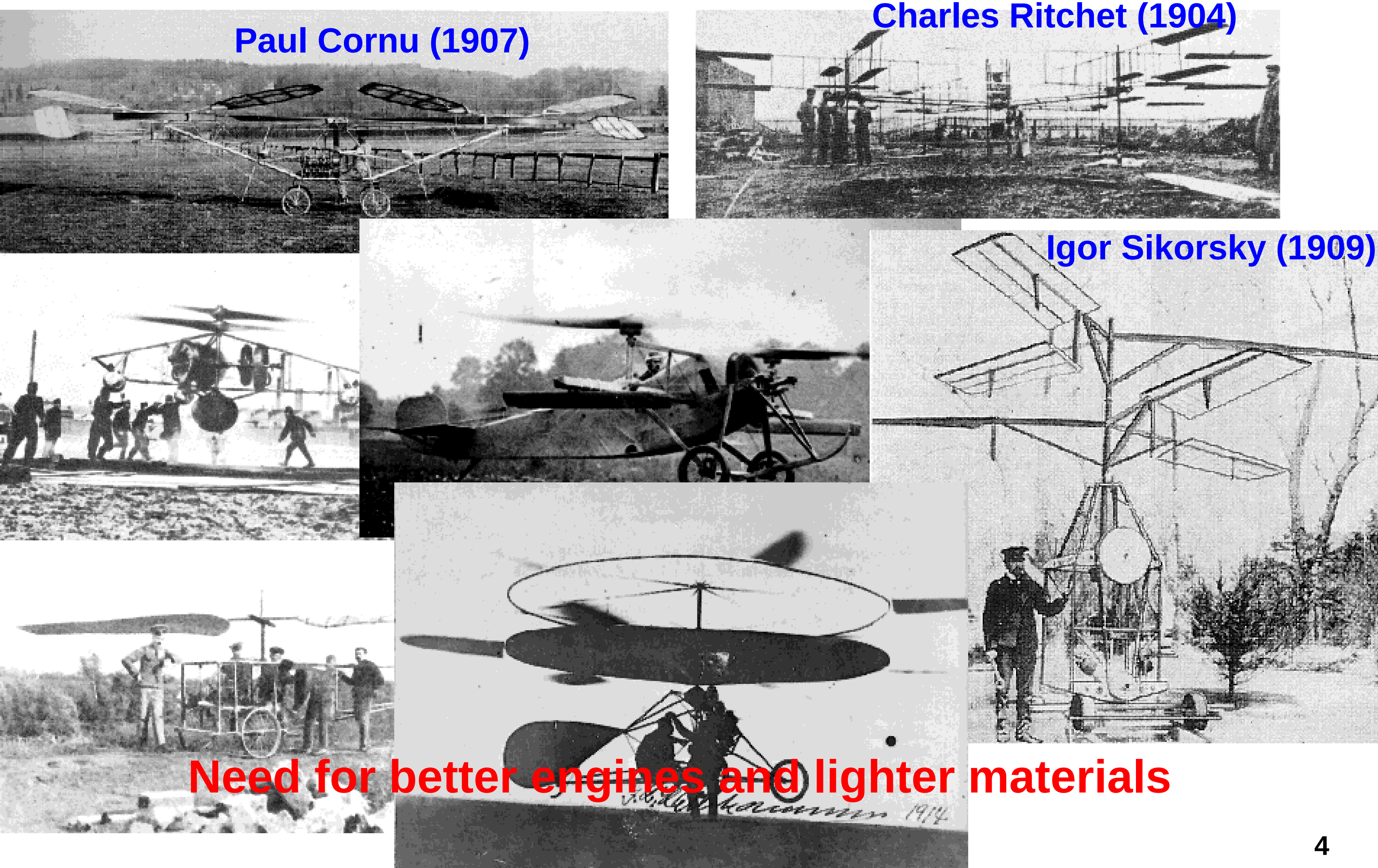


Chinese Top

Sir George Cayley's Aerial Carriage (1790)

da Vinci Airscrew (1483)

The First Hoppers



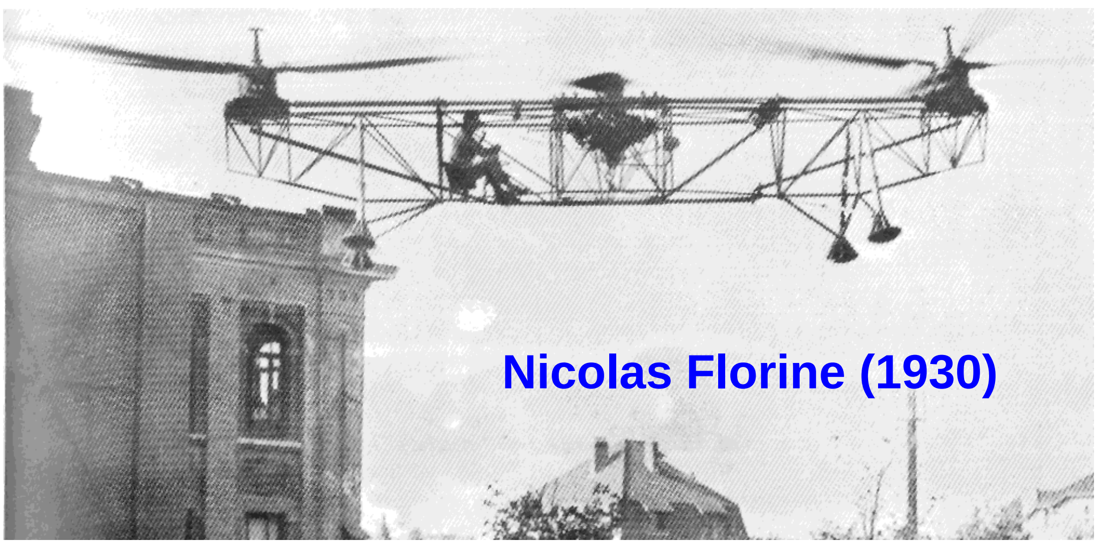
Need for better engines and lighter materials

History of Rotorcraft

I I T K A N P U R

Georges de Bothezat (1919)

Corradino d'Ascanio (1930)



