Die Flugsteuerung des Hubschraubers

von den Grundlagen bis zur Einzelblattsteuerung

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Fachhochschule Hamburg
Hamburg, d. 28.10.2004

Helicopter Flight Control – from primary to individual blade control

- **Overview**
- **History / Configuration and Performance of a Helicopter**
- **Main Rotor / Main Rotor Control Design**
- **Problems of the Main Rotor**
  - **Aerodynamics**
  - **Vibrations**
  - **Noise**
- **Individual Blade Control (IBC)**
  - **Principle of Operation**
  - **Effects in Wind Tunnel and Flight Tests**
  - **IBC System Design**
- **Conclusion and Outlook**

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Comparison of 1930 Aircraft Maturity, Helicopter vs. Fixed Wing

<u>Do X giant seaplane:</u>

MTOW: 48to
Distance: 2800km
Endurance: 14h

<u>Helicopter by C. d'Ascanio:</u>

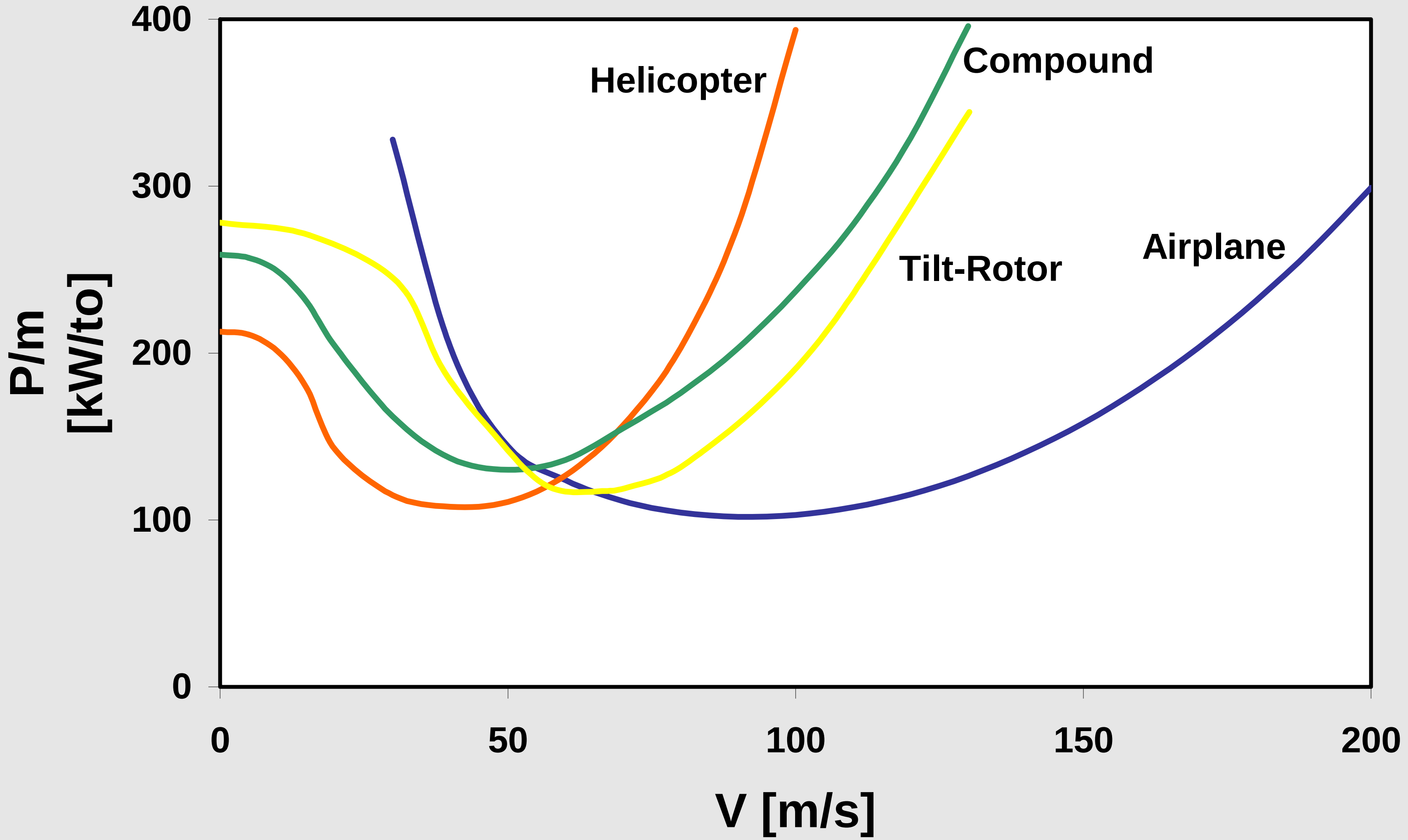
Altitude: 18m
Distance: 1078m
Endurance: 8:45min

Helicopter Standard Configuration

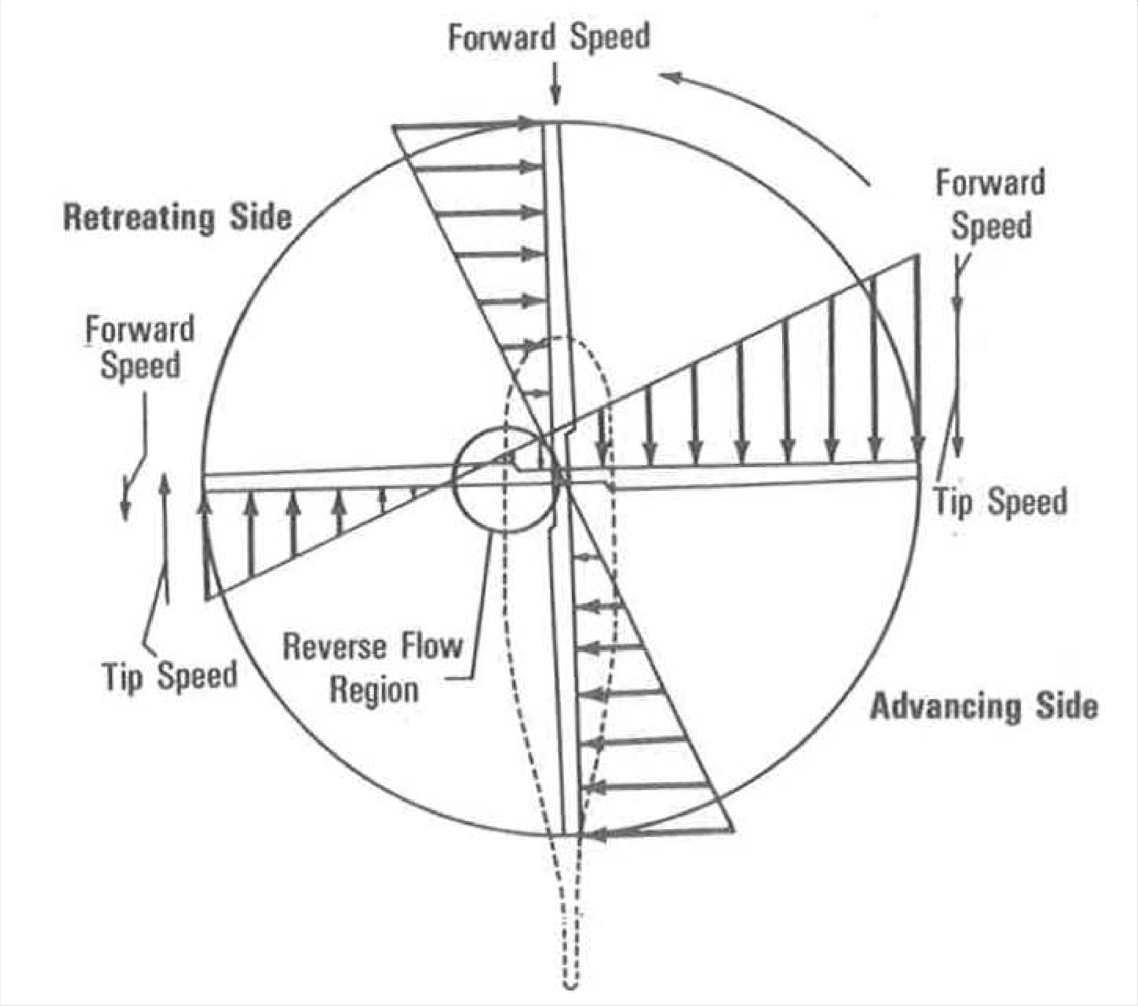
Lockheed AH-56A Cheyenne Compound Aircraft

Tiltrotor Aircraft Bell/Boeing V-22 Osprey

Relative Power Required vs. Forward Speed



Velocity Distribution over Rotor Disk (Advanced Ratio $\mu = \Omega R / V$)



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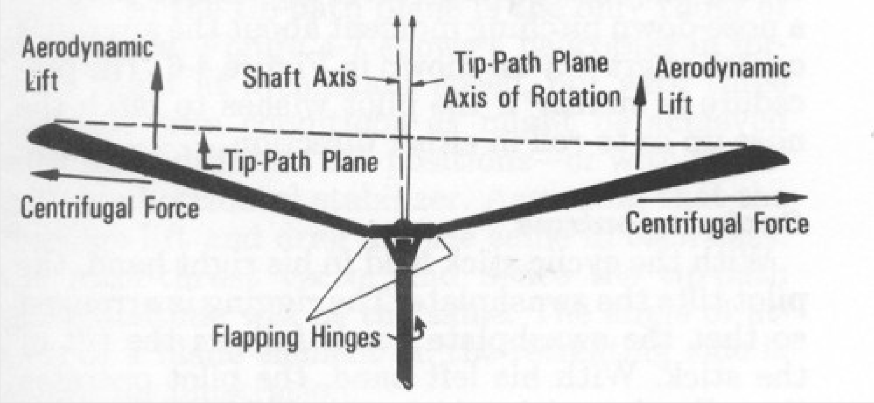
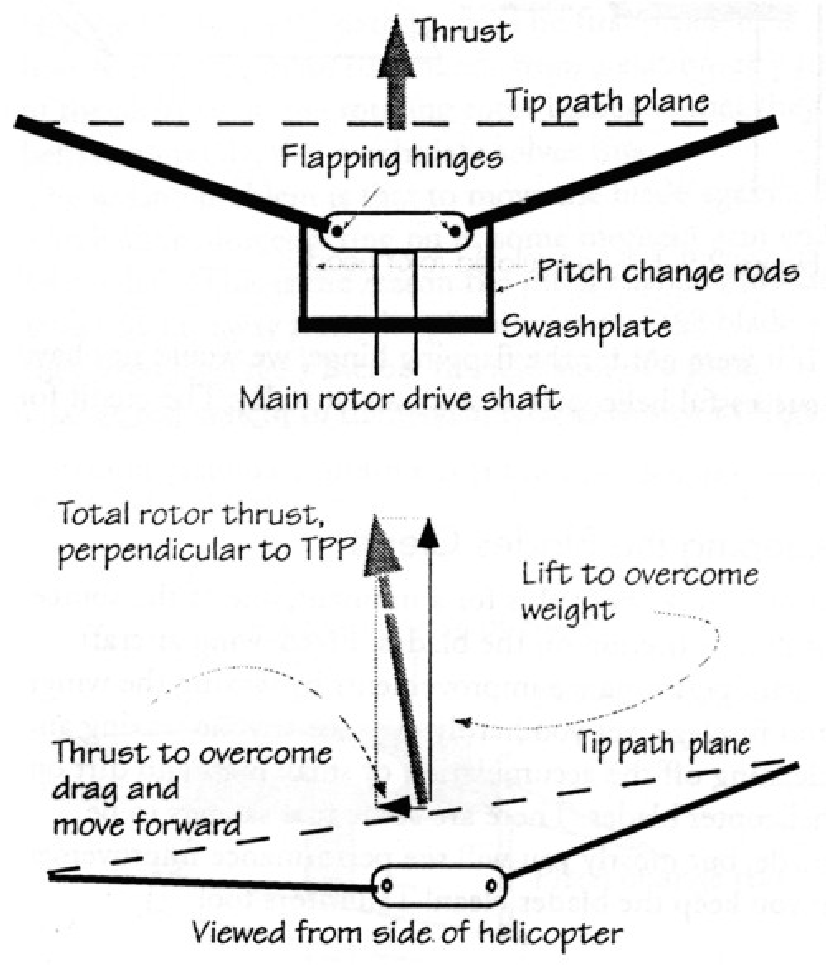
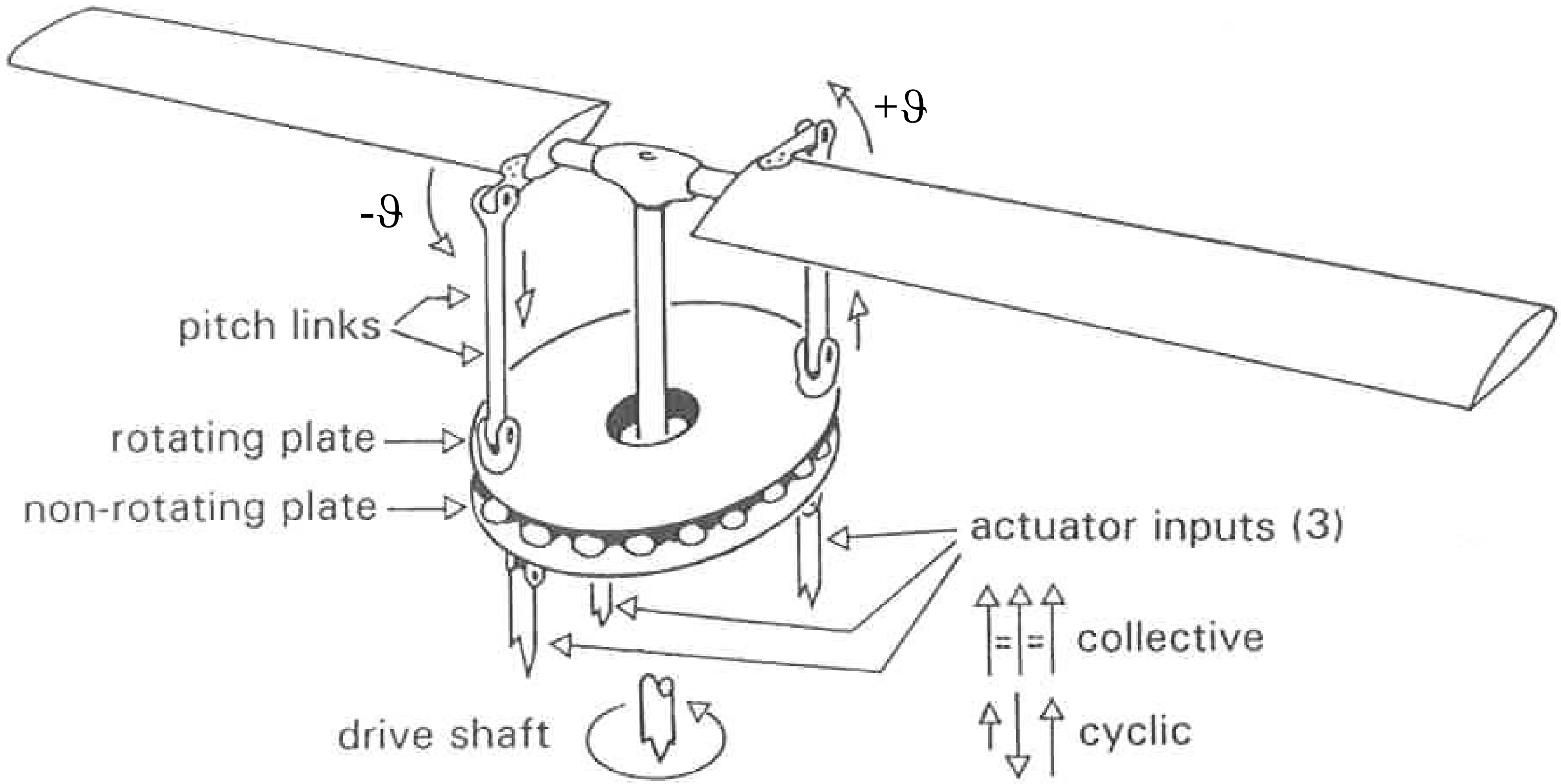
Rotor Blade Lift and Flap

