Presented to:

DARPA
Mission Adaptive Rotor
Industry Day

RDECOM

Rotor Performance and Mission Benefits of Active Rotor Controls

AMRDEC
STRENGTH THROUGH TECHNOLOGY

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Dr. Hyeonsoo Yeo

Aeroflightdynamics Directorate (AMRDEC)
U.S. Army Research, Development, and Engineering Command
Ames Research Center, Moffett Field, California

March 3, 2009

Approved for public release; distribution unlimited. Review completed by the AMRDEC Public Affairs Office; March 2, 2009; FN3869.

Introduction

- Evaluated the capability of active controls for rotor performance improvements and assessed its impact on aircraft design

- Active Controls
  - Leading edge slat
  - Oscillatory jet
  - Variable droop leading edge
  - Gurney flap
  - Trailing edge flap
  - Active twist
  - Individual blade pitch control

- Rotor performance analysis using CAMRAD II
  - Thrust sweep at 80 and 150 knots, 4k/95^{o}F
  - Speed sweep at C_T/σ = 0.075, 4k/95^{o}F

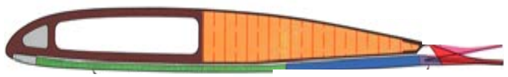
- Aircraft design study using NDARC (NASA Design and Analysis of Rotorcraft)

Active Rotor Concepts

Leading edge slat

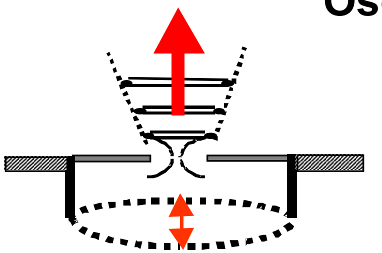
Variable droop leading edge

Trailing edge flap

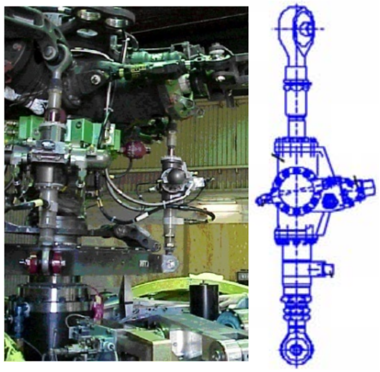


Gurney flap

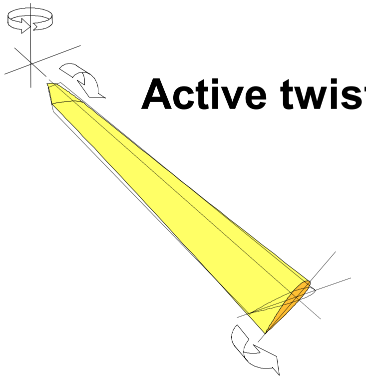
Oscillatory Jet



These concepts change airfoil section cl, cd, cm values.



Individual blade pitch control



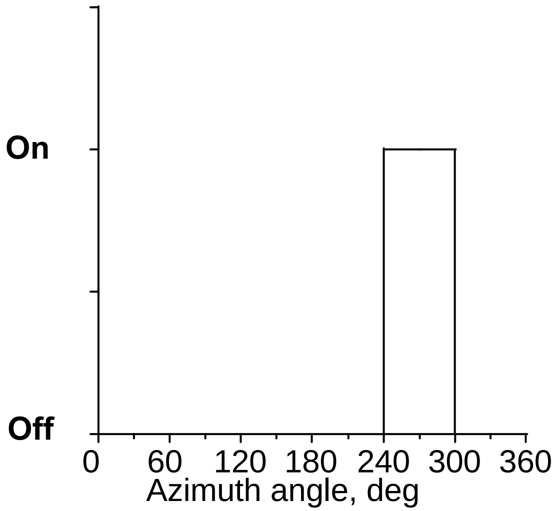
Active twist

These concepts change blade root pitch or twist.