Nicolas Florine (1930)

de la Cierva inspired hinges that allowed for flapping and feathering capability to change blade pitch – control was achieved by using auxiliary wings or servo-tabs on the trailing edges of the blades

For details: http://terpconnect.umd.edu/~leishman/Aero/history.html

History of Rotorcraft

- **No “inventor” for helicopters**
- **Incremental development with contributions from several inventors**

First fully controlled Heli: **Focke-Wulf Fw 61** (1936) built by Focke-Wulf under license from Cierva Autogiro

For details: http://terpconnect.umd.edu/~leishman/Aero/history.html

Types of Rotorcraft

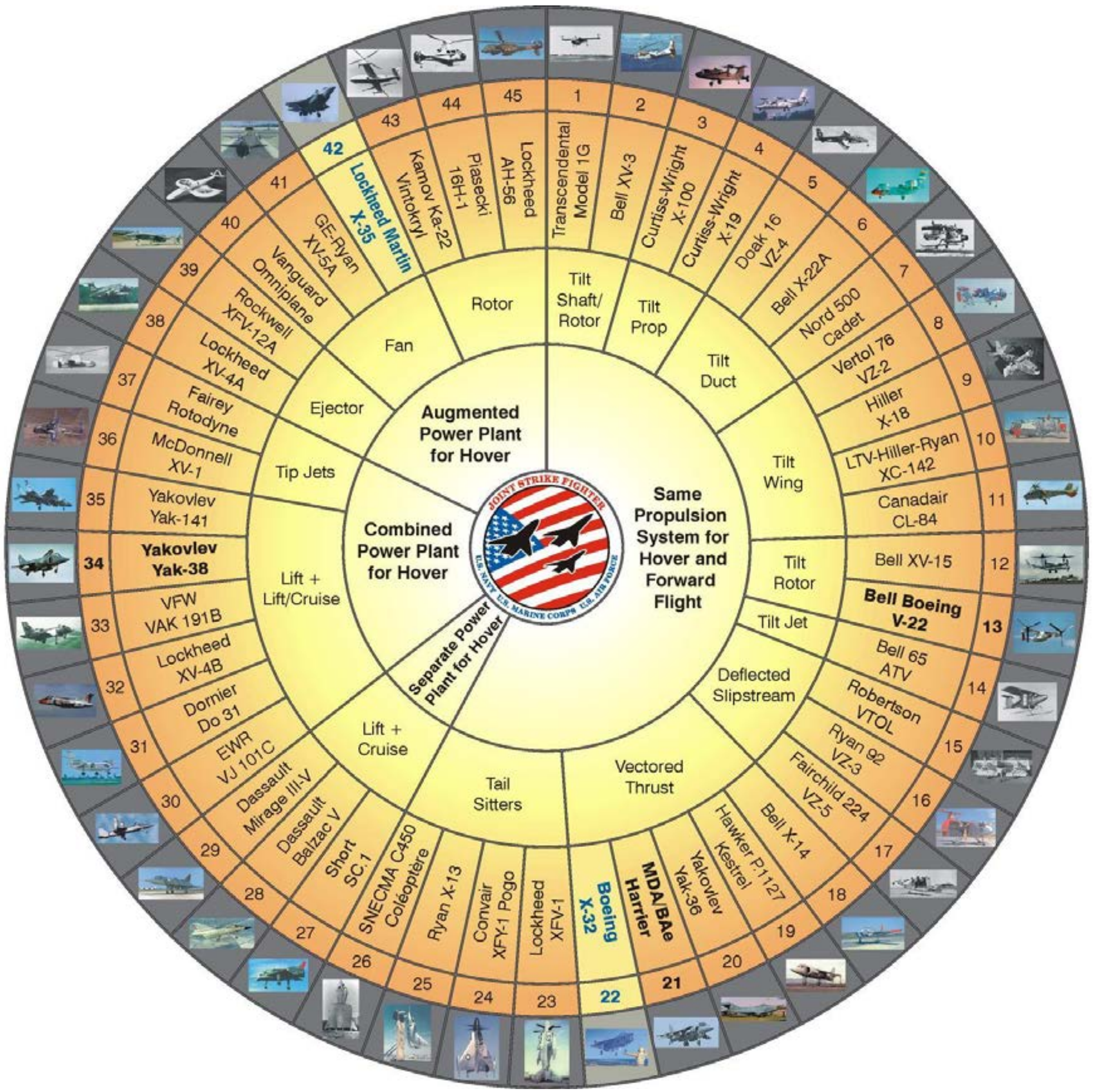
I I T K A N P U R

An Overview of the History of Vertical and/or Short Take-Off and Landing (V/STOL) Aircraft

Michael J. Hirschberg
CENTRA Technology, Inc.

www.vstol.org

Types of Rotorcraft



The V/STOL Wheel is a graphic diagram of all 45 types of vertical and/or short take-off and landing (V/STOL) aircraft that had been built and tested through 1996. It was updated from the McDonnell Douglas Wheel of the 1960s for the Joint Strike Fighter (JSF) Program Office.

All were built to be flown, but only three (**shown in bold)** have led to operational aircrafts. Lockheed **X-35 to be the next generation V/STOL vehicle**

Boeing-Sikorsky RAH-66 Comanche

23 February 2004, U.S. Army cancelled RAH-66 Comanche program after having spent US $ 6.9 billion

Types of V/STOL Concepts

Vertical and/or short take-off and landing

- **Conventional Helicopter**
  - Single main rotor
  - Multi rotor
- **Compound Helicopter**
- **Tilt-rotor, tilt-wing, tilting ducted fans, fan-in wing**
- **Vectored Jet lift**

Single Main Rotor Configurations

Mil Mi -26

90 troops
or
20 ton cargo

Used during
Afghan war to rescue two
Chinook helicopters (12 ton)

Largest and most powerful helicopter

Conventional Helicopter

Advantages	Disadvantages
• Efficient hover • Low downwash (slipstream velocity) • Good low speed maneuverability • Low empty weight	• Low maximum speed • Low high speed maneuverability • Fuselage attitude depends on speed • High vibration • Low range

Compound Helicopter

Groen Brothers Hawk 5 Gyroplane

Fairey Rotodyne

Sikorsky X2

Eurocopter X3

Compound Helicopter

Lockheed AH56A Cheyenne

Compound Helicopter

Advantages

- Faster than “pure” helicopters
- Good maneuverability at all speeds
- Fuselage attitude independent of speed
- Reasonable hover efficiency