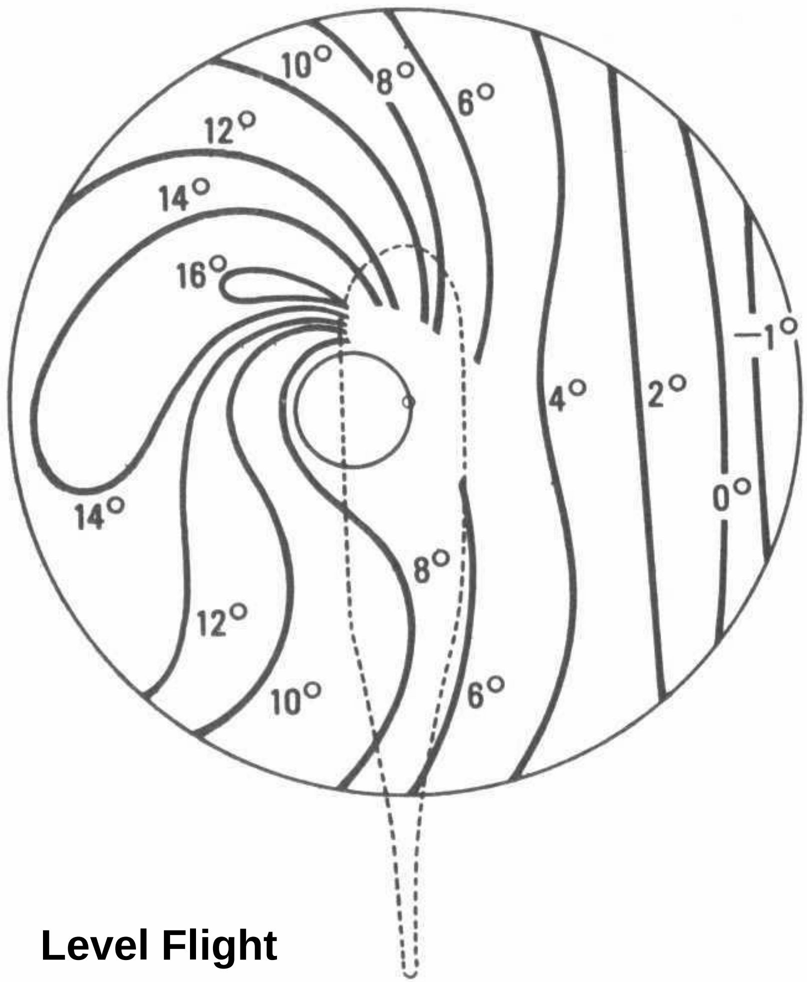




Blade Control System Using a Conventional Swashplate Arrangement

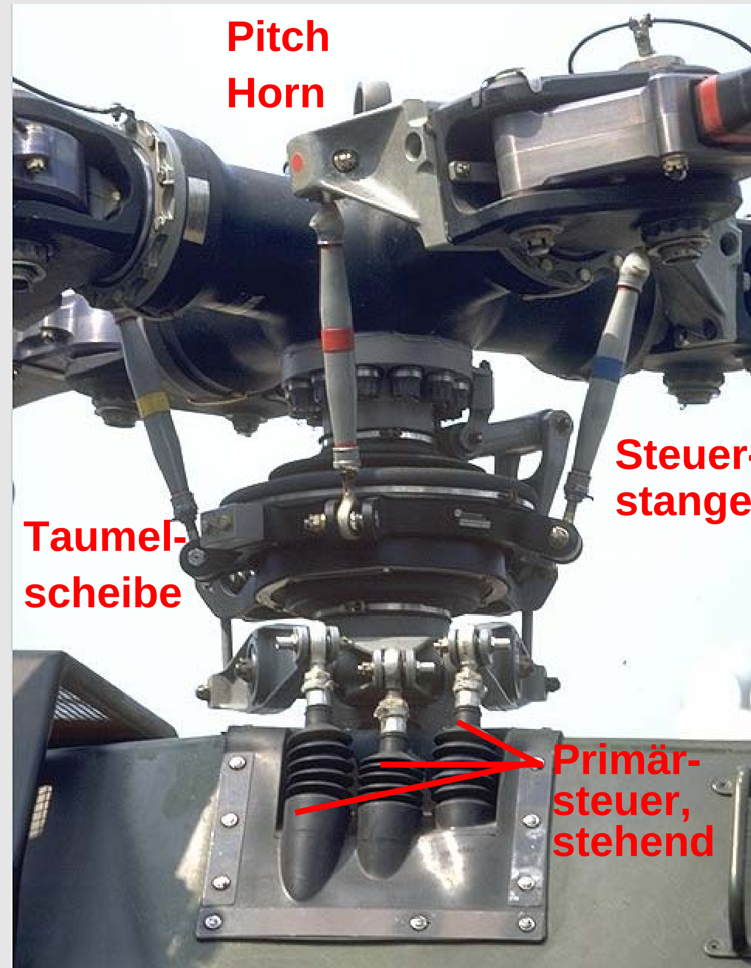


Angle-of-Attack Distribution in Forward Flight

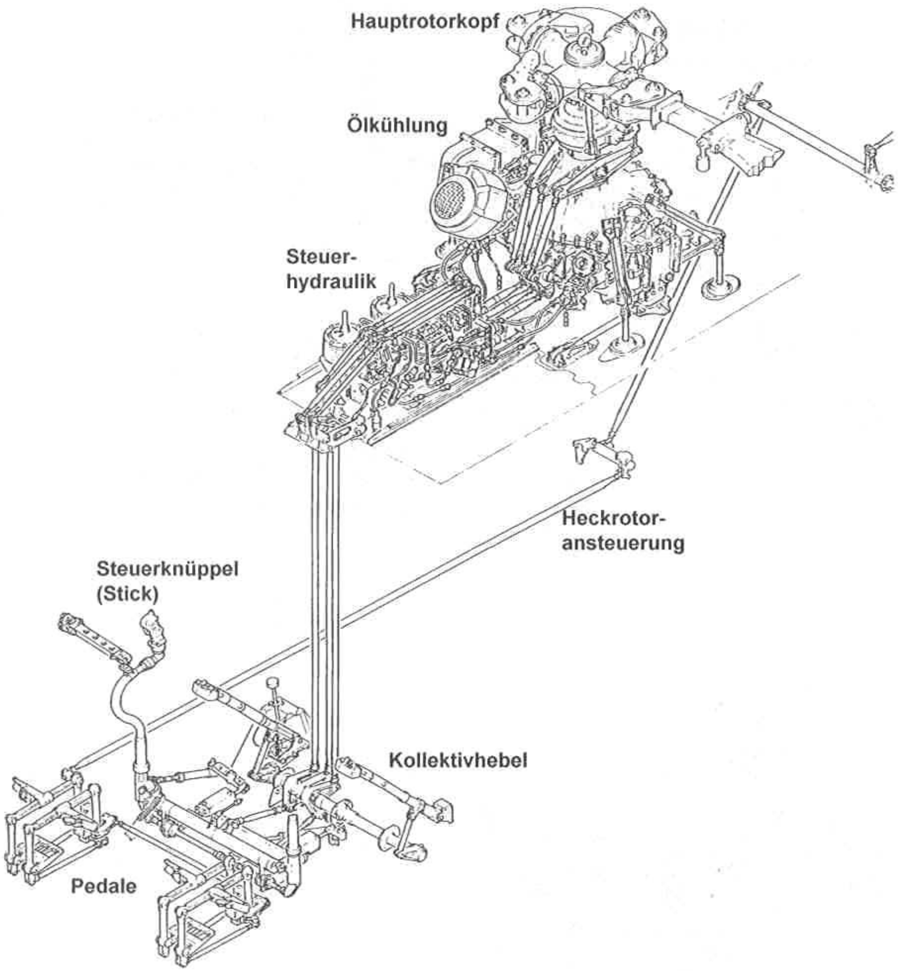


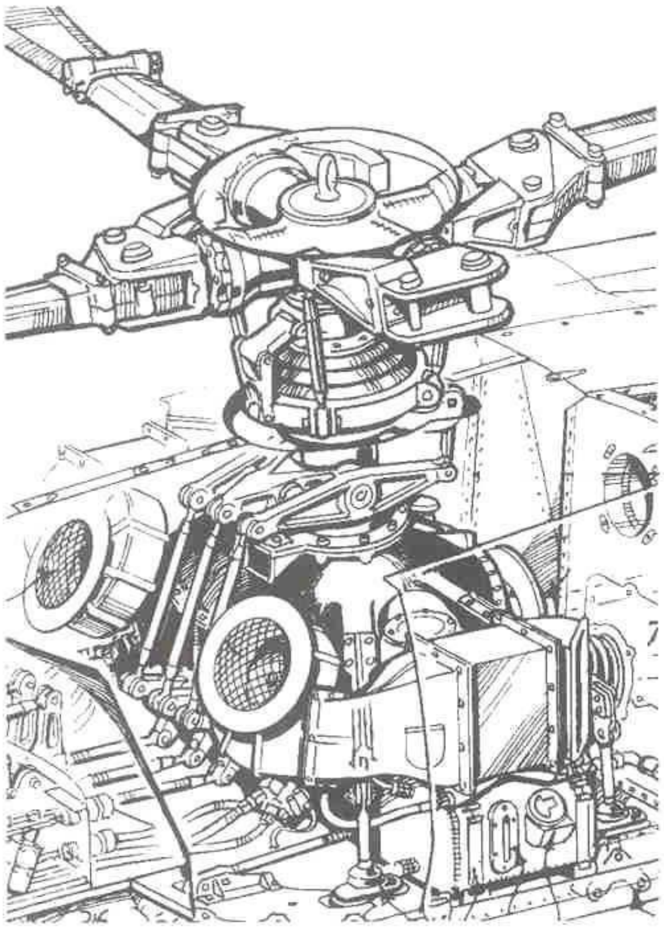
Level Flight

Main Rotor Control System
Eurocopter (MBB) BO105

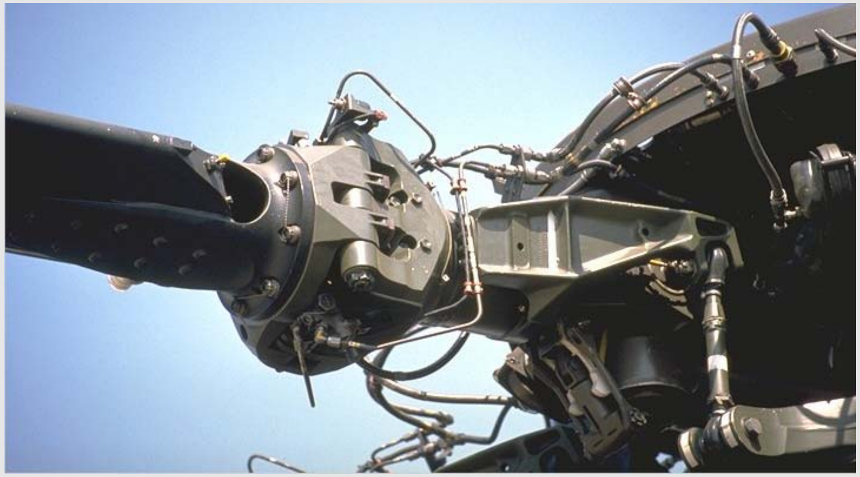


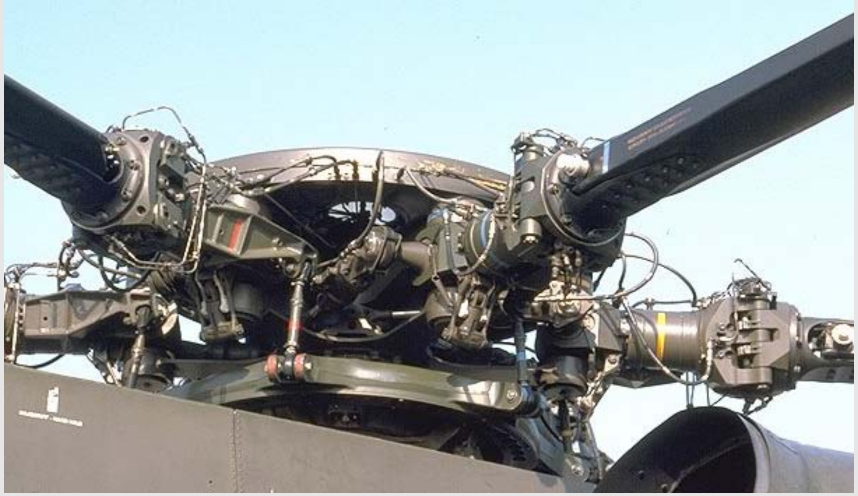
Conventional Mechanical Primary Control System





Main Rotor Sikorsky CH-53G





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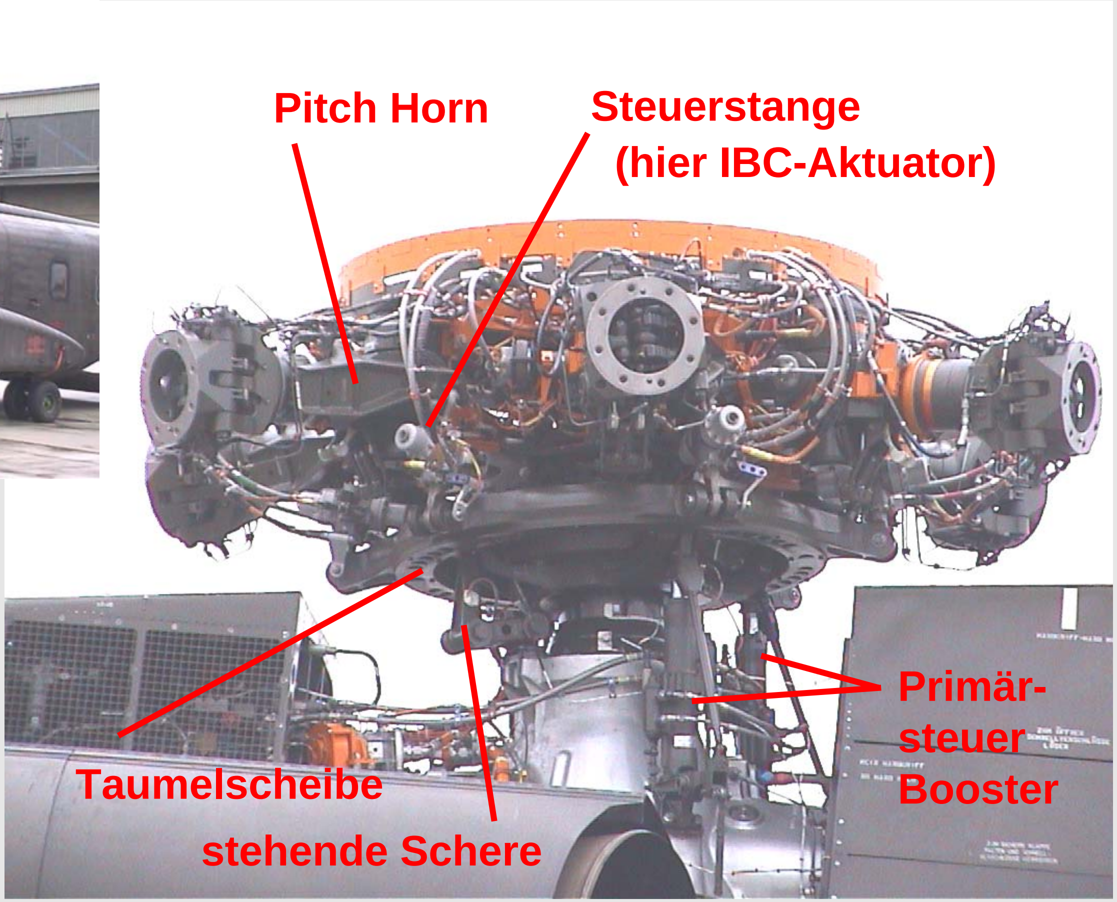
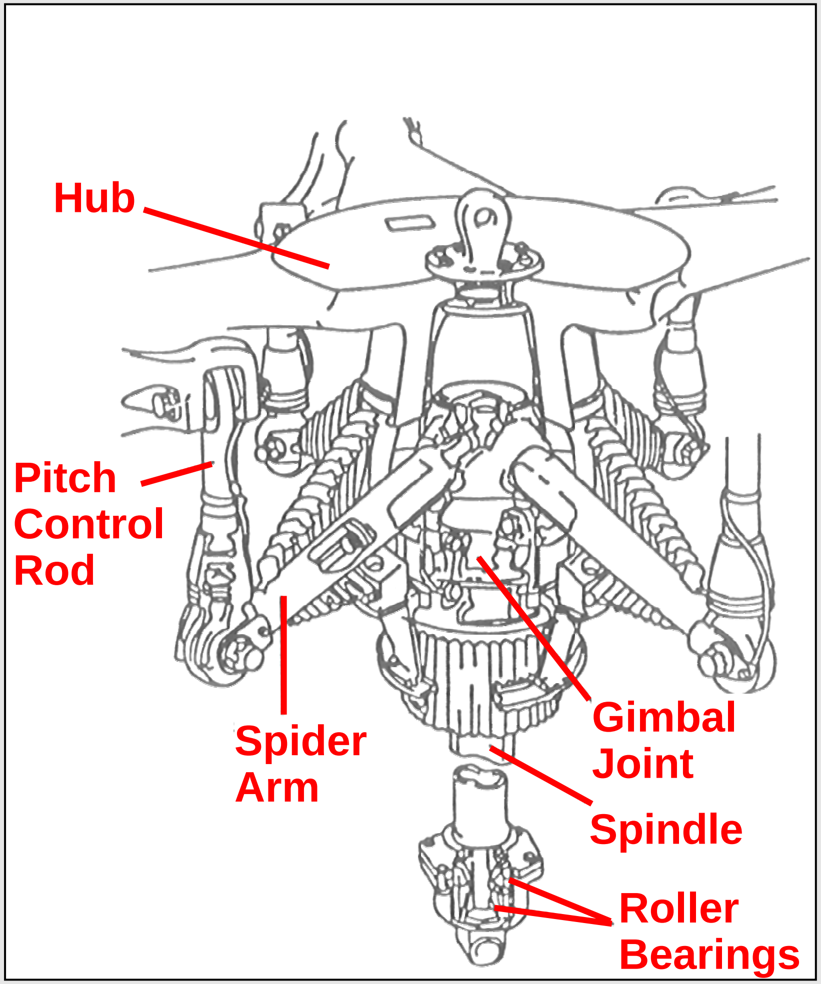