Active Control Scheme

- Harmonic Control
  - Trailing edge flap: 1/rev, 2/rev
  - Active twist: 1/rev, 2/rev
  - Individual blade pitch control: 2/rev

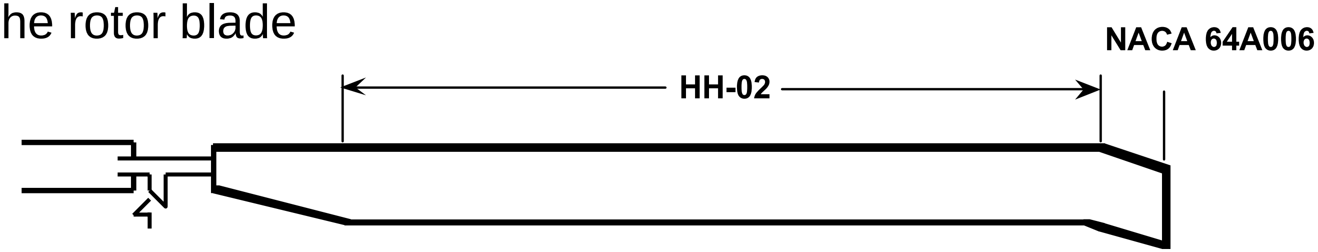
- Discrete Control
  - Leading edge slat, Oscillatory jet, Variable droop leading edge, Gurney flap
  - Activated over a segment of azimuth



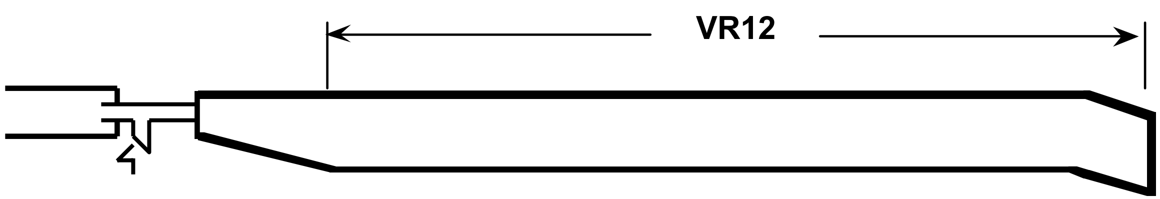
- Radial Variation
  - Leading edge slat, Oscillatory jet, Variable droop leading edge, Gurney flap, Trailing edge flap