Disadvantages

- More complex than “pure” helicopters
  - More thrusters
  - More lifting / control surfaces
- Higher empty weight fraction
- Low cruise efficiency

Canard Rotor Wing

Advantages

- Potential for high subsonic speed
- Good maneuverability in cruise
- No anti-torque rotor
- Low vibration in high speed mode

Disadvantages

- Complexity (rotor stop-ping, exhaust shifting)
- Limited maneuverability in conversion
- Limited yaw control in hover

Boeing X50 Dragonfly Canard Rotor Wing

Twin Rotor Concepts

CH 47 CHINOOK

Kamov Ka 27

Advantages

- **No tail rotor – Increased safety, tail rotor power saving**
- **Tandem Rotor Design has Lower Downwash than Single Rotor Design**

Disadvantages

- **Complexity – two main rotors**
- **Higher drag (increased parasite loss) due to two Hubs**

Twin Rotor Concepts

Kaman Kmax

Advantages

- No tail rotor – Increased safety, tail rotor power saving
- Tandem Rotor Design has Lower Downwash than Single Rotor Design

Disadvantages

- Complexity – two main rotors
- Higher drag (increased parasite loss) due to two Hubs

Tilt Wing

Hiller X-18 (1959)

LTV XC-142 (1964)

Advantages

- Good cruise speed
- Good cruise efficiency
- Good high speed maneuverability
- Better hover efficiency than tiltrotor

Disadvantages

- High downwash in hover
- Conversion problematic
- Complexity
- Increased Empty Weight
- Limited Autorotation Capability

Tilt Rotor


Bell Boeing V-22 Osprey (1981-2007)

Advantages

- Good maximum speed
- Good maneuverability
- Attitude independent of speed
- Ground Safety (no tail rotor)
- Low Vibrations in Airplane Mode

Disadvantages

- High disc loading – high downwash
- Download on wing in hover
- Complexity and aeroelastic issues
- Limited autorotation capability

Tilting Ducted Fans

Bell X -22A

Advantages

- Safety (enclosed thrusters)
- No tail rotor
- Small footprint (rotors)
- Moderate high speed capability

Disadvantages

- Low efficiency in hover
- Limited low speed maneuverability
- Limited autorotation capability
- High empty weight
- Complexity (transition)

Fan-in-wing

I I T K A N P U R

Vanguard Omniplane

Urban Aero Airmule

Advantages

- Good maximum speed
- Good cruise efficiency
- Good maneuverability in cruise
- Low vibration in cruise
- Small footprint
- Attitude independent of speed

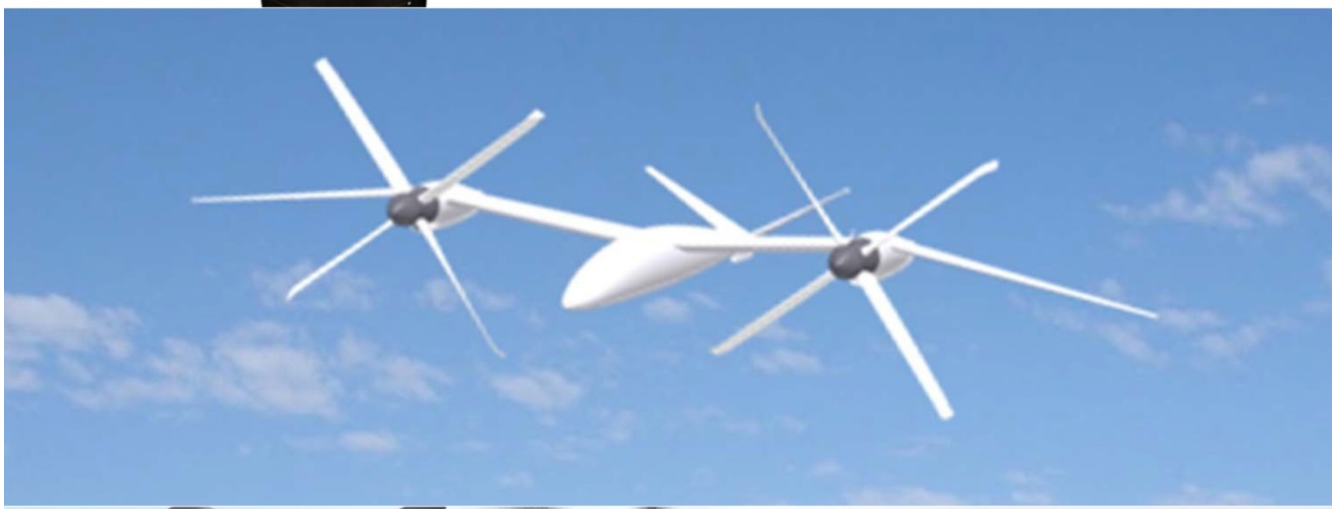
Disadvantages

- Low hover efficiency
- High downwash
- Limited autorotation capability
- Complexity

DARPA VTOL X-PLANE

- **VTOL X-Plane seeks to develop a technology demonstrator that could**
  - **Achieve a top sustained flight speed of 300 kt-400 kt**
  - **Raise aircraft hover efficiency from 60 percent to at least 75 percent**
  - **Present a more favorable cruise lift-to-drag ratio of at least 10, up from 5-6**
  - **Carry a useful load of at least 40 percent of the vehicle's projected gross weight of 10,000-12,000 pounds**

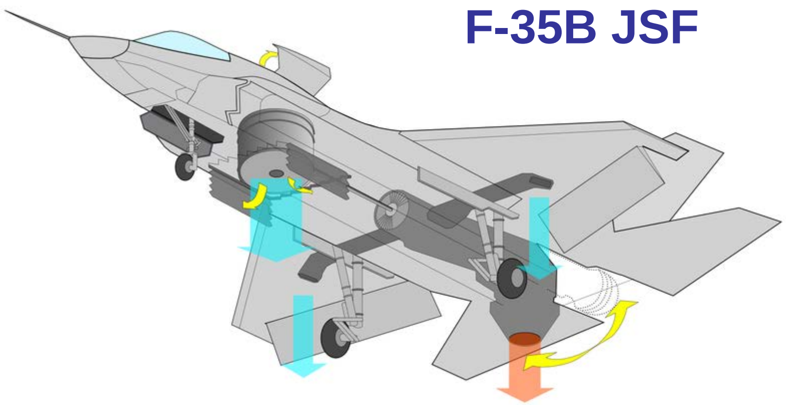

PhantomSwift
BOEING




Sikorsky Innovations

Vectored Jet Lift

F-35B JSF



Advantages

- High maximum speed
- High maneuverability at speed
- Attitude independent of speed
- Low vibrations