Main Rotor Control with Spider
Westland Sea Lynx MK88

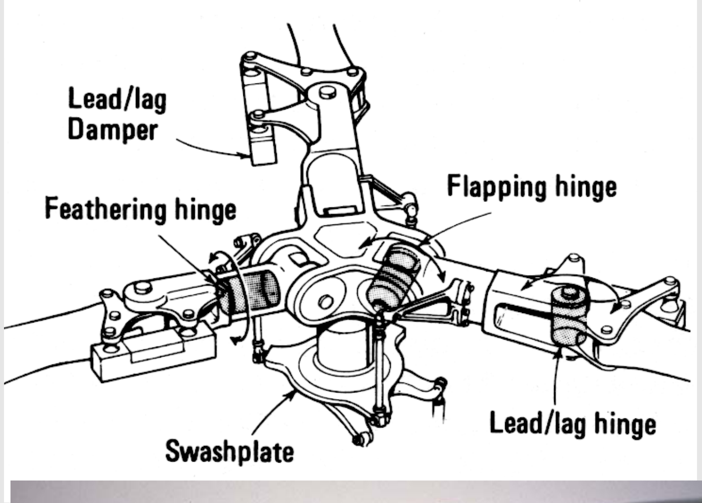


NHI NH-90

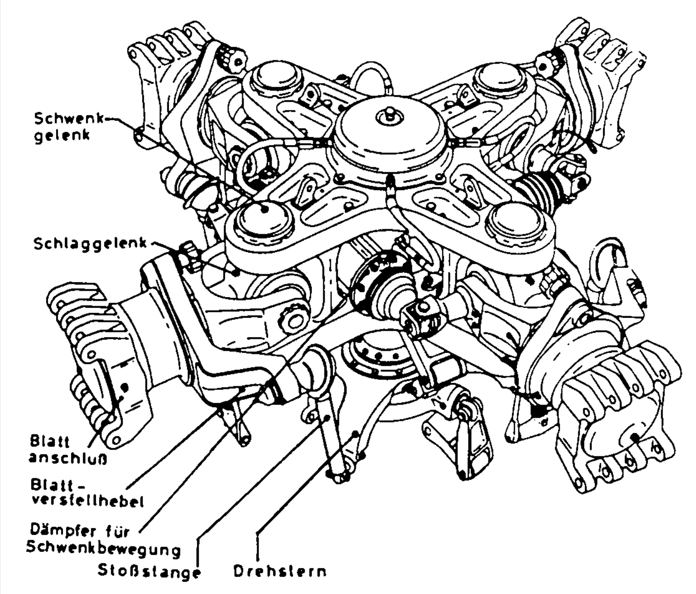
- ➔ Erstflug: 18. Dezember 1995
- ➔ Quadruplex fly-by-wire Steuerung

Main Rotor Design – 1950/60s

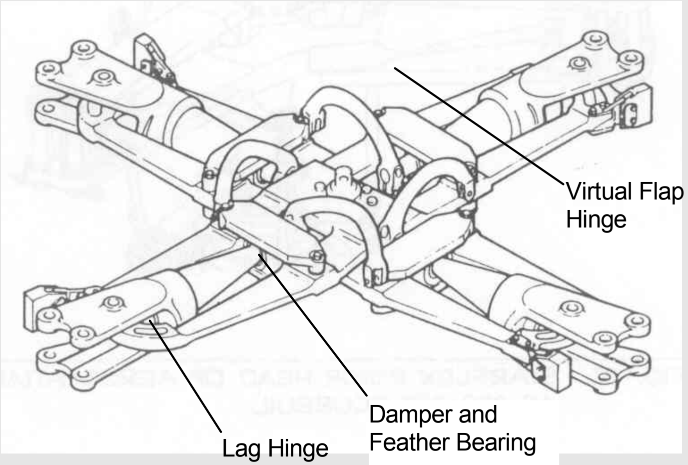
AEROSPATIALE AS 341



Sikorsky S-58



Main Rotor Design – Bell 412



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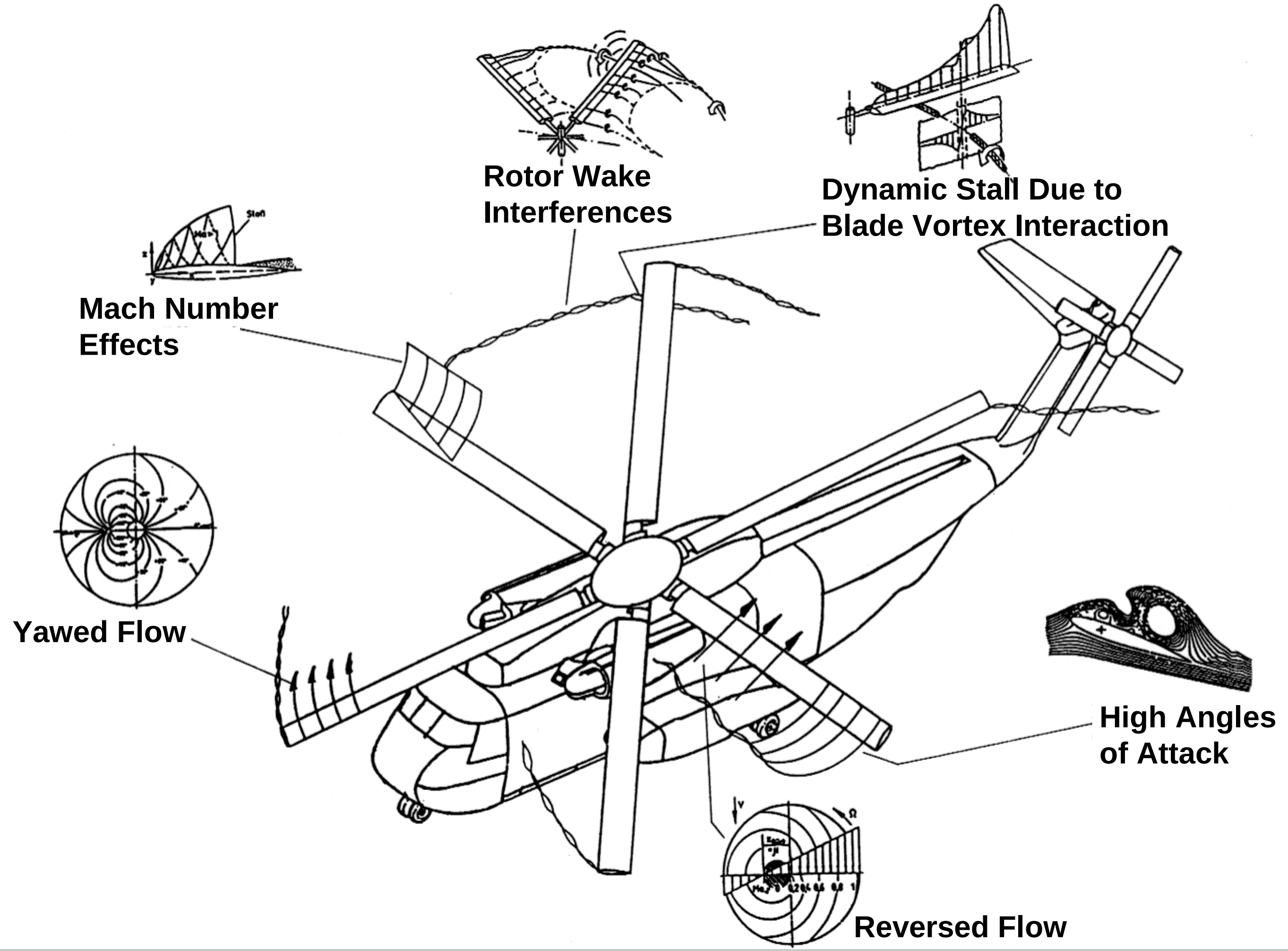
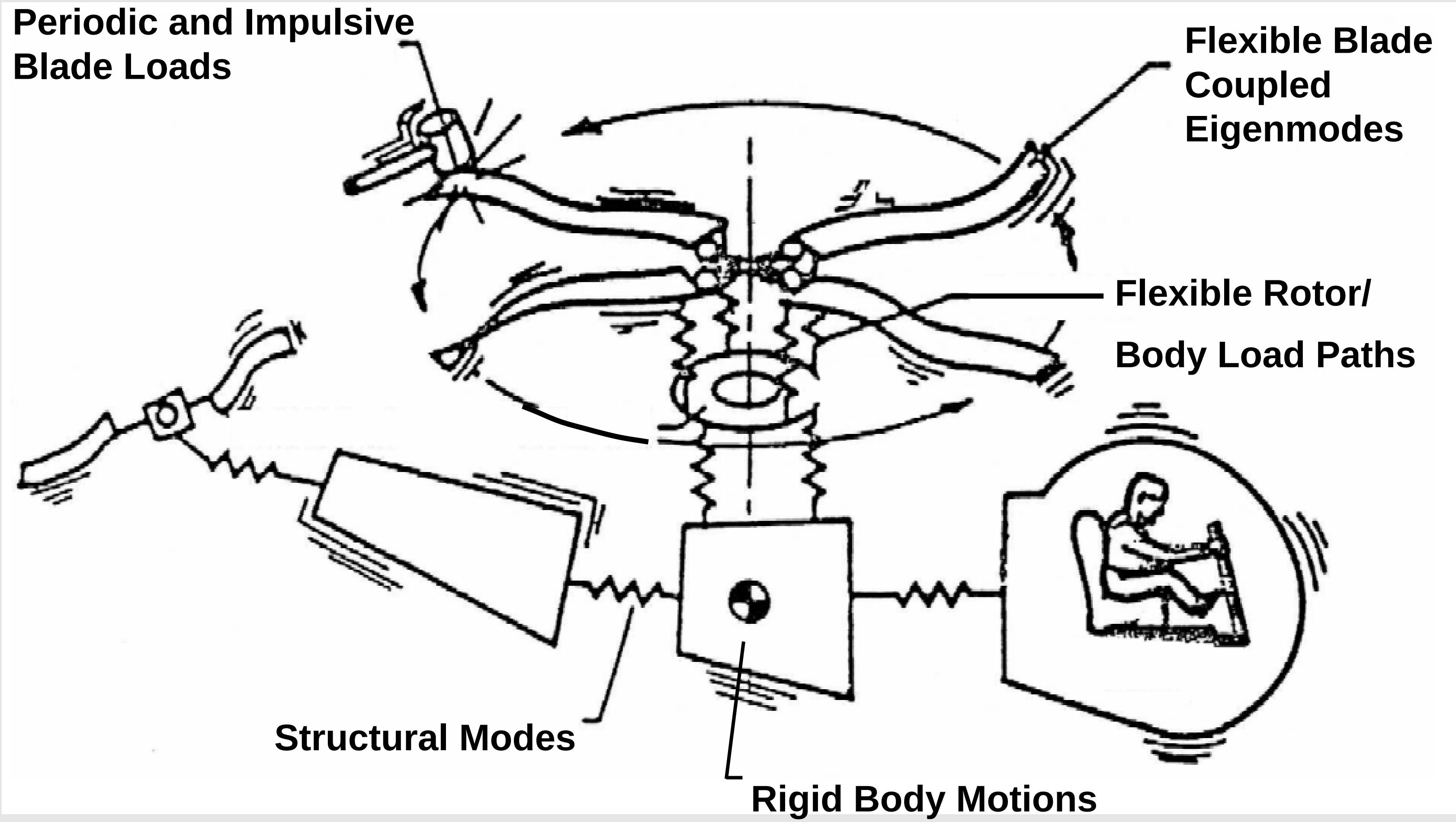
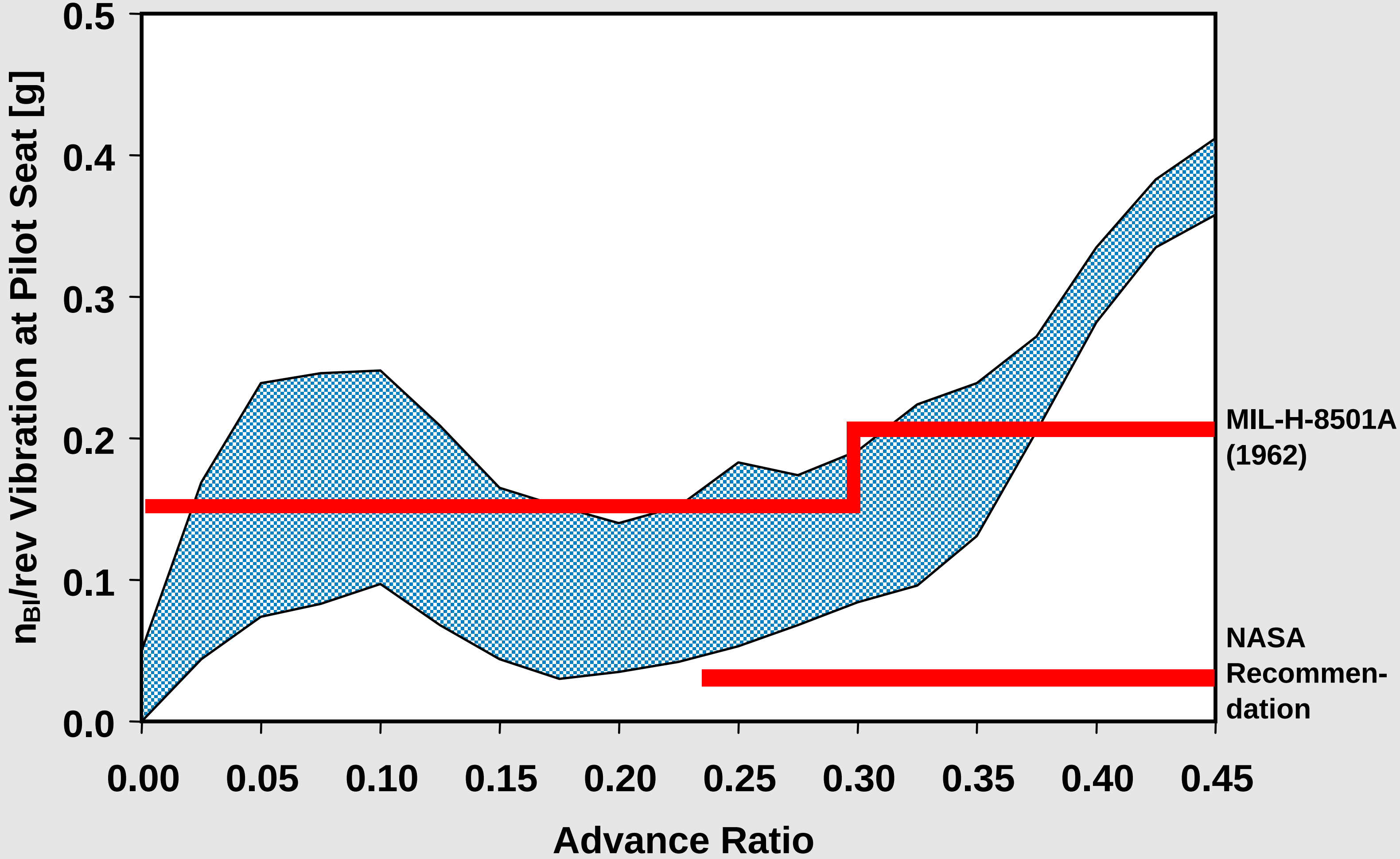
Limiting Phenomena Encountered by a Helicopter Rotor in Forward Flight



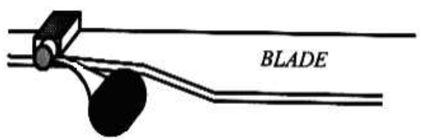
Helicopter Vibrations:
Source ⇒ Flexible Structure ⇒ Reaction



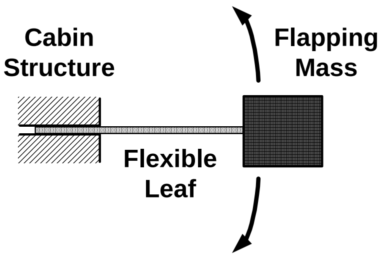
Vibration Levels of 6 Different Helicopter Types (BO-105 4- and 5-Bladed, CH-53G Aluminium and IRB Blades, Tiger, UH-60)



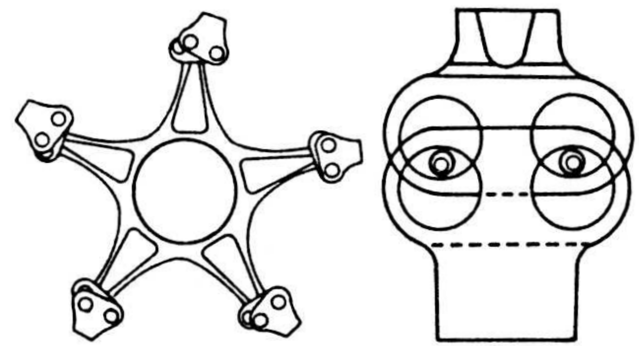
Passive Vibration Absorber and Isolation Systems