Rotor Models

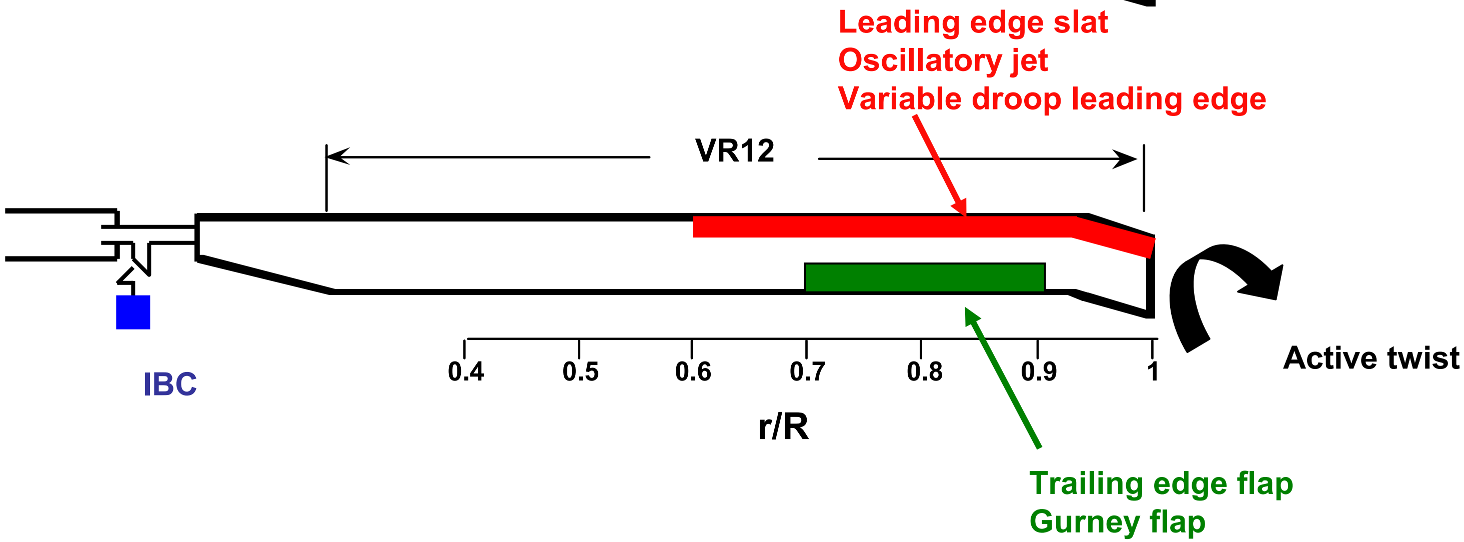
Baseline Apache rotor blade



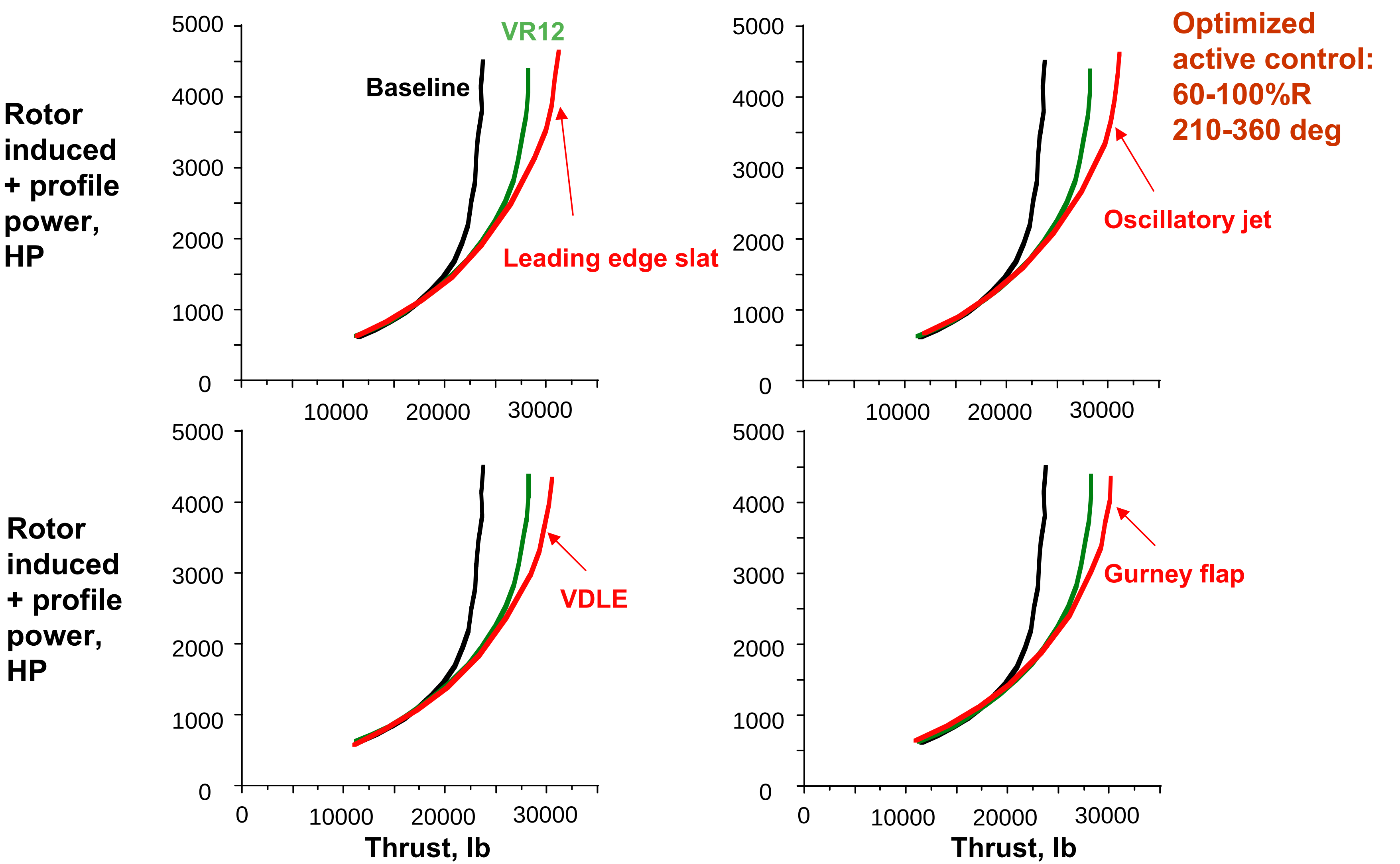