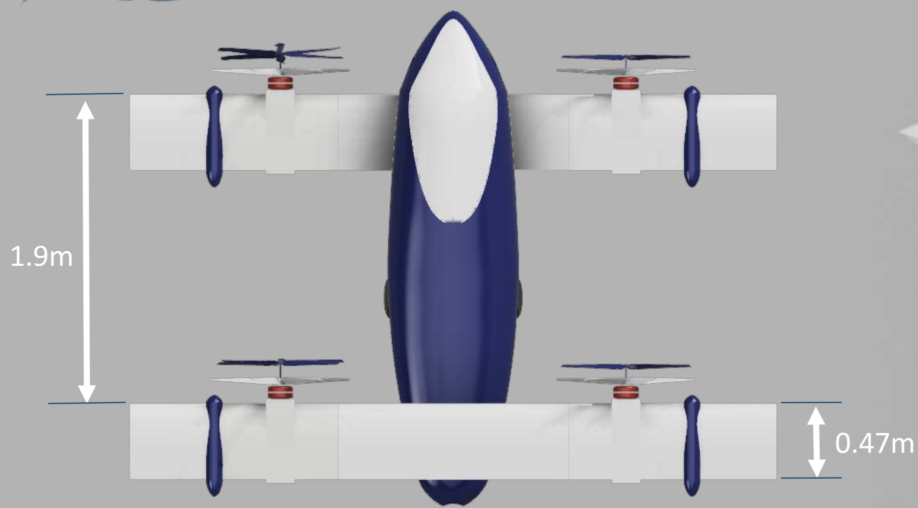
Disadvantages

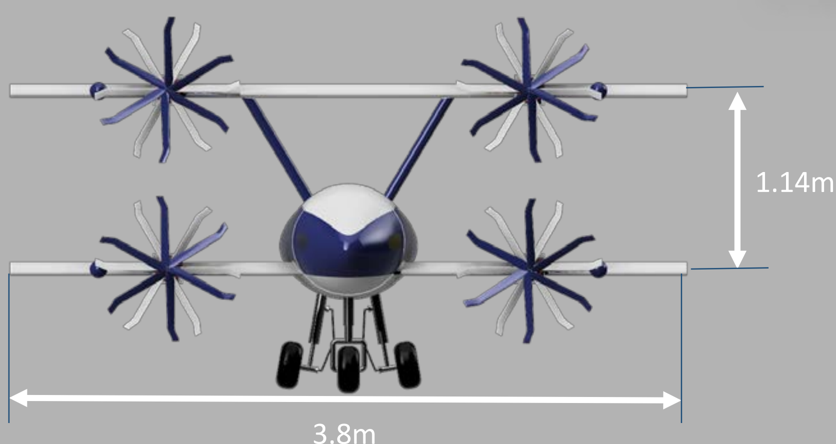
- Poor hover efficiency
- Poor autorotative capability
- Very high downwash
- Limited maneuverability at low speeds
- Complexity