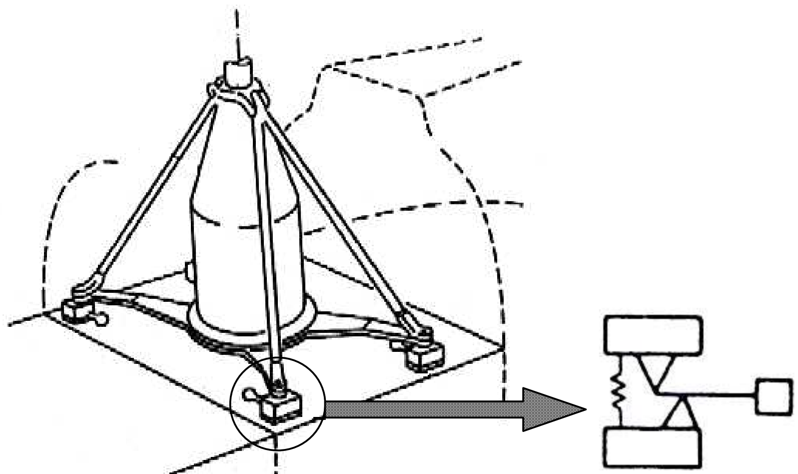
Pendulum Absorber



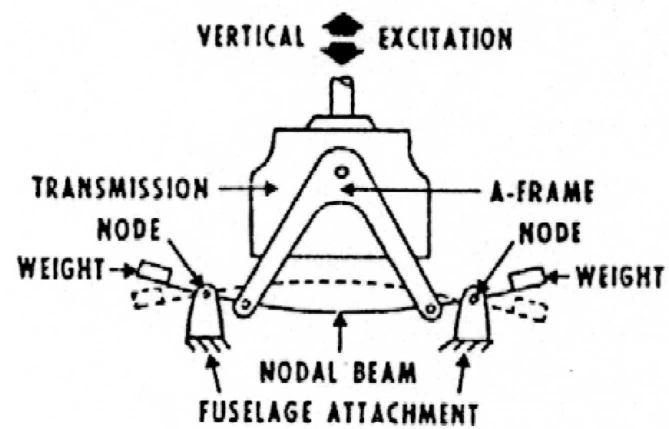
Cabin Absorber



Bifilar Absorber

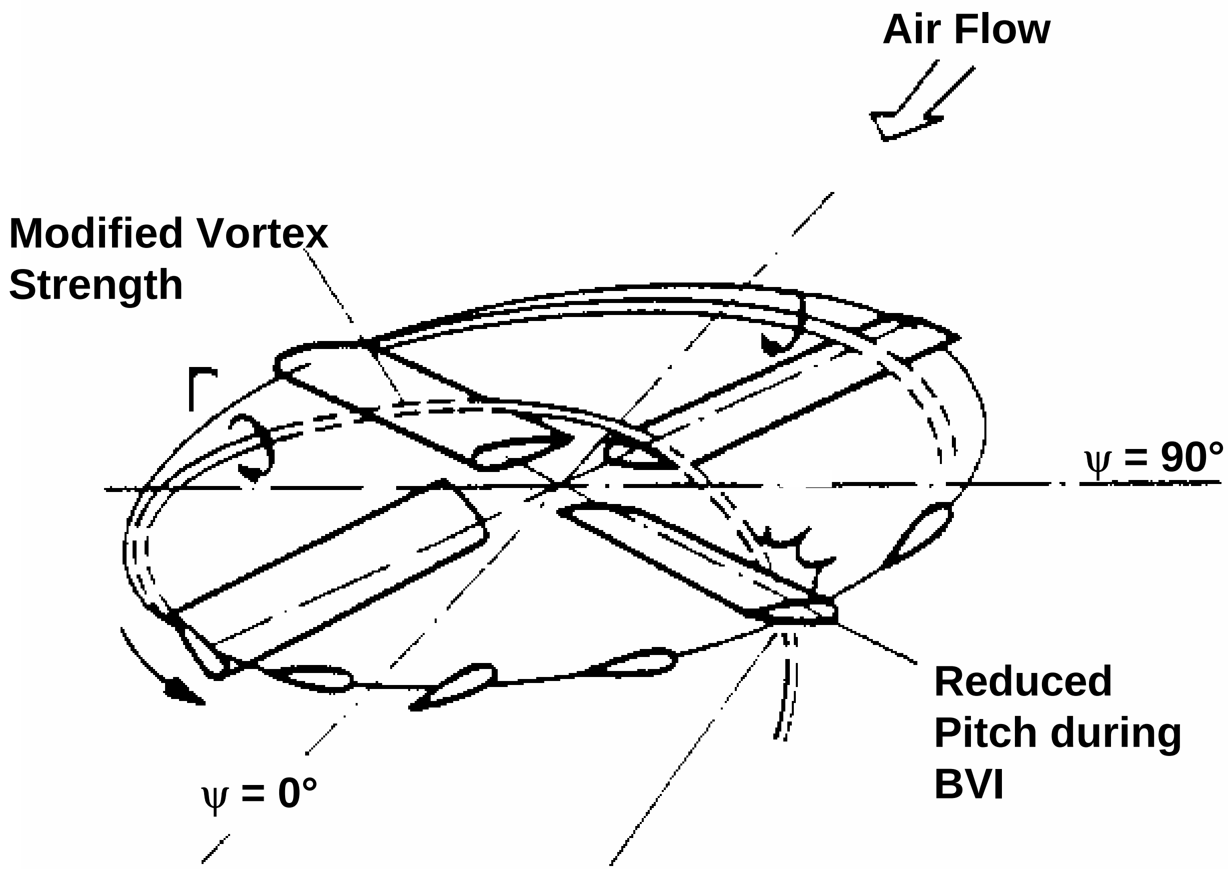


Antiresonance Isolation System

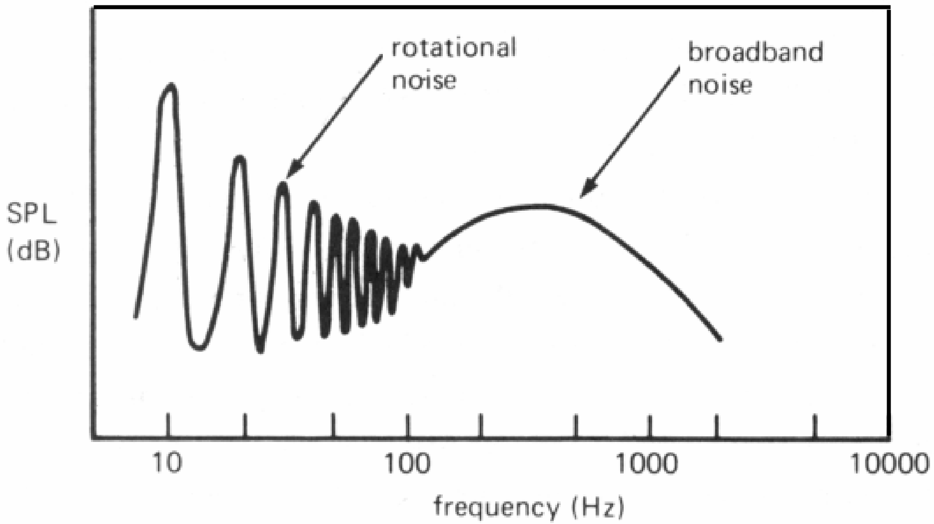


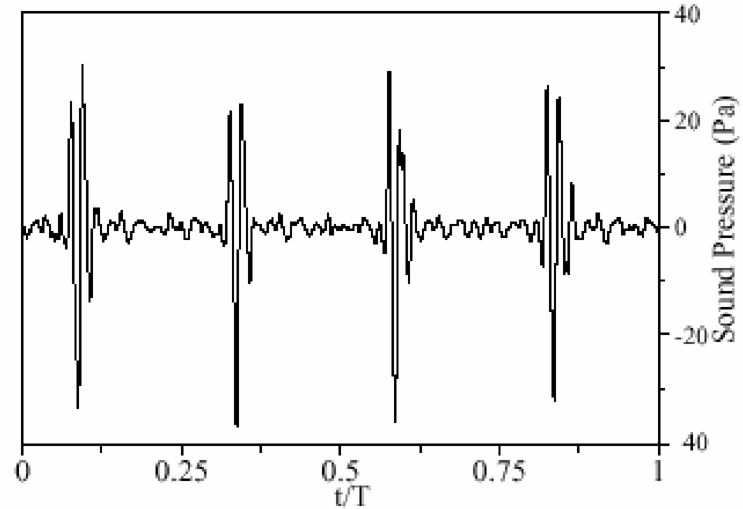
Nodal Beam Isolation System

BVI-Noise Generating Mechanism



Example of Helicopter Rotor Sound Spectrum (l.h.s.) and Average Time History (r.h.s.)





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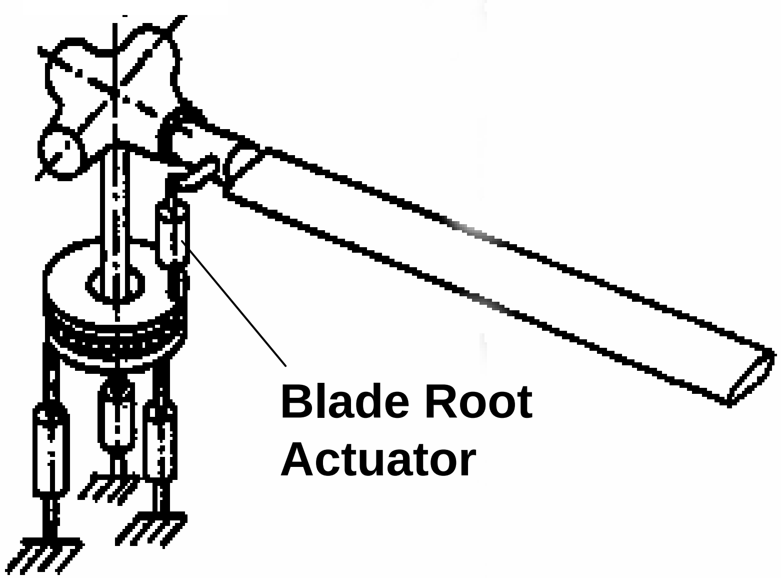
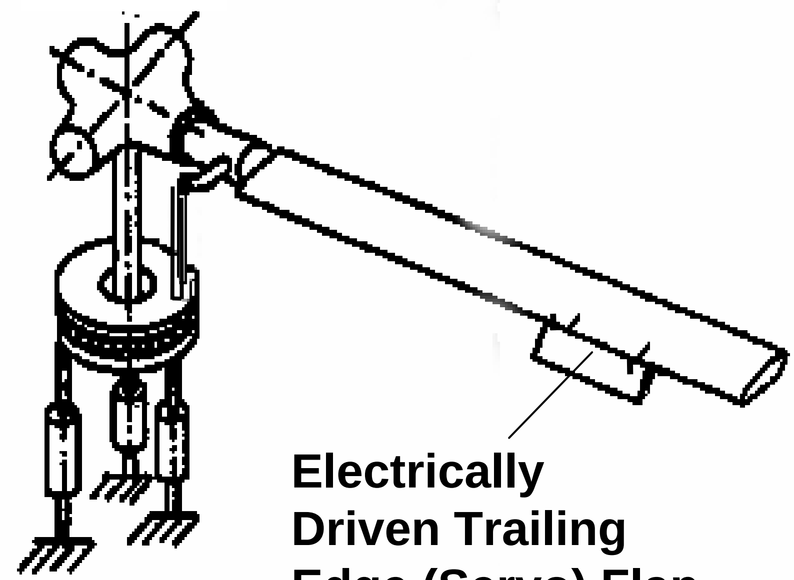
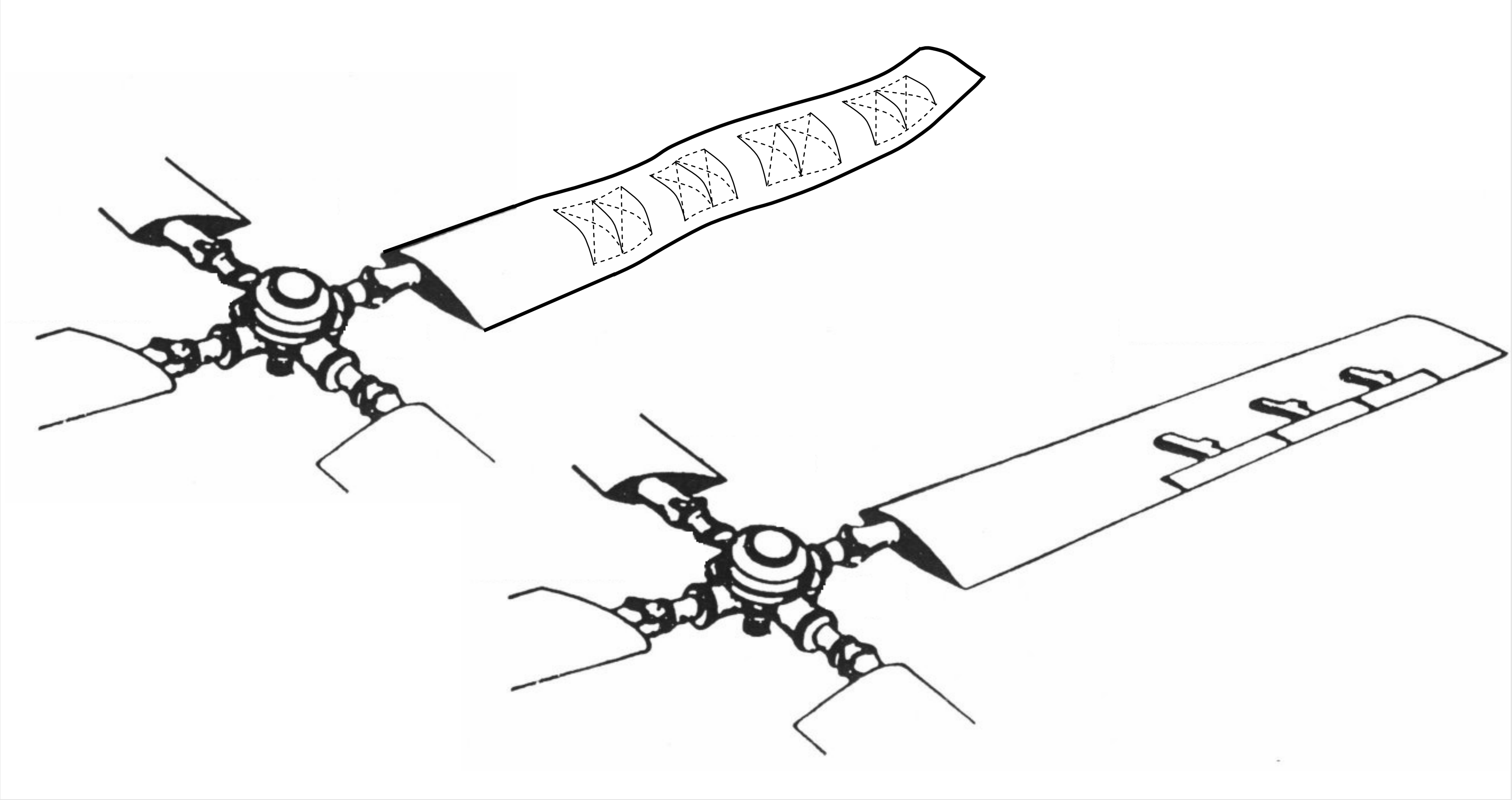
Individual Blade Control through Blade Root or Trailing Edge Flap Actuation