Baseline with VR12 Airfoil



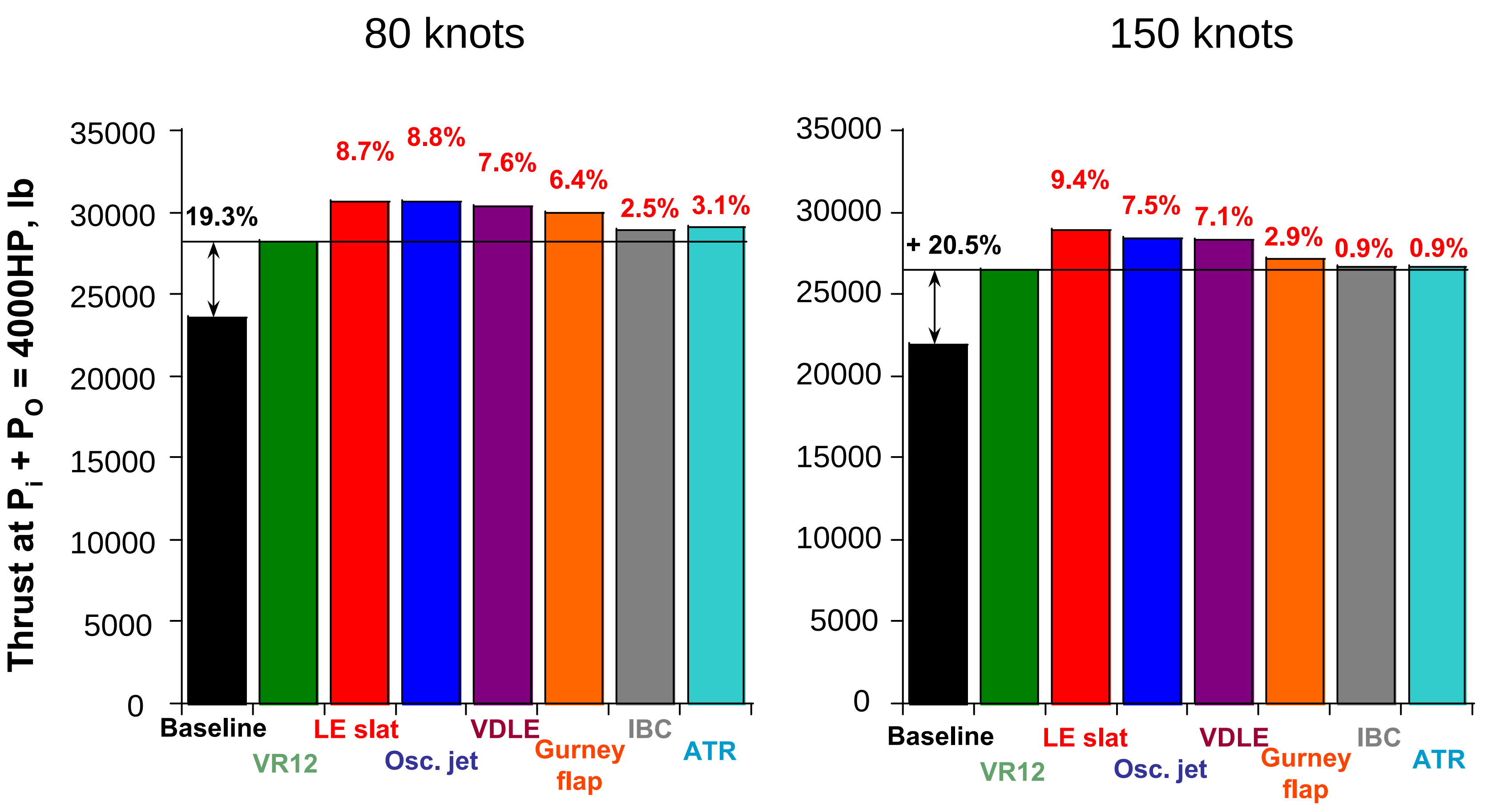
Active controls