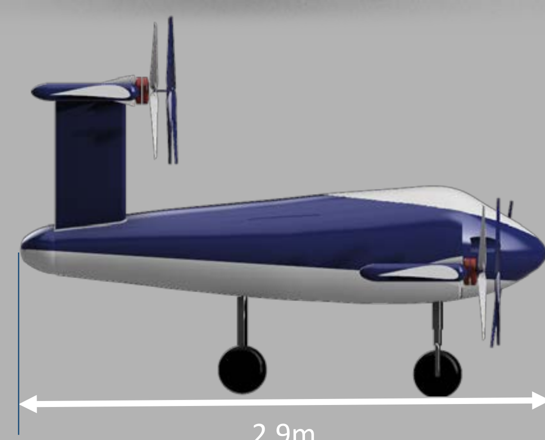
VTOL Concepts Developed at IIT Kanpur

eVTOL – Air Taxi System

AIRFRAME VIEW







MARLIN

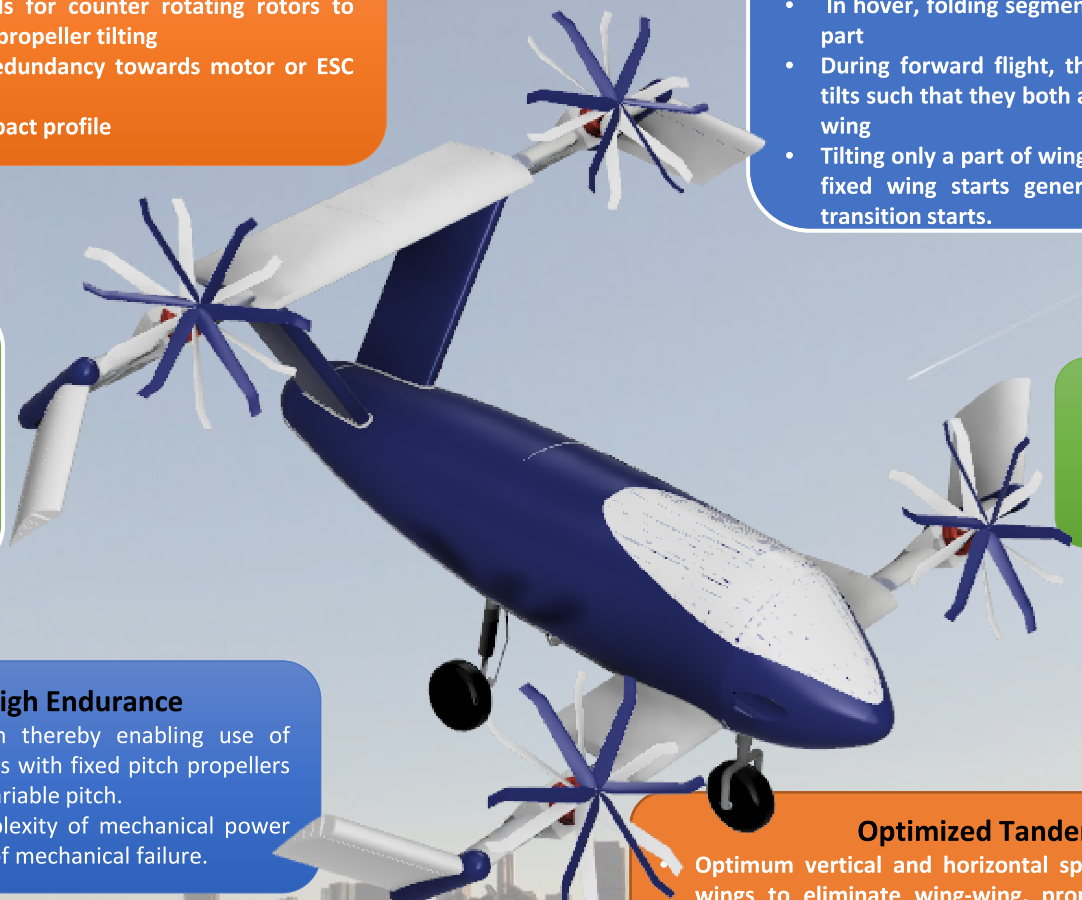
NOVELTY

Optimized Reconfigurable Coaxial Proprotors

- Optimized for efficient hover and high speed forward flight
- Gyroscopic moment reaction cancels for counter rotating rotors to reduce control moment required for propeller tilting
- Octa rotor configuration provides redundancy towards motor or ESC failure
- Maximum performance in most compact profile

Reconfigurable Wing system

- Rotors along with wing segment under the rotor downwash are in vertical orientation during hover
- In hover, folding segment is perpendicular to tilting part
- During forward flight, the tilting and folding parts tilts such that they both aligns with the fixed part of wing
- Tilting only a part of wing makes transition easier as fixed wing starts generating lift as soon as the transition starts.



Wing Span Morphing

- Folded wing during hover for compactness and low footprint for stowage and hovering in tight corners
- Unfolds to increase wing span to for high efficiency forward flight

Bio-Inspired Fuselage

- Swordfish shaped fuselage to minimize parasite drag in forward flight

Hybrid Power Plant for High Endurance

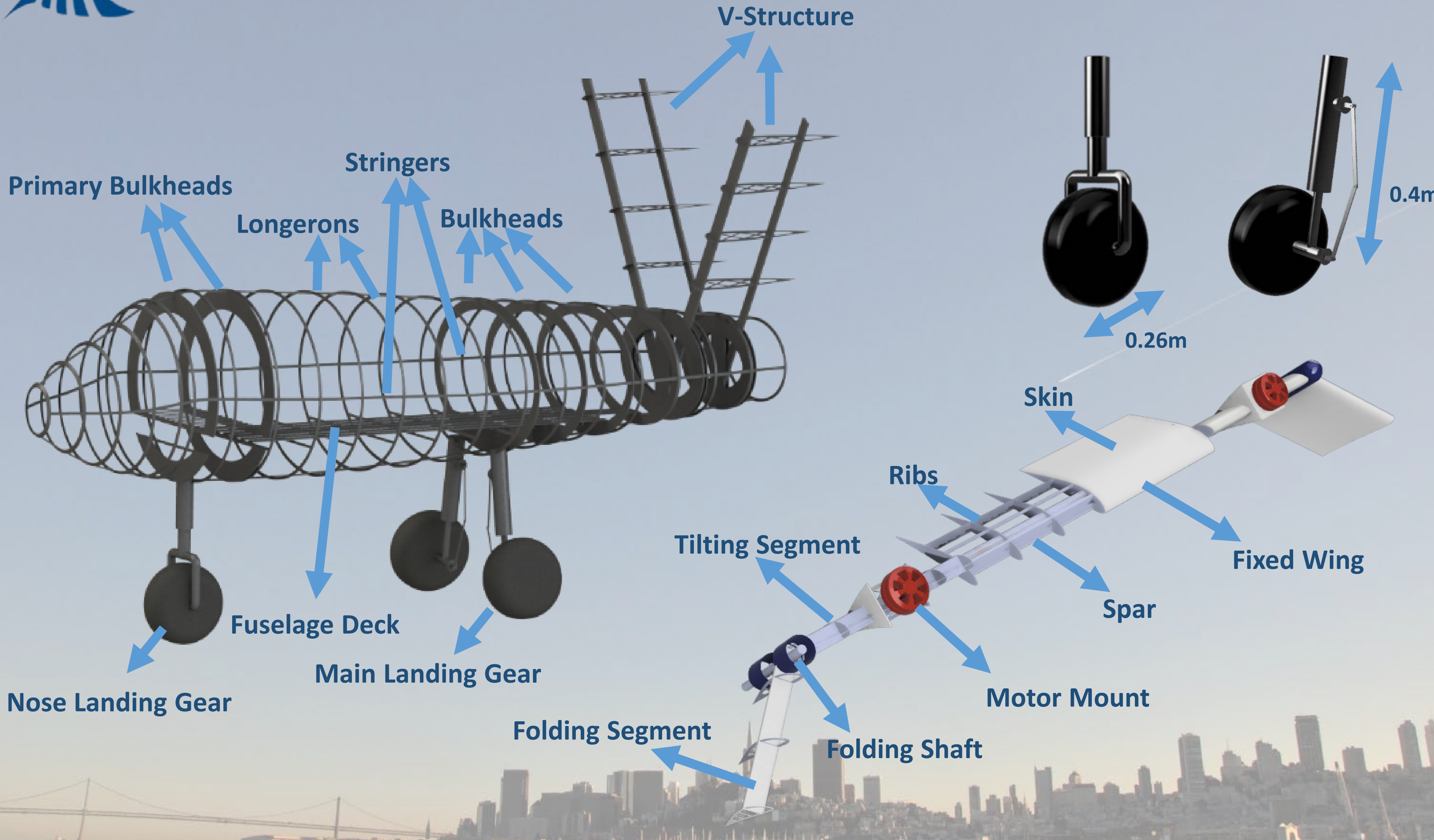
- Features electrical power generation thereby enabling use of variable RPM rotors via electric motors with fixed pitch propellers instead of constant RPM rotors with variable pitch.
- Reduces the added weight and complexity of mechanical power transmission system and reduces risk of mechanical failure.