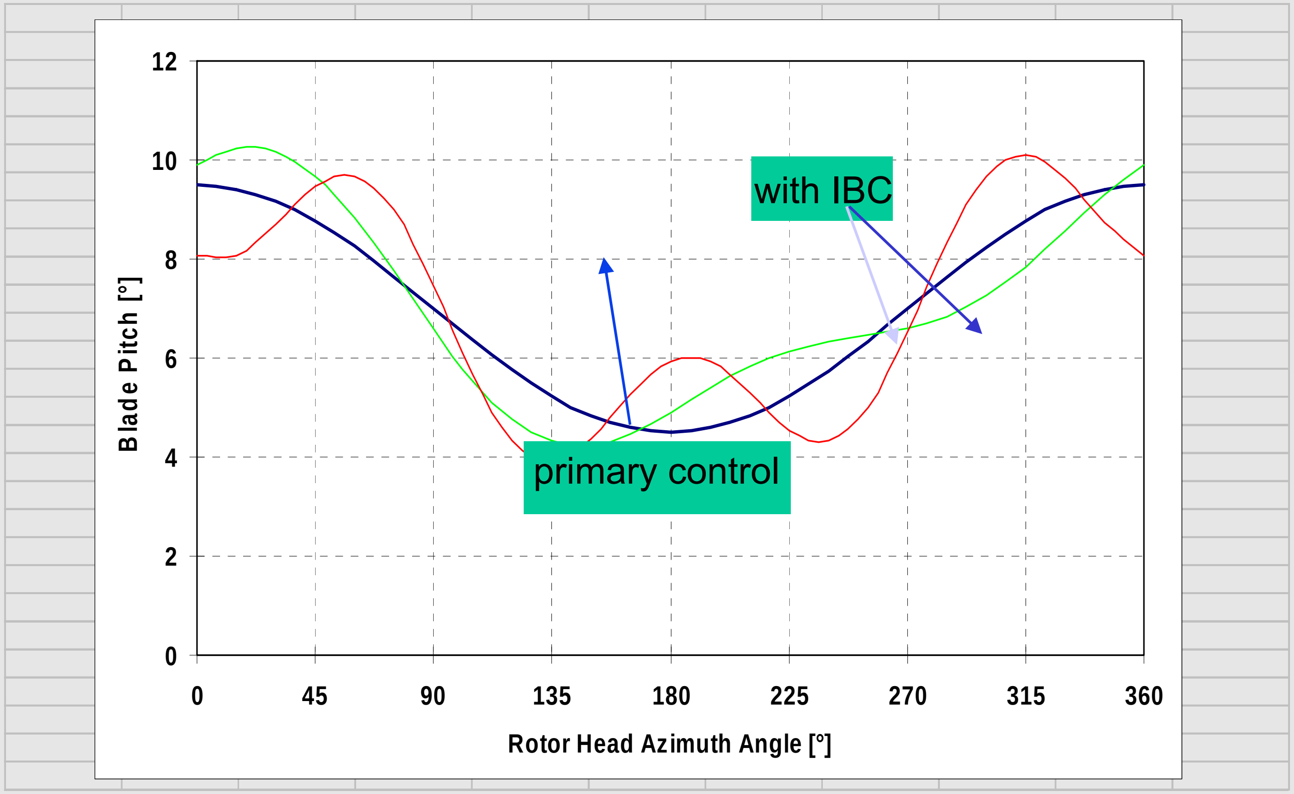




Individual Blade Control through Blade Twist or Trailing Edge Flap Actuation



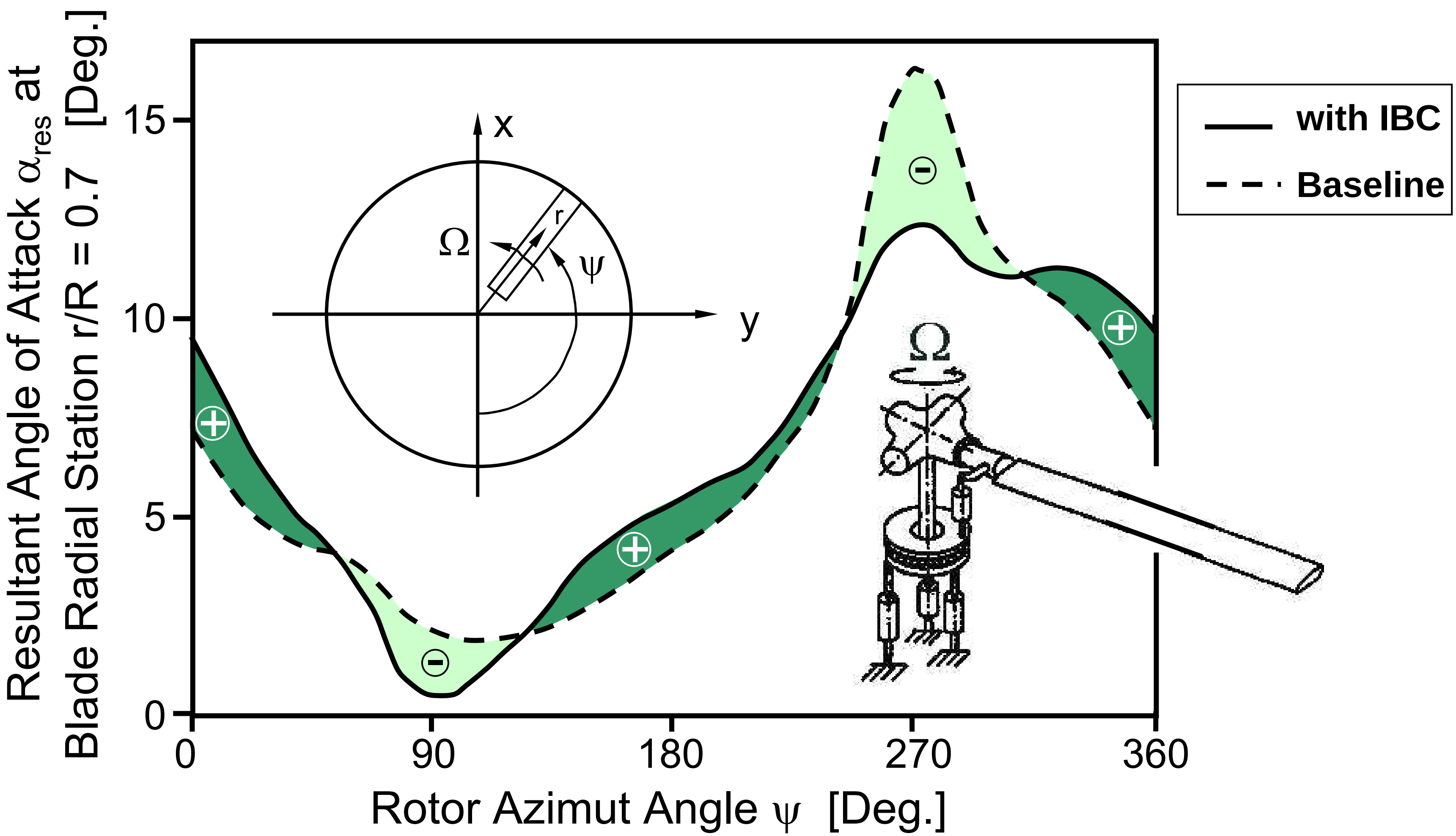
IBC Blade Pitch Control with higher harmonic blade pitch movements



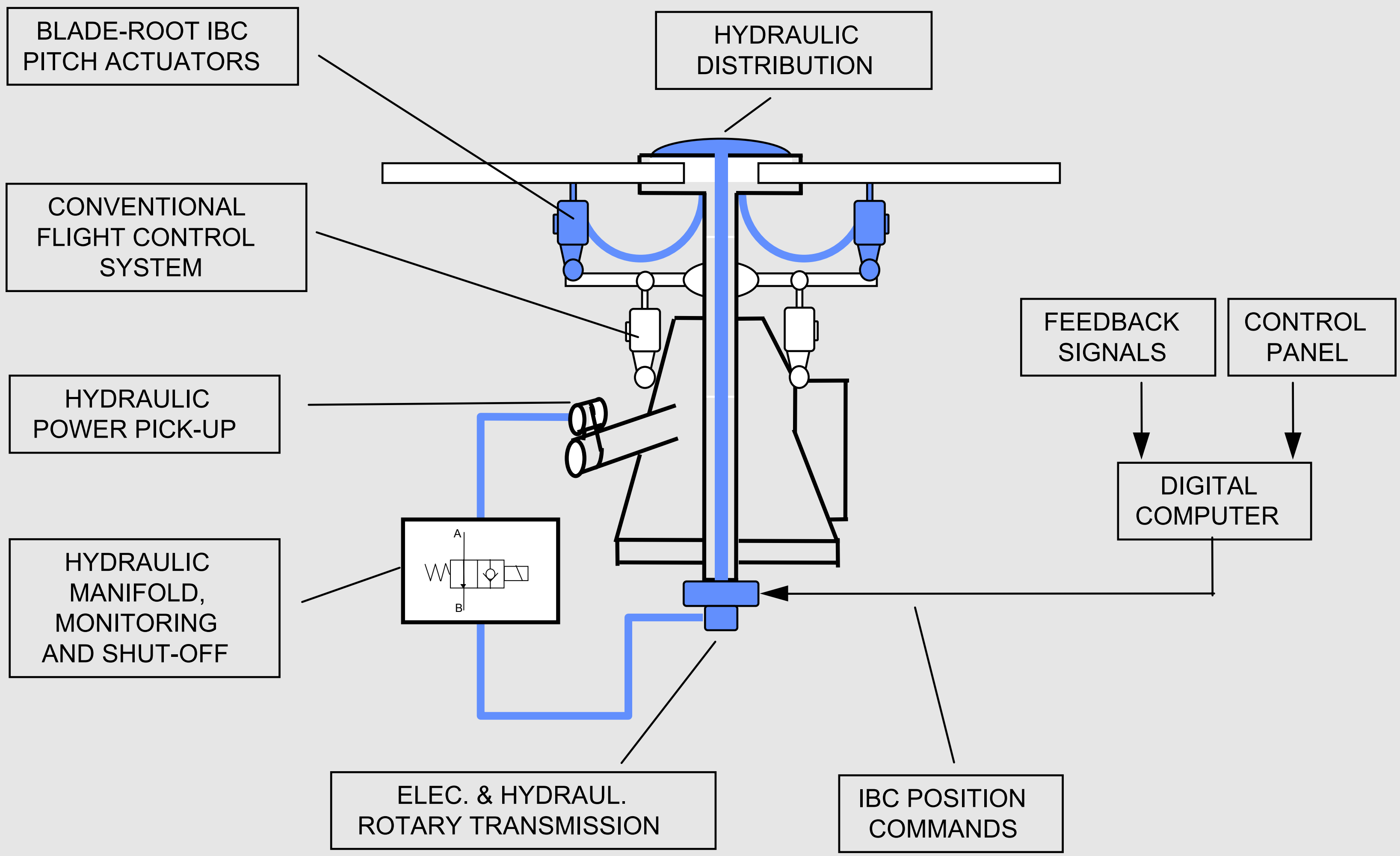
IBC Blade Pitch Movement characterization:

- frequency (2 .. 7 Ω_{Rotor})
- amplitude (0..3..6°)
- phase (0..360°)

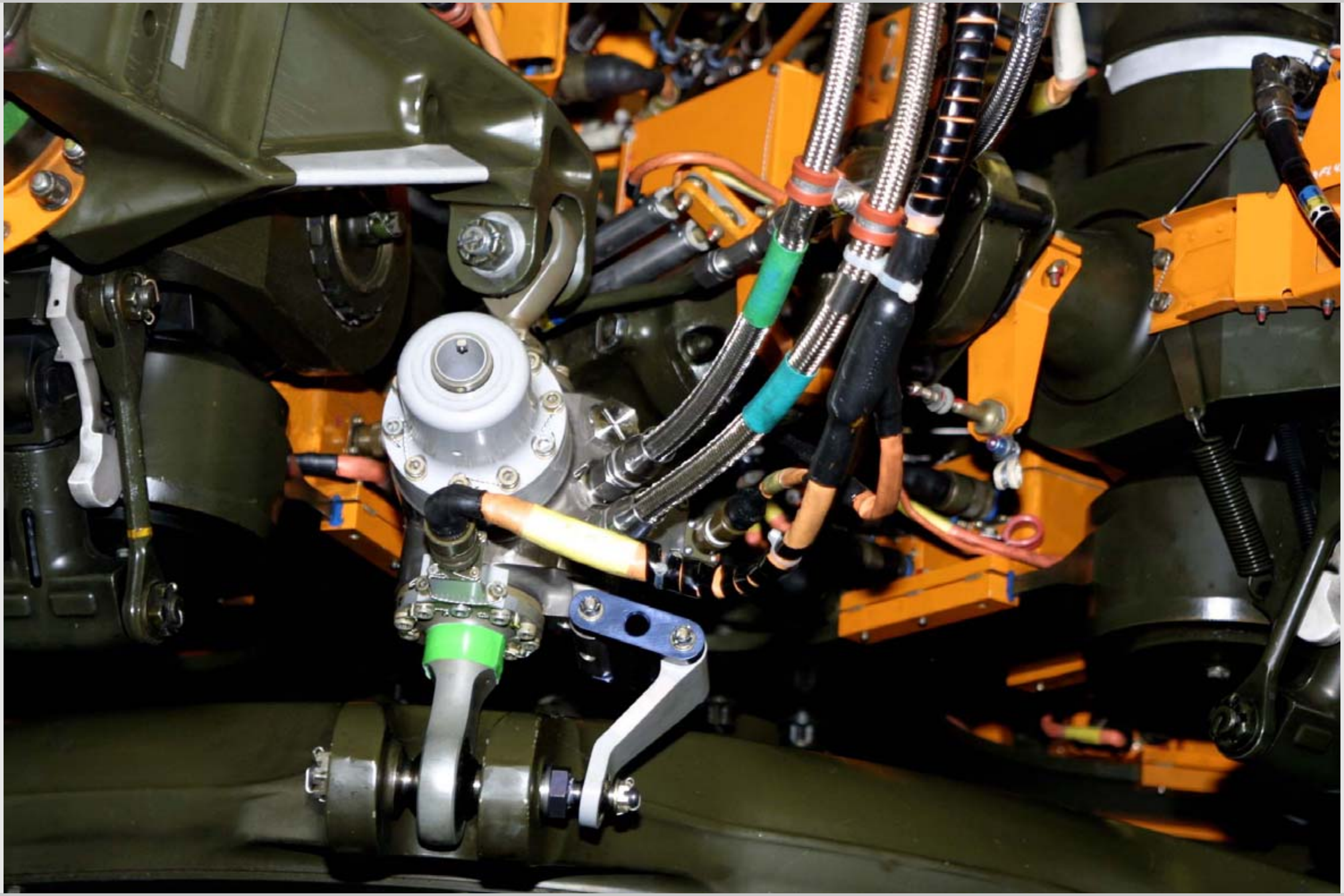
Modification of Local Angle of Attack through IBC



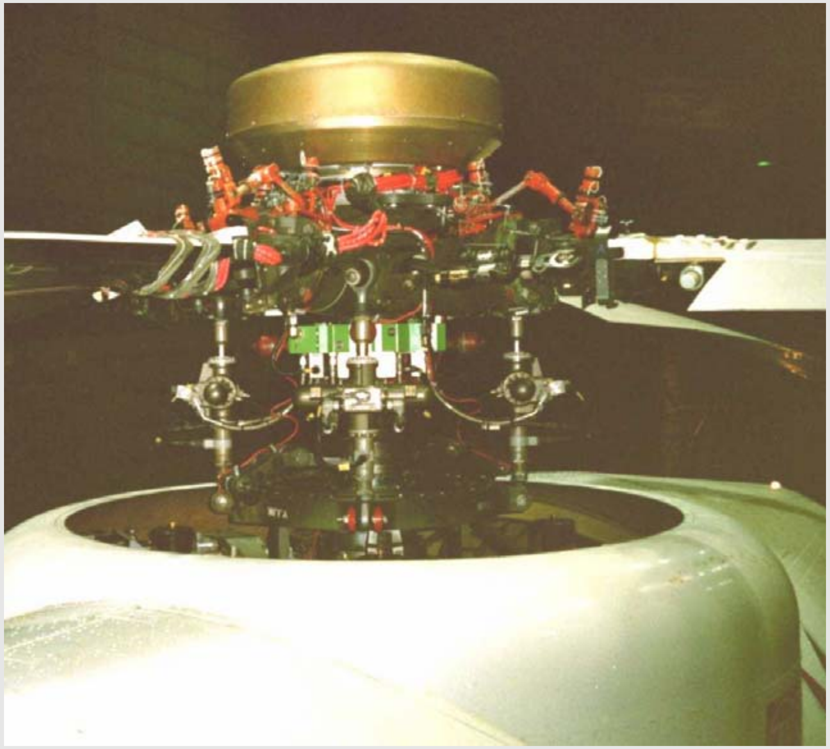
Principle Layout of IBC System



IBC Actuator Mounted between Swashplate and Blade Pitch Horn Replacing the Rigid Pitch Rod



Full Scale UH-60 Rotor Wind Tunnel Tests conducted at NASA Ames



IBC Inputs and Test Conditions

Test Condition	Shaft Angles	IBC Harmonics and Max. Amp.	
Vibration	-3.0°	2/rev to ±1.0°	*
(C_L/σ = 0.0725;	-0.69°, -3.0°	3/rev to ±1.0°	*
Constant Hub	-0.69°, -3.0°	4/rev to ±1.0°	*
Moment &	-3.0°	5/rev to ±0.25°	
Propulsive	-3.0°	6/rev to ±0.75°	
Force at	-3.0°	7/rev to ±0.25°	
46 kts)	-0.69°, -3.0°	2/rev + 3/rev	*
	-0.69°, -3.0°	3/rev + 4/rev	*
BVI Noise	4.0°, 7.0°	2/rev to ±3.0°	
(C_T/σ = 0.09;	7.0°	3/rev to ±0.5°	
Minimum	7.0°	4/rev to ±0.5°	
Flapping &	7.0°	5/rev to ±0.5°	
M_{Tip} = 0.65 at	7.0°	6/rev to ±0.5°	
75 kts)	4.0°	2/rev + 5/rev	

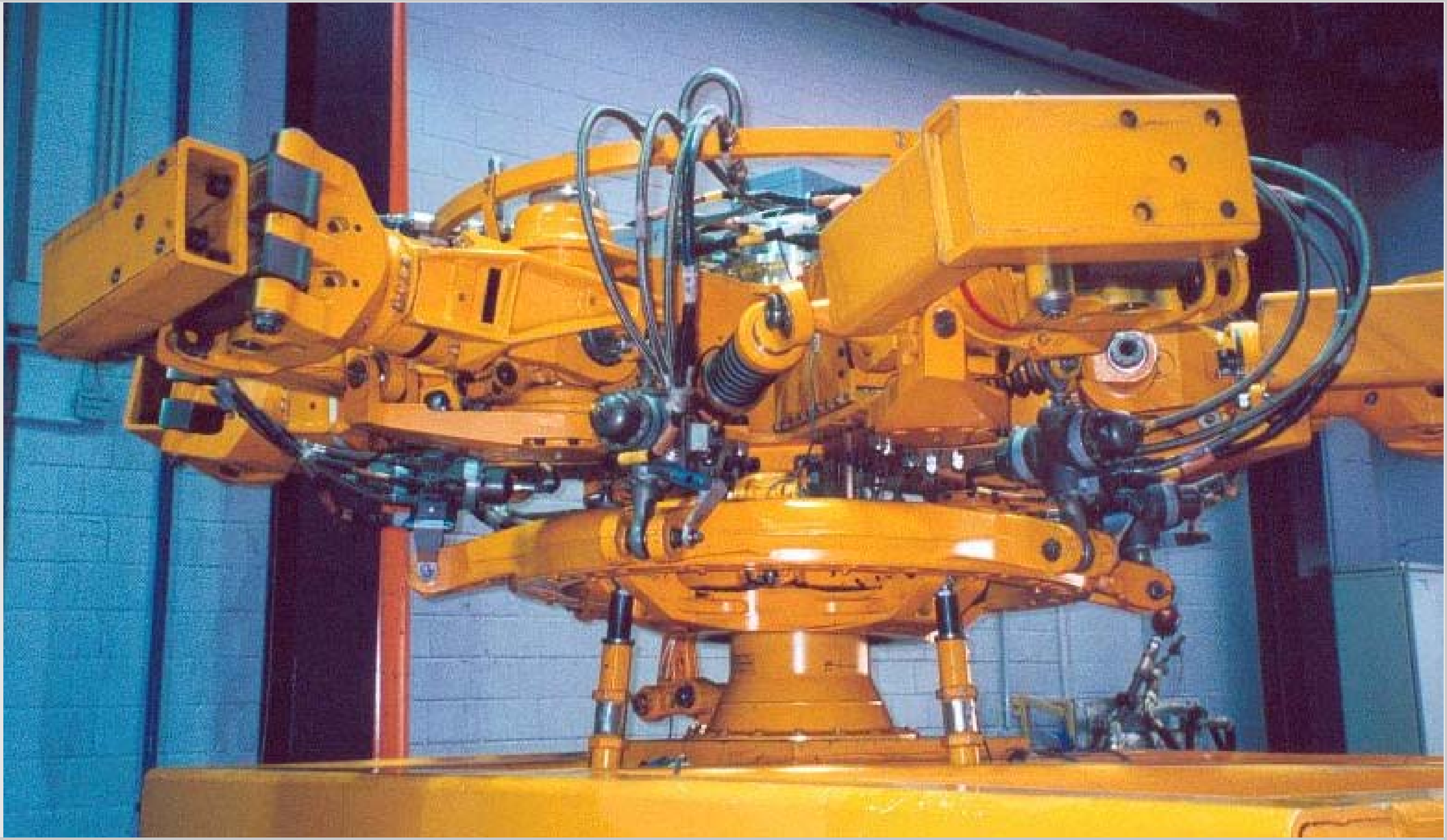
* Shaft angles adjusted up to ±0.5° to maintain rotor trim.

Large Wind Tunnel at NASA Ames Research Center

Testbed BO-105 S1 with IBC System

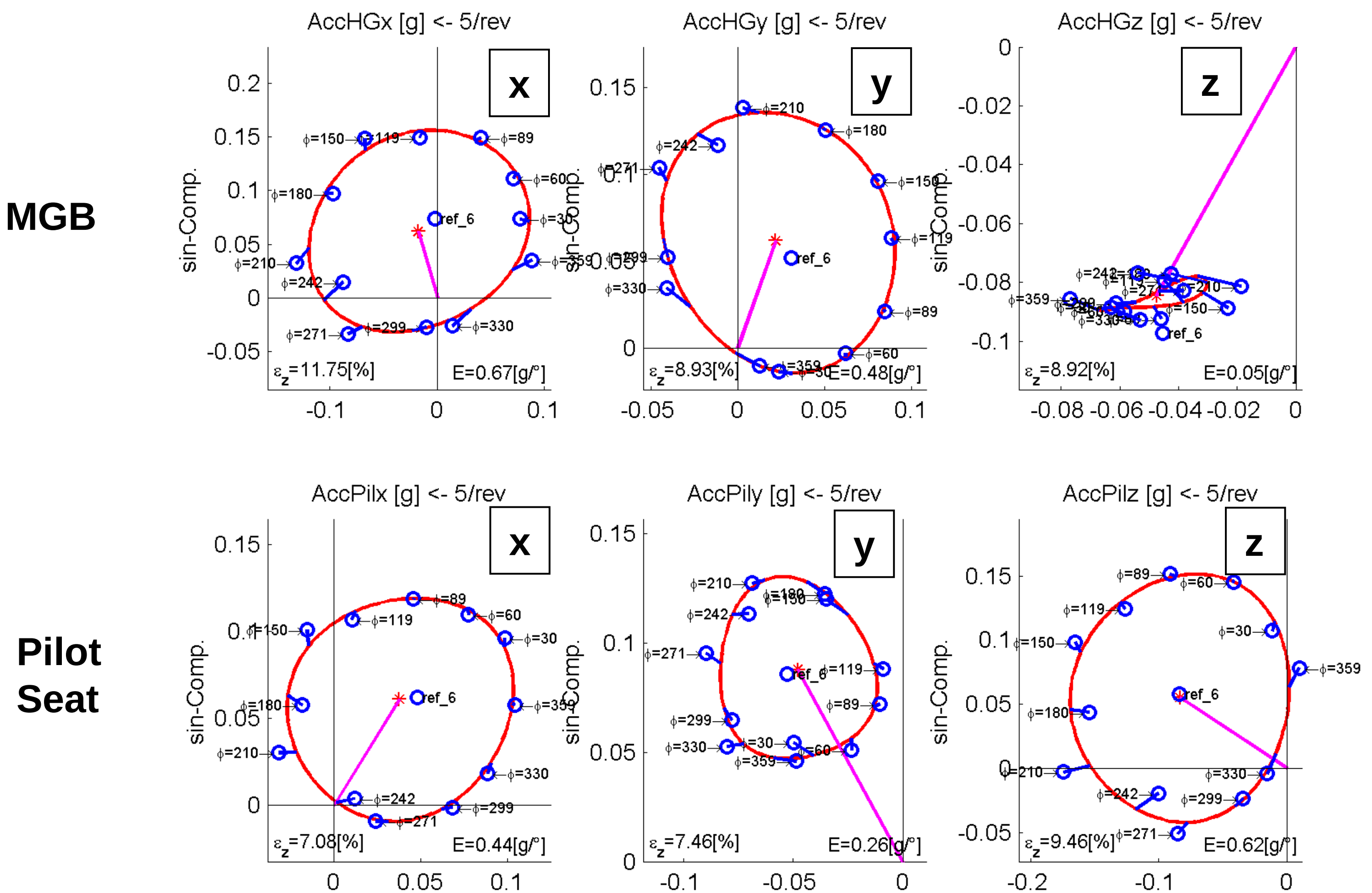
IBC Testbed CH-53G 84+02 Operated by WTD 61

Dynamic Components with IBC Mock-Up

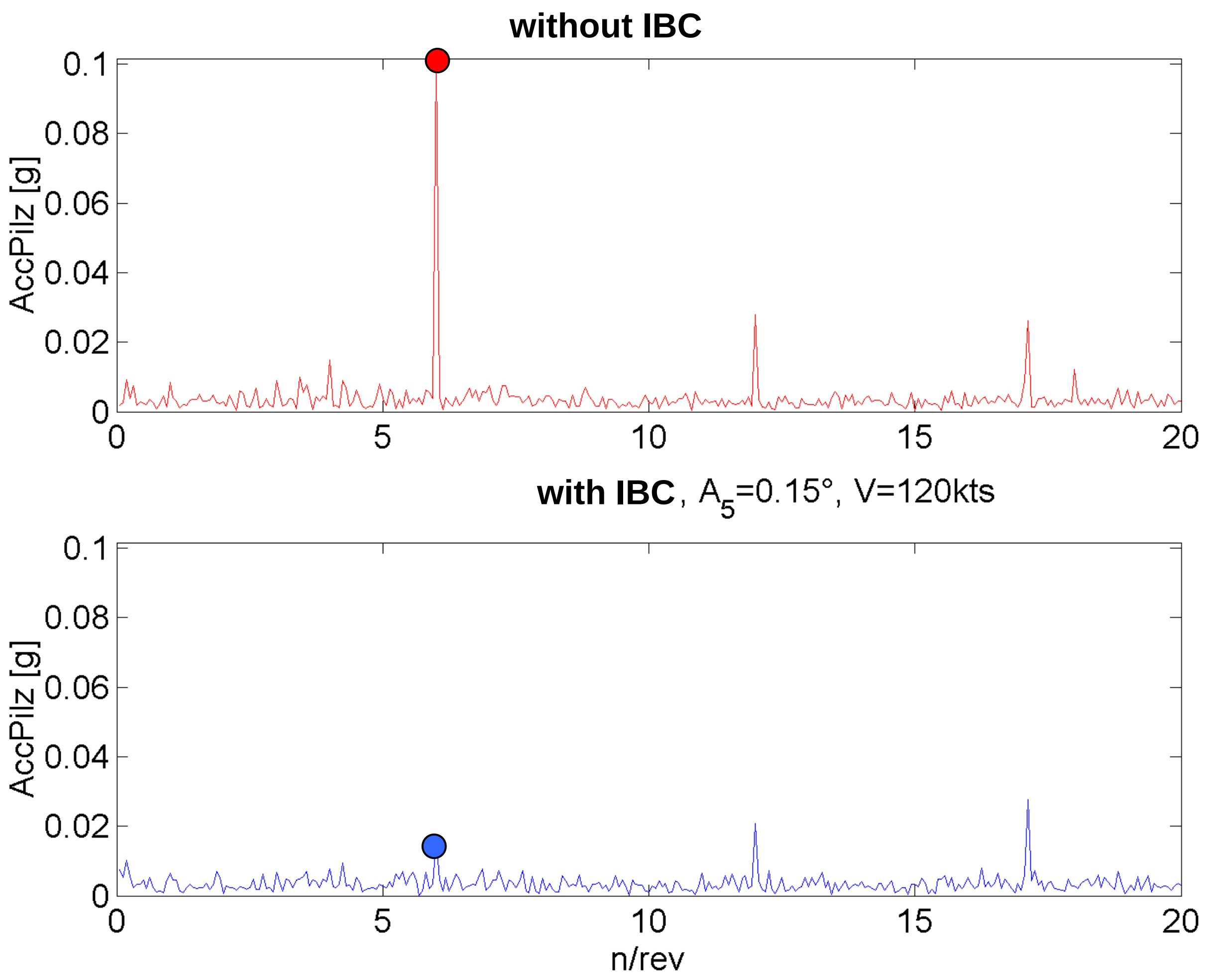


IBC Data Processing and Control Computer (ZFL) and Data Gathering System (WTD 61)

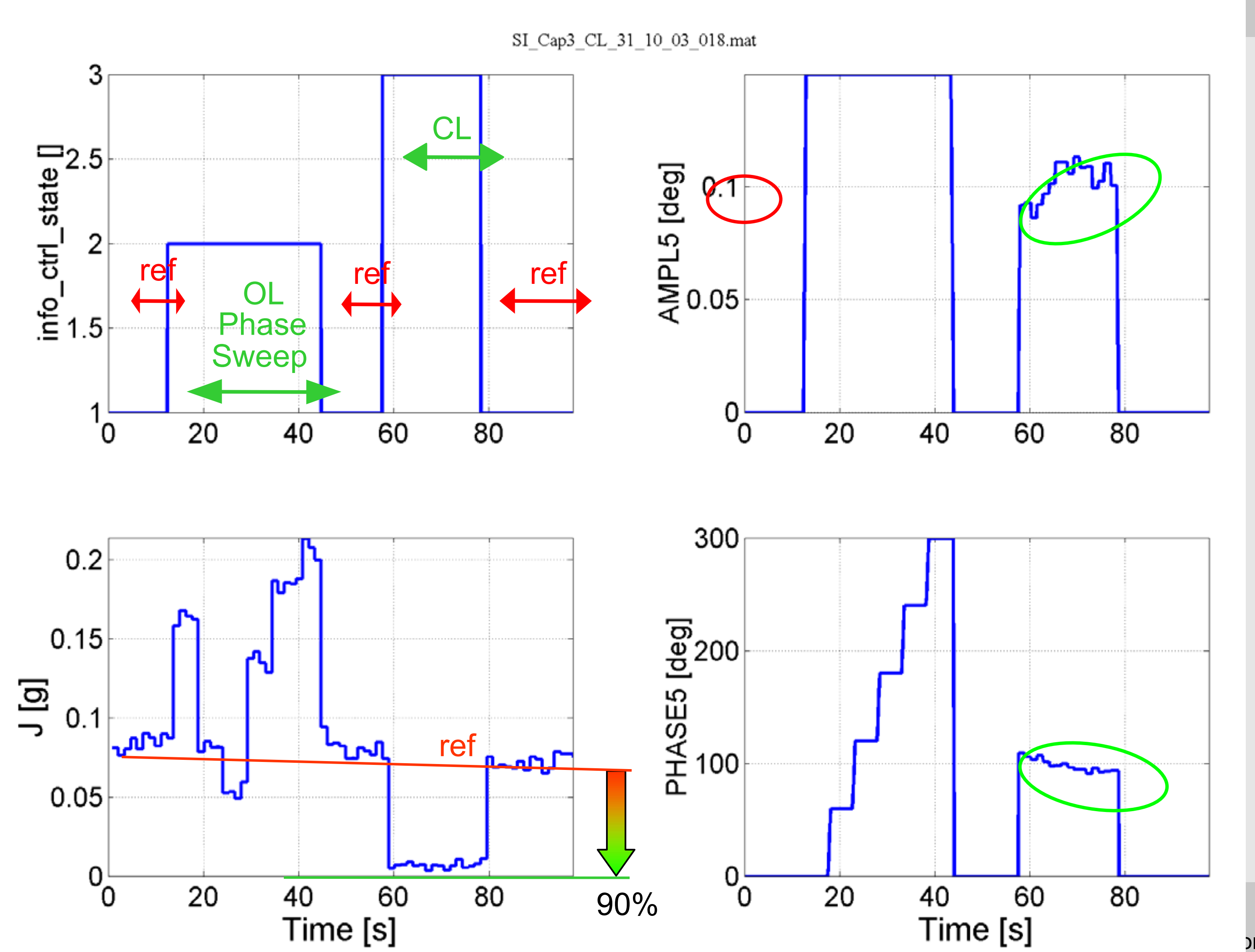
Effect of 0.15deg 5/rev IBC on 6/rev Accelerations at Main Gear Box and Pilot Seat @120kts



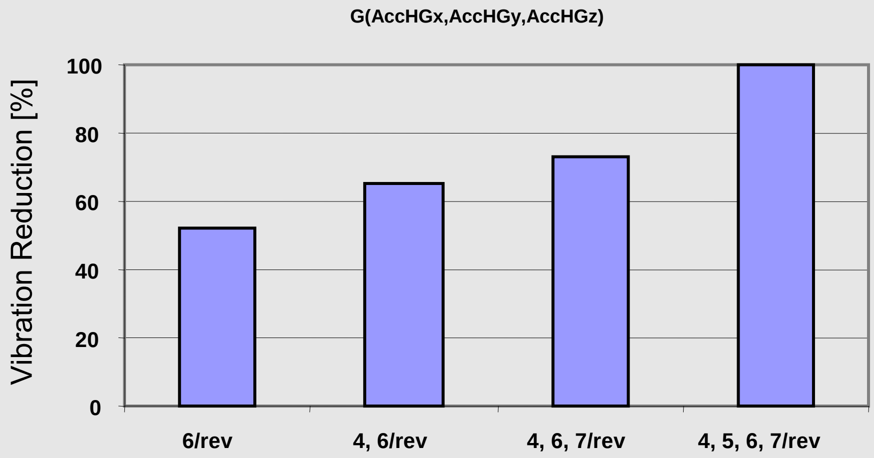
Effect of 0.15deg 5/rev IBC on z-Vibration Spectrum at Pilot Seat @120kts



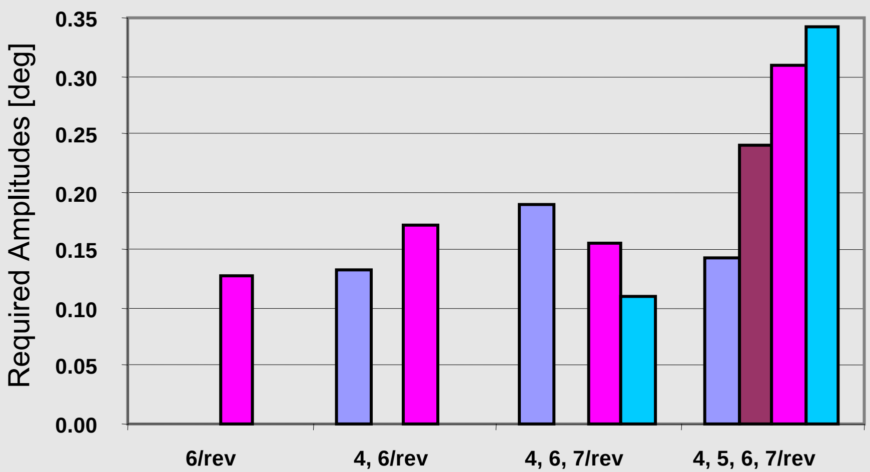
C.L. Test Sequence @70kts, Single Mode 5/rev IBC
Controlled Variable: 6/rev AccPilz



Predicted Multi Harmonic Vibration Reduction at Main Gear Box Based on Single Harmonic Flight Test Data (0.15deg IBC at 90kts)