Optimized Tandem Wings

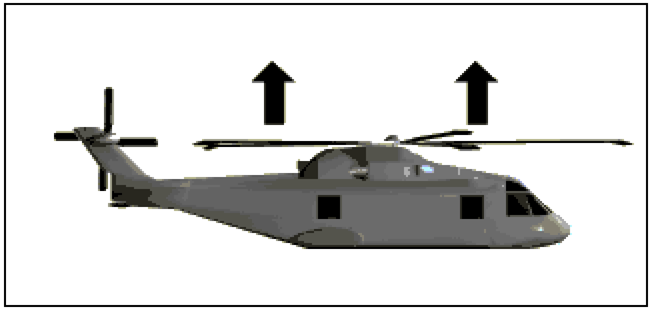
- Optimum vertical and horizontal spacing between aft and fore wings to eliminate wing-wing, proprotor-proprotor, proprotor-wing interactions
- Highest performance for most compact profile

Hover and Transition

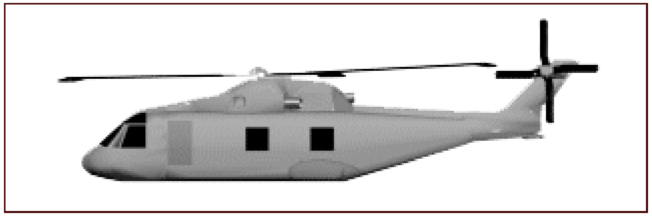
STRUCTURAL LAYOUT



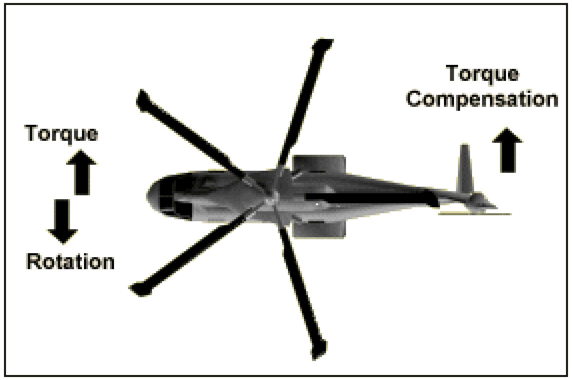
Principles of Rotary-wing Flight



Rotor does work on air by pushing it downwards and imparting a small velocity to it



Propulsion achieved by tilting rotor disk by use of mechanical device swashplate



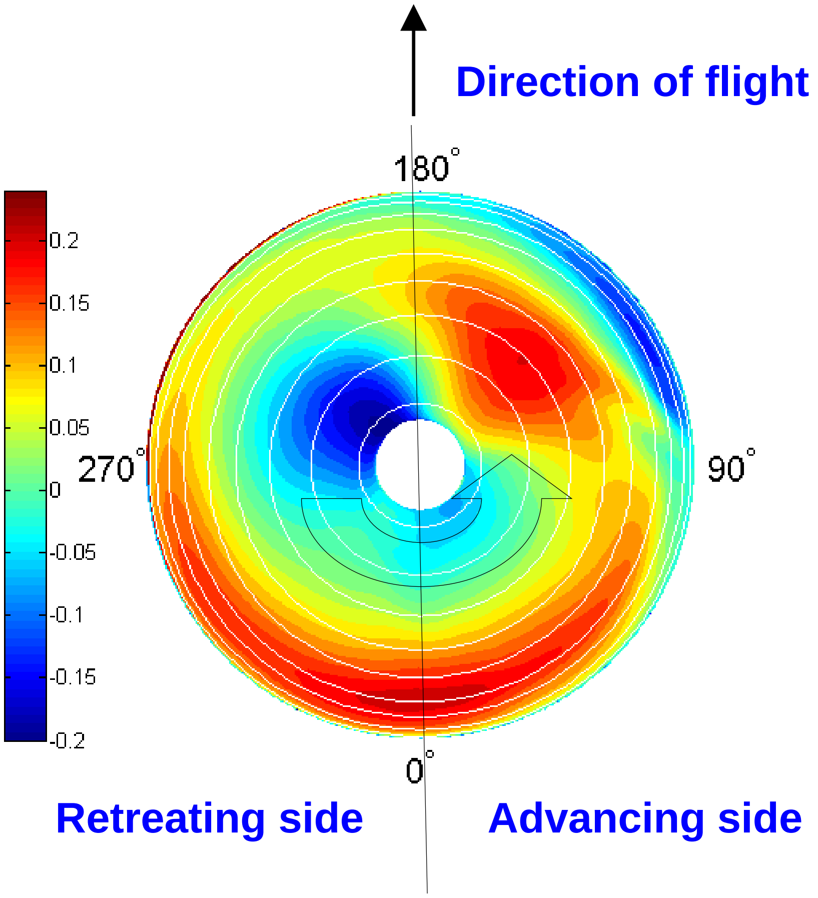
Mechanism for anti torque

Study of Rotorcraft

- **Fundamentally different from that of fixed wing vehicles**
  - **Centrifugal force**
  - **Coriolis force – causes coupling of flap lag and torsion degrees of freedom**
  - **Extremely complicated aerodynamic environment resulting from a mix of asymmetric flow, reverse flow, dynamic stall, transonic effects, blade-vortex interaction**
- **Study of rotor of primary importance**
  - **Source of thrust, propulsion as well as vibration and noise**

Complex Aerodynamics

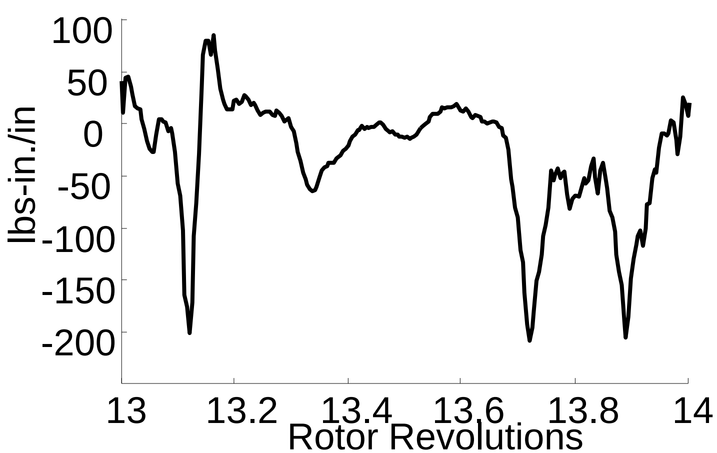
- **Asymmetric flow on advancing and retreating sides: control pitch angle variation**
- **Reverse flow on the retreating side: low effective air speeds and lift asymmetry**
- **Tip vortices**

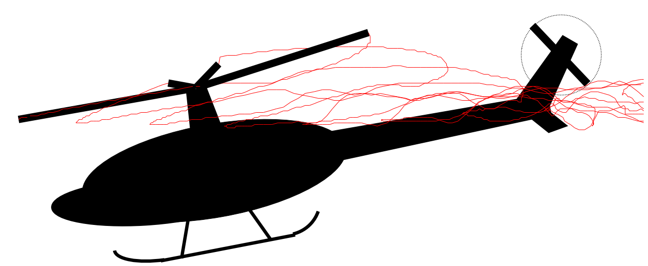


Complex Aerodynamics

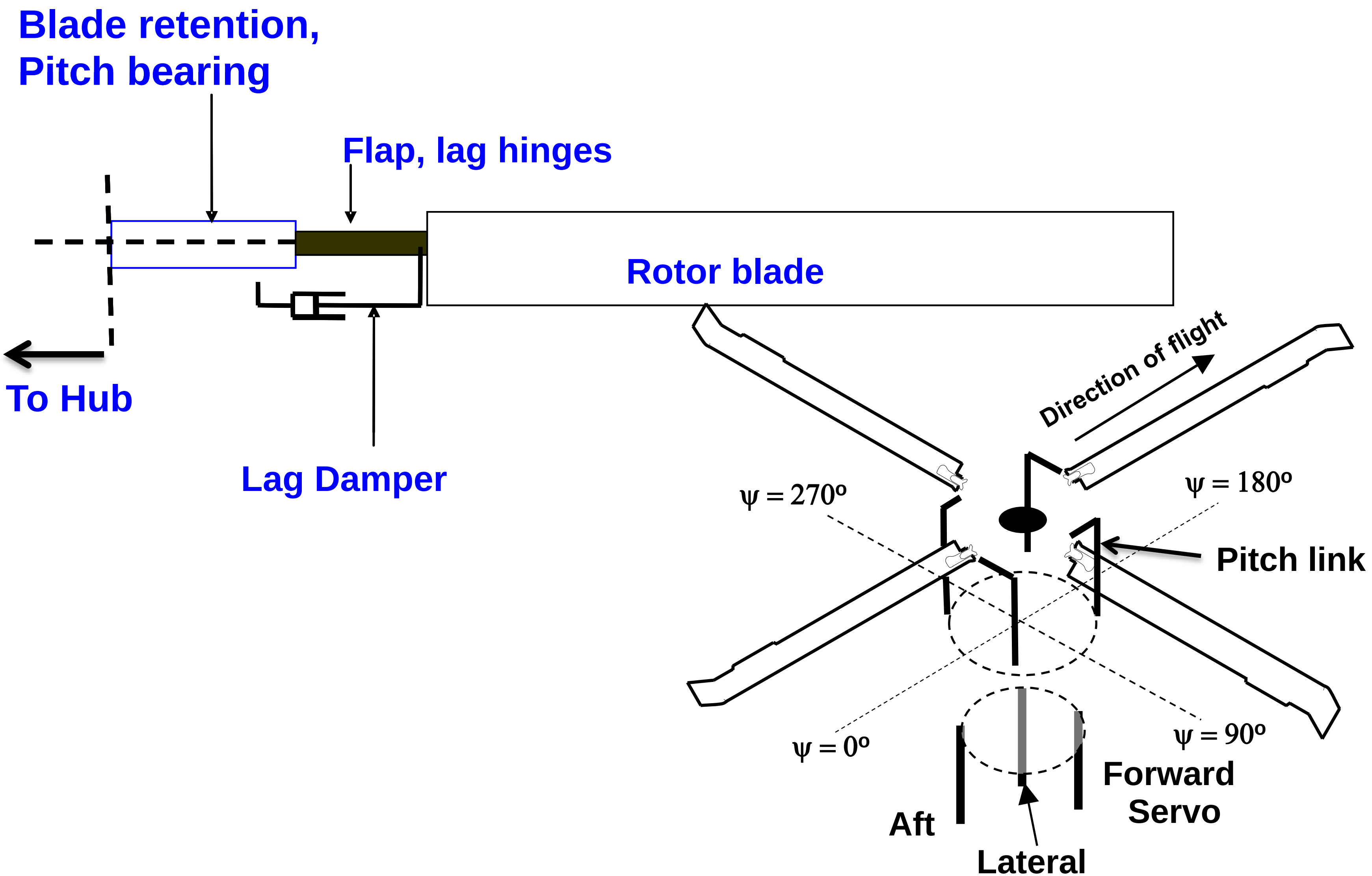
- **Multiple dynamic stall cycles**
- **Compressibility and 3D transonic effects on the advancing side**
- **Rotor wake interaction with oncoming blades**

Sectional Pitching Moment





Functional Diagram of a Rotor



Rotor Hub

- **Functions of rotor hub**
  - **Transfer driving torque**
  - **Retain rotor blades**
  - **Provide flap and lag hinges**
  - **Provide mechanism for torsion /pitch change**

- **Types of hubs:**
  - **Articulated, teetering, hingeless, bearingless**
  - **Soft-in-plane or stiff-in-plane**

Areas of Interest

- **Structural dynamics**
  - Blade rotating frequencies in vacuum
- **Aerodynamics**
  - Unsteady aerodynamics (shed wake)
  - Trailed wake or far wake
- **Flight dynamics**
  - Handling qualities
  - Flight stability and control

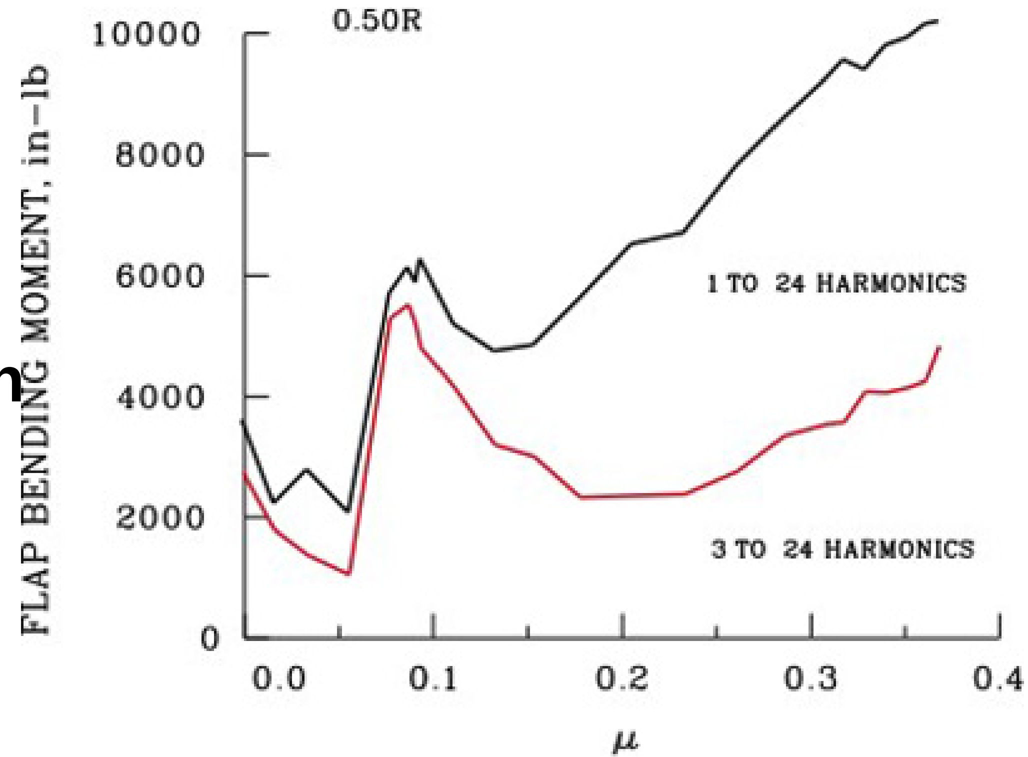
Rotorcraft dynamics

- **Loads prediction: structural, aerodynamic, control**
  - Steady flight: critical for vibration study
  - Unsteady maneuver: sizing of critical helicopter components
- **Acoustics**

Structural Loads – Vibration

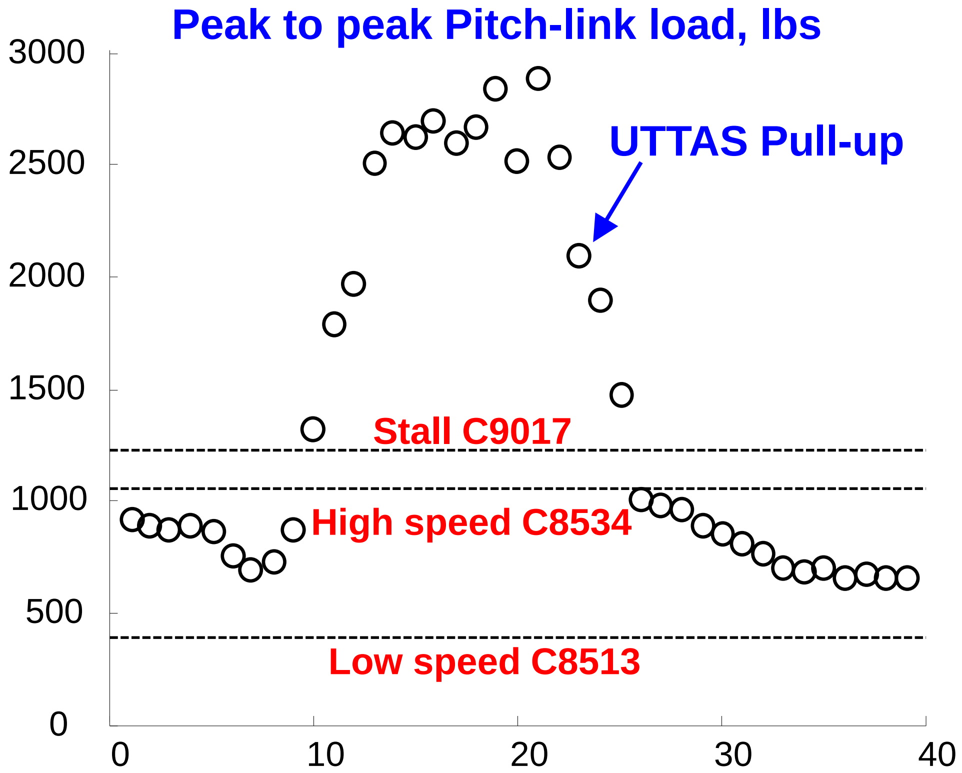
- Rotor blade loads are low near hover
- As airspeed increases flap bending moments at midspan of the blade (1 to 24 harmonics) increase
  - Greatest at high speed

- These vibratory loads cause fatigue – high speed regime important for vibration sizing



Enormous Loads in Maneuvers

- **Pull up maneuver**
  - **Terrain avoidance maneuver: Based on Utility Tactical Transport Aerial System (UTTAS)**
  - **Third highest pitch link load (2.5 times steady flight)**



High Loads: Dynamic stall, vortex loading, transonic effects

Helicopter Design

- Main rotor structural loads encountered during aggressive severe maneuvers size all rotor components (blades, hub, control linkages, fixed frame servos)

- Limited analysis tools to predict these design loads

Current Design Practices

- Current design based on loads "estimated" from flight test loads survey
  - Ground qualification tests
  - Aircraft flight tests
  - Service and evaluation tests
  - Limited analysis (quasi steady) based heavily on empirical factors
    - Sub-optimal, conservative design, with significant weight penalty
    - Testing necessary due to assumptions associated with analysis
- Accurate analysis necessary to reduce weight and risks/cost associated with extensive flight testing

Lot to be done to understand dynamics and aerodynamics