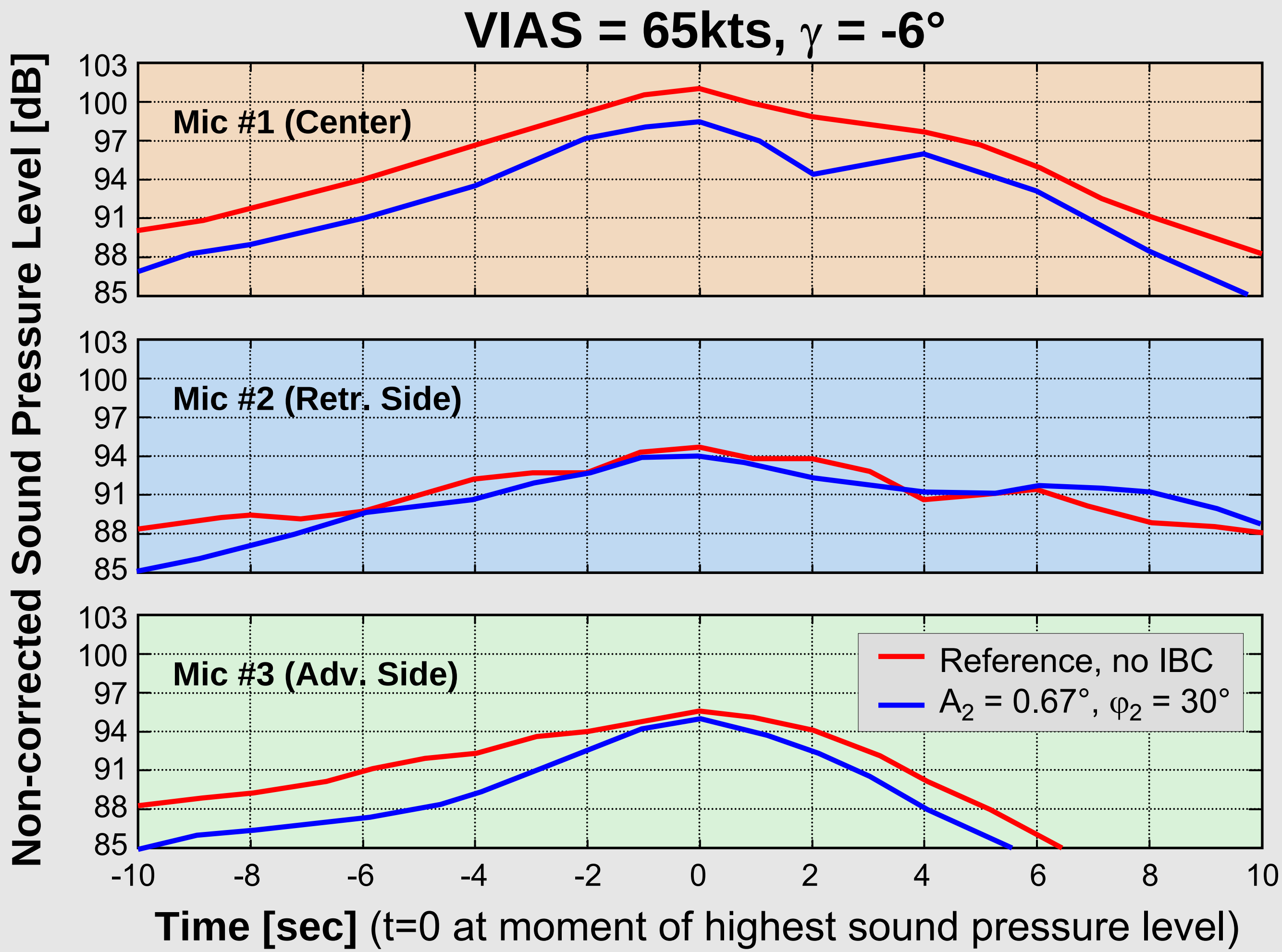


Numerically Predicted 6/rev Vibration Reduction at Main Gear Box (All Three Axes) Due to Different IBC Frequency Combinations

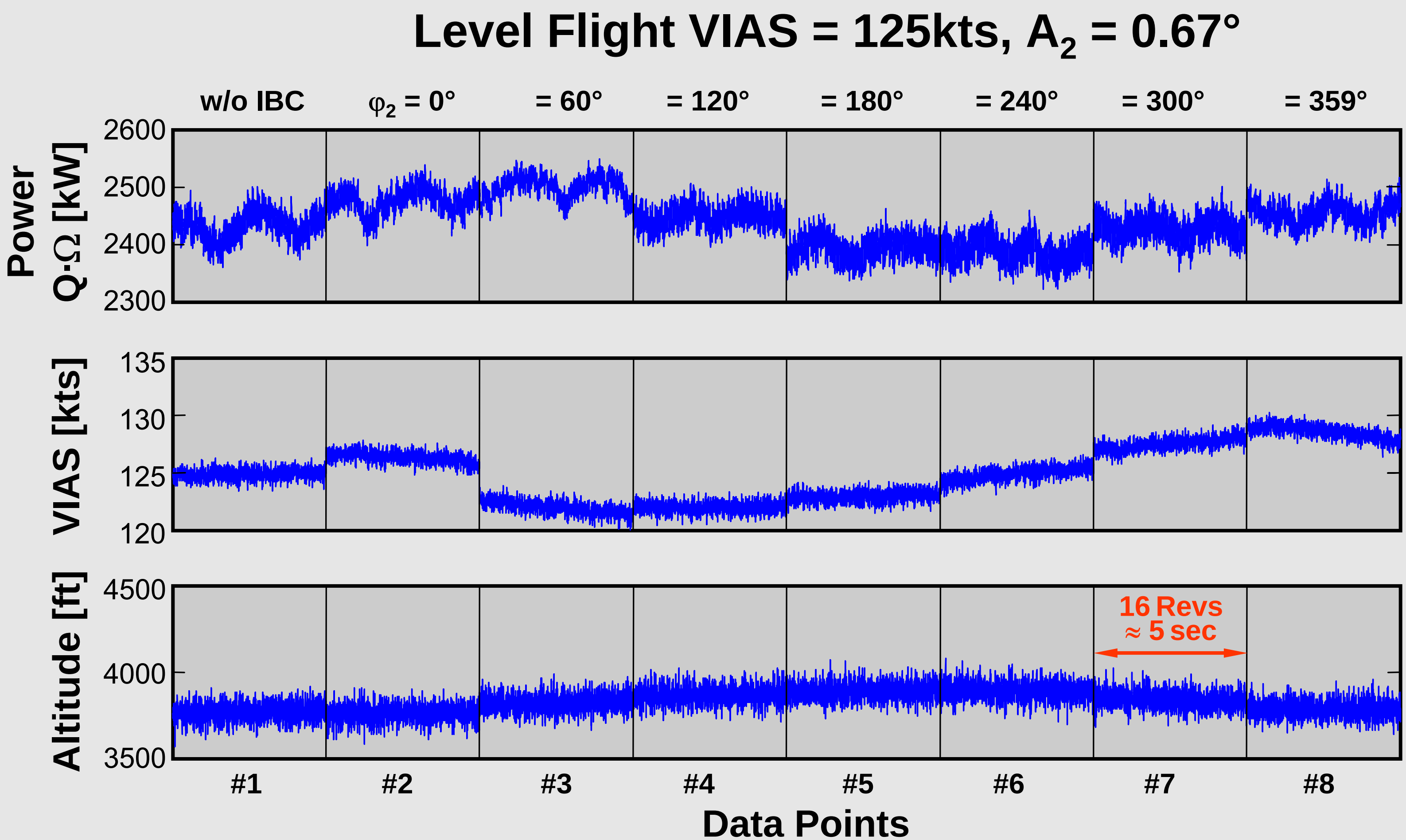


Corresponding Amplitudes Required

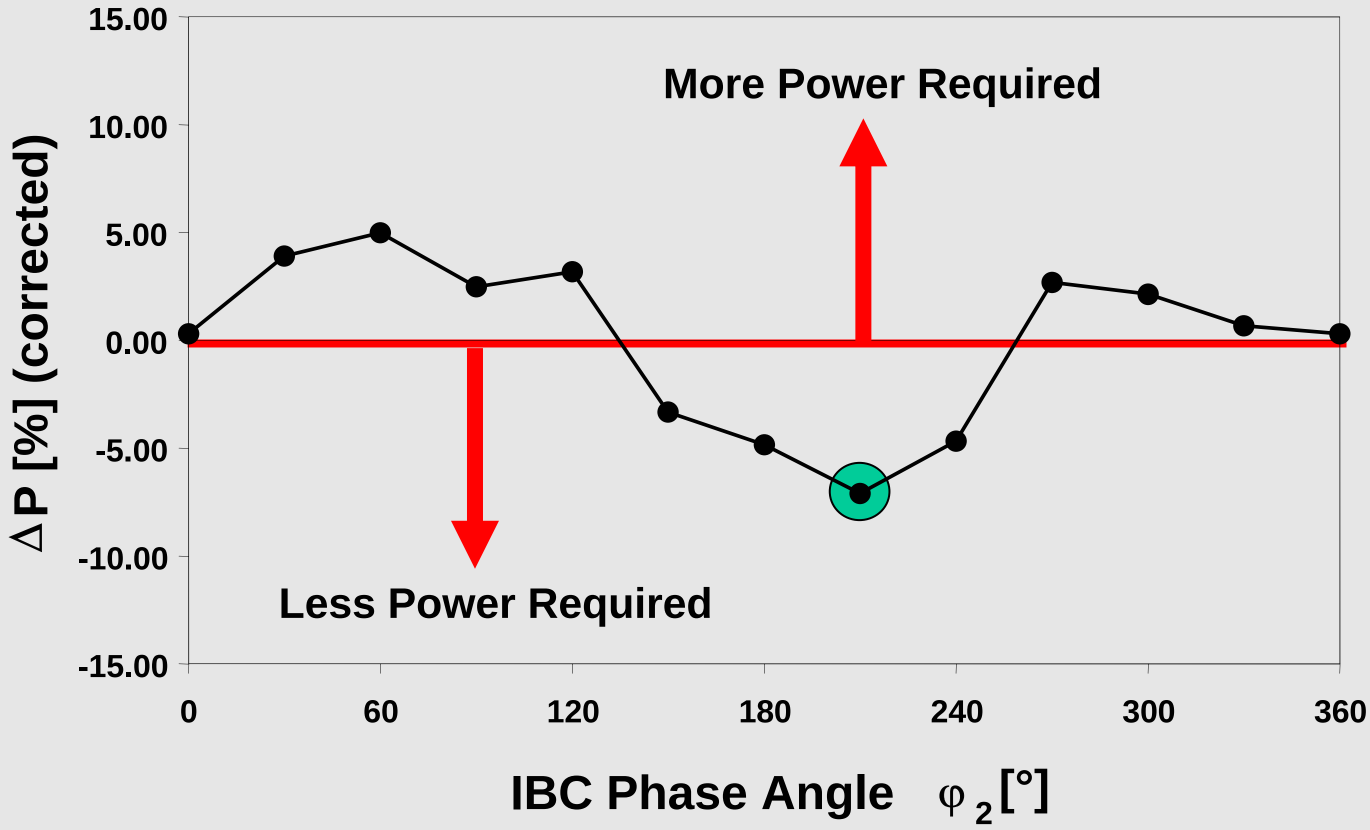
Noise Reduction Due to 2/rev 0.66deg IBC at Three Microphones (65kts, -6deg, Optimum IBC Phase)



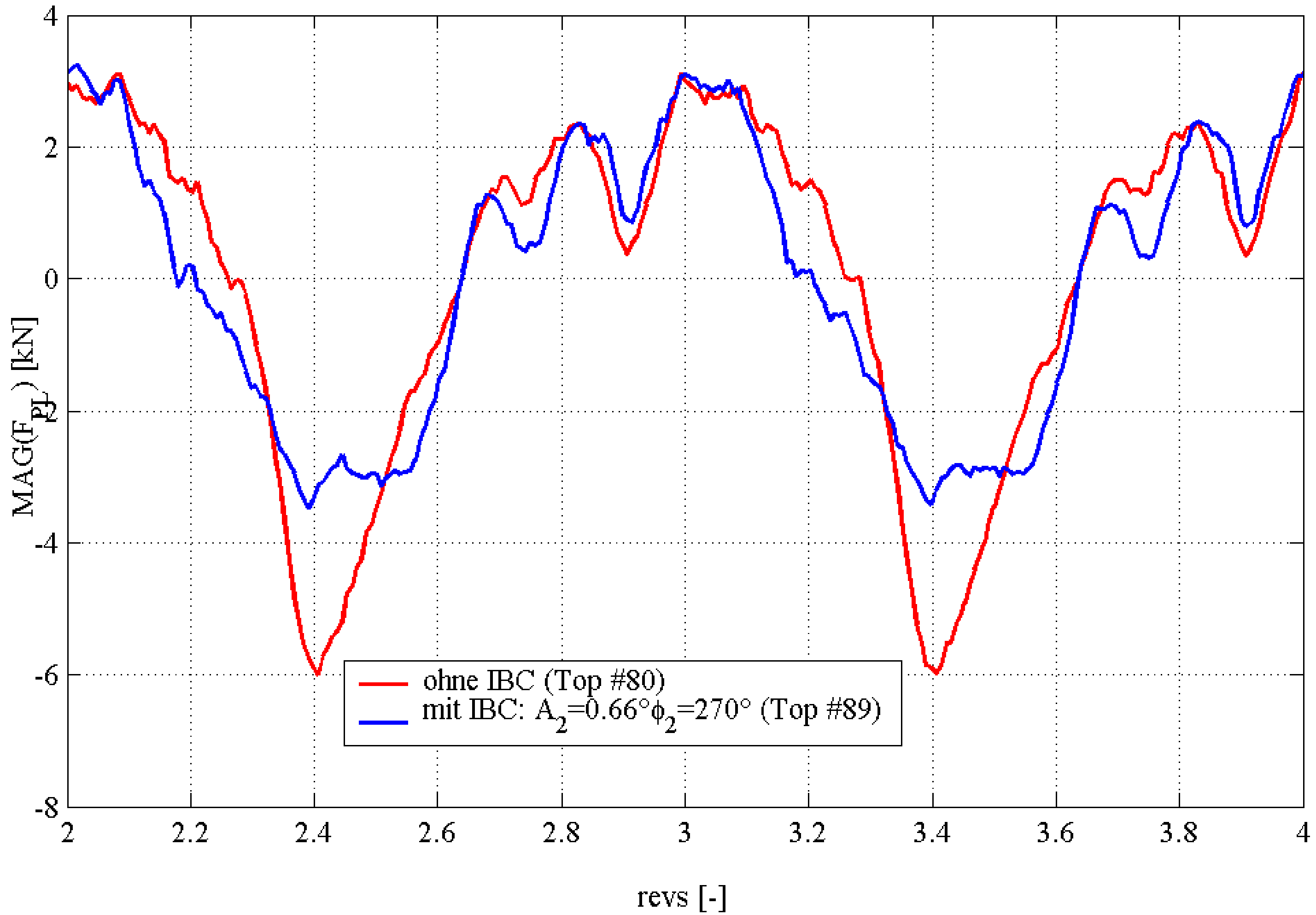
Flight Performance Relevant Parameters During 2/rev IBC Phase Sweep



Effect of 2/rev 0.66deg IBC on Power Required (125kts, Net Effect, Corrected by Speed, Accel. and Heave Effects)



Reduction of Pitch Link / Actuator Load by Application of Optimum Phase 2/rev IBC (A_2 = 0.66° φ_2 = 270°)



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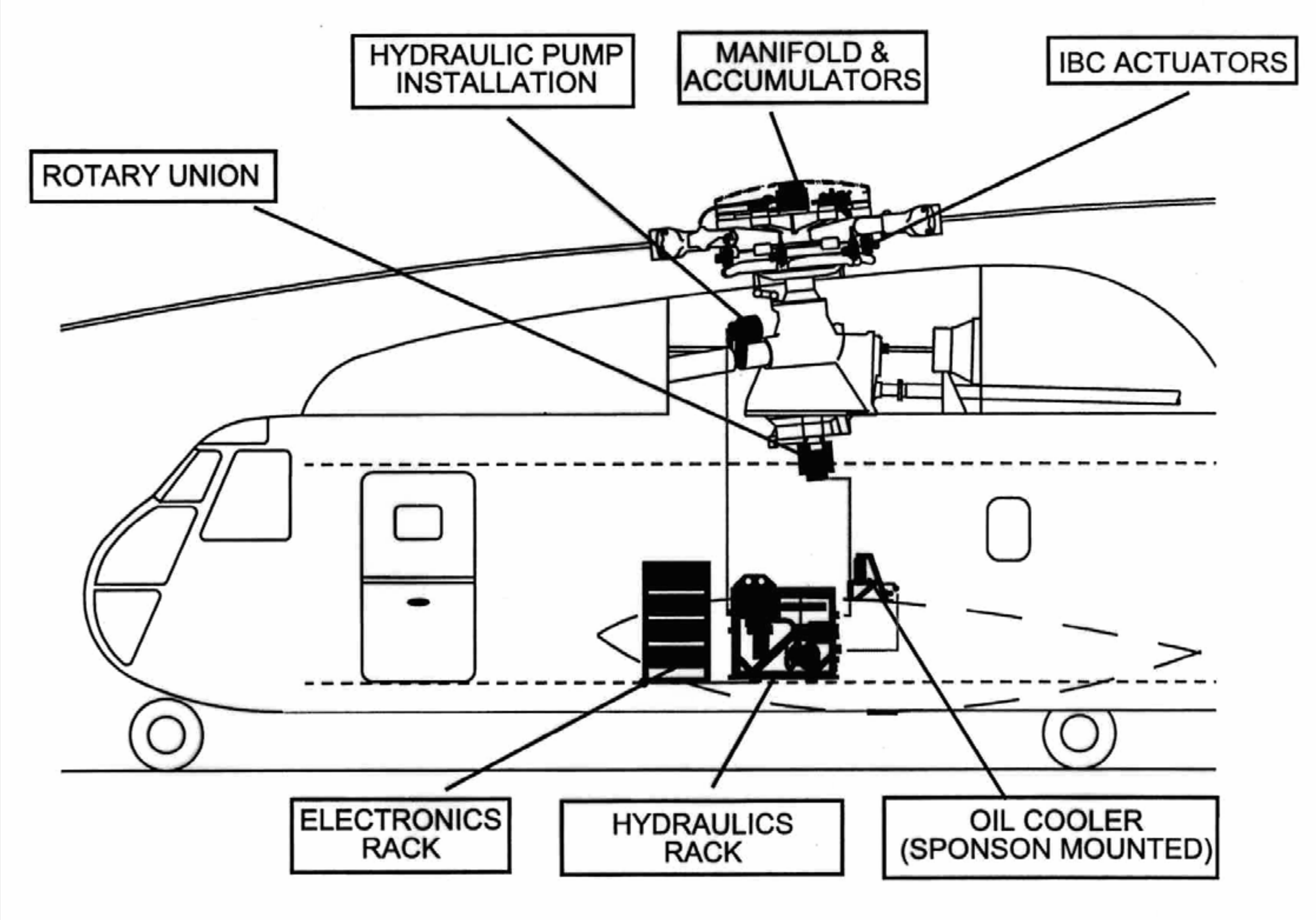
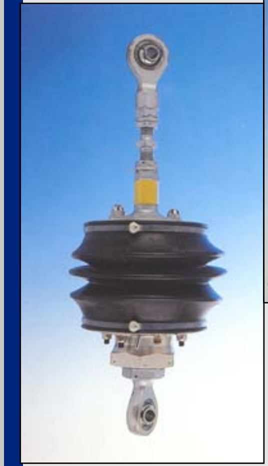
Integration of IBC-System into CH-53G Testbed



ZFL´s IBC Actuator Evolution

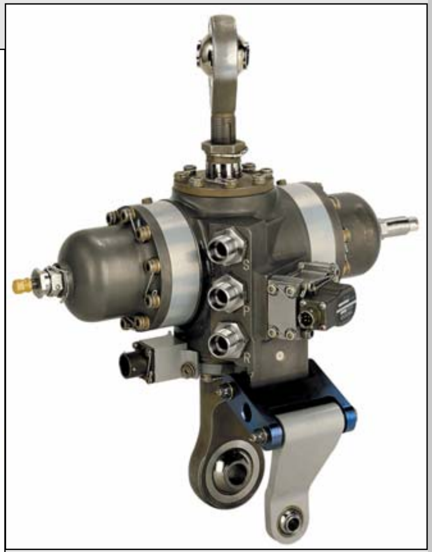
TSS



BO 105 F/T

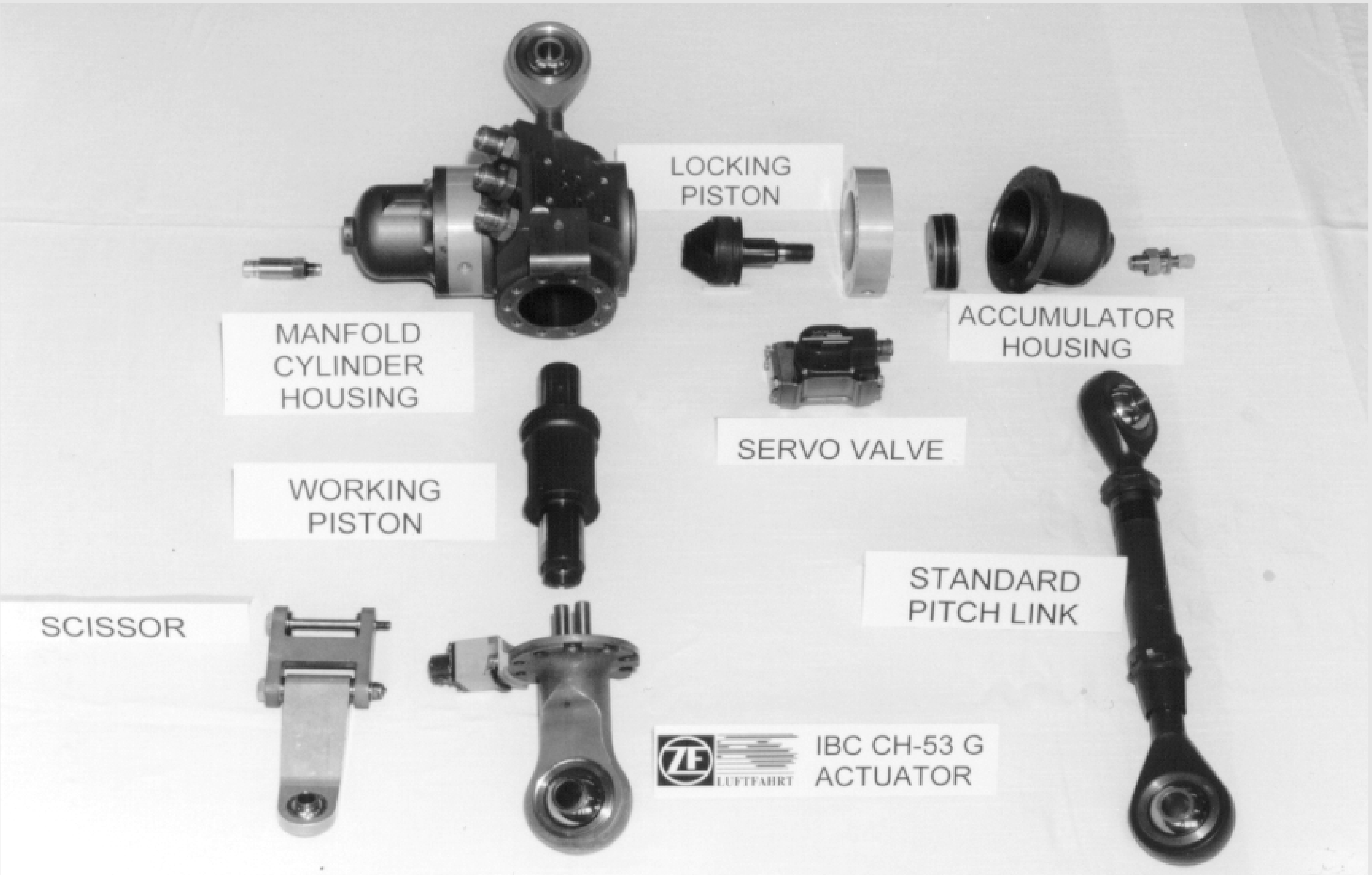
BO 105 WT/T

UH-60A WT/T

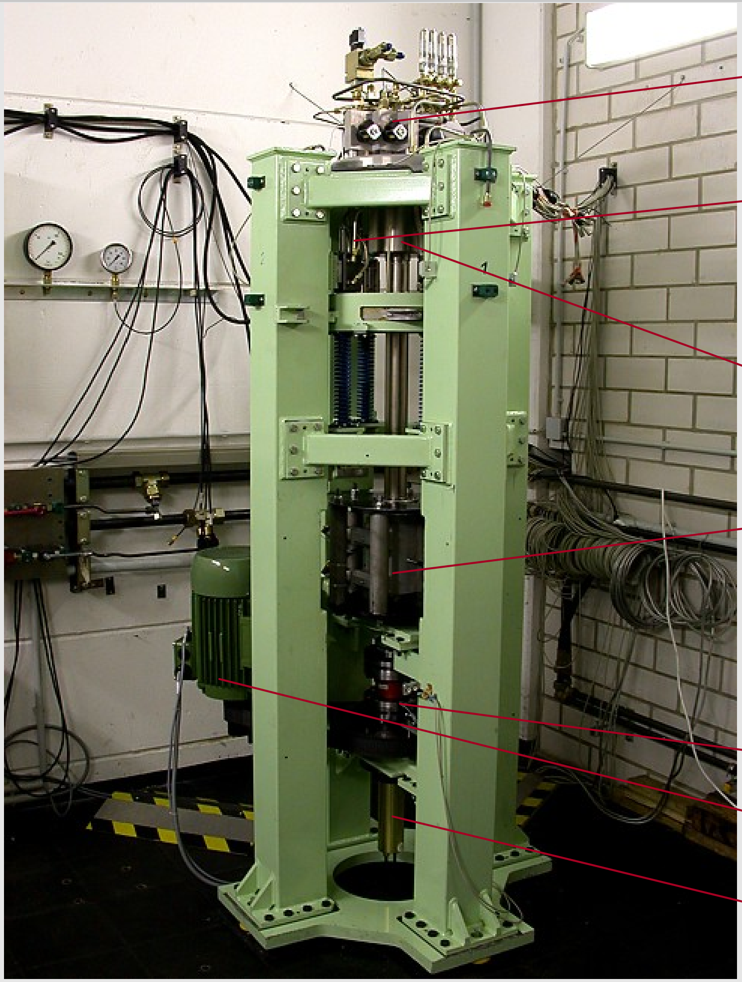


CH-53G F/T

CH-53G IBC Experimental System
Actuator Design



IDS IBC DC test bench with reversed kinematics non rotating ↔ rotating



hydraulic manifold

4 IBC actuators

IBC DC pump

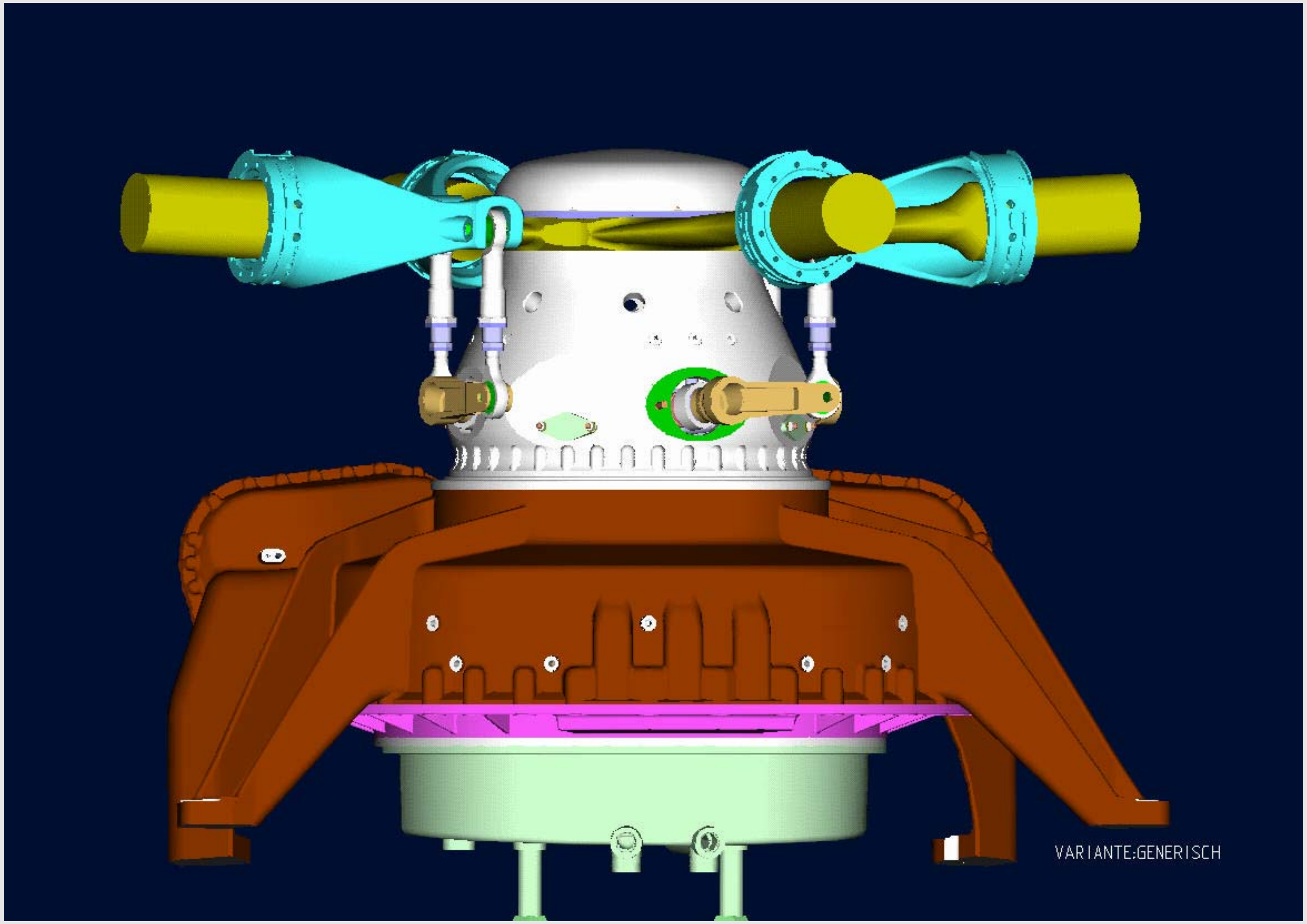
pump control unit
in drive cage

torque/speed sensor

11 kW electrical drive

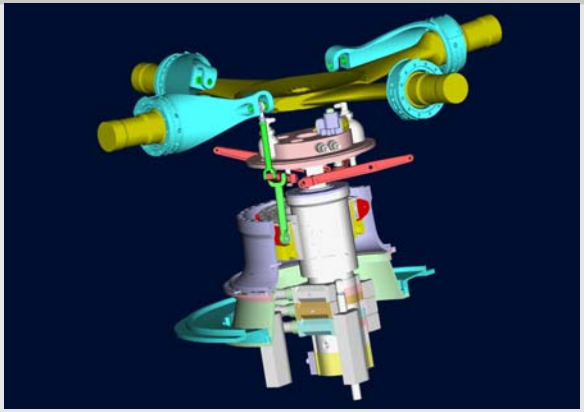
electrical slip ring

Adaptation of Existing IDS to Lynx Rotor Hub



InHuS: Innovative Integrated Primary and Individual Blade Control System for Helicopters

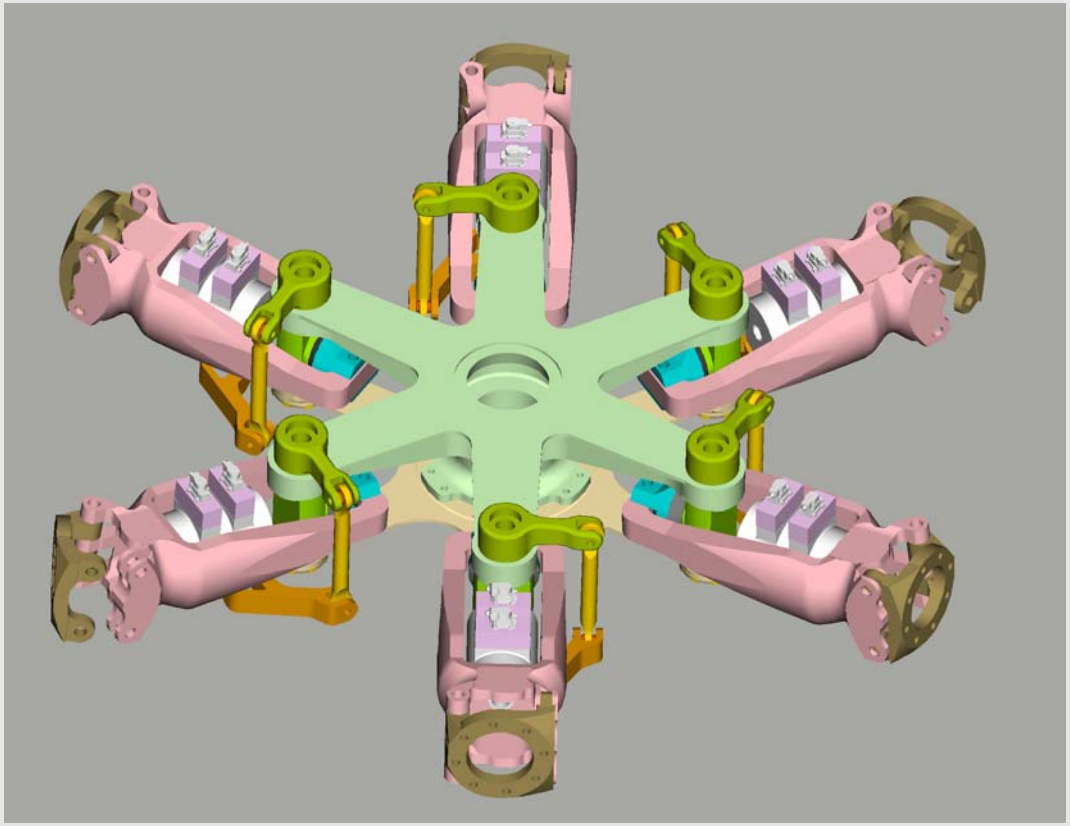
IDS:
Integration of Both Primary Control <u>and</u> IBC into Gearbox/Rotorhub



InHuS:
Control System in the Rotating Frame at Blade Root, Combining Both Primary Control and IBC Using <u>One</u> Actuation System

IBC:
Hydraulic and Electrical Individual Blade Control Systems with High Bandwidth but Low Authority

InHuS: Innovative Integrated Primary and Individual Blade Control System for Helicopters (preliminary design)



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- **Overview**
- **History / Configuration and Performance of a Helicopter**
- **Main Rotor / Main Rotor Control Design**
- **Problems of the Main Rotor**
  - **Aerodynamics**
  - **Vibrations**
  - **Noise**
- **Individual Blade Control (IBC)**
  - **Principle of Operation**
  - **Effects in Wind Tunnel and Flight Tests**
  - **IBC System Design**
- **Conclusion and Outlook**

Conclusion

- **Helicopter versatile aircraft**
- **Complex aerodynamics of main rotor in forward flight causes performance restrictions**
- **advanced main rotor blade control can reduce vibation & noise and extend flight envelope**
- **extensive research work on IBC effects has been done**
- **world-wide development activites of the helicopter industry in the field of application to production helicopters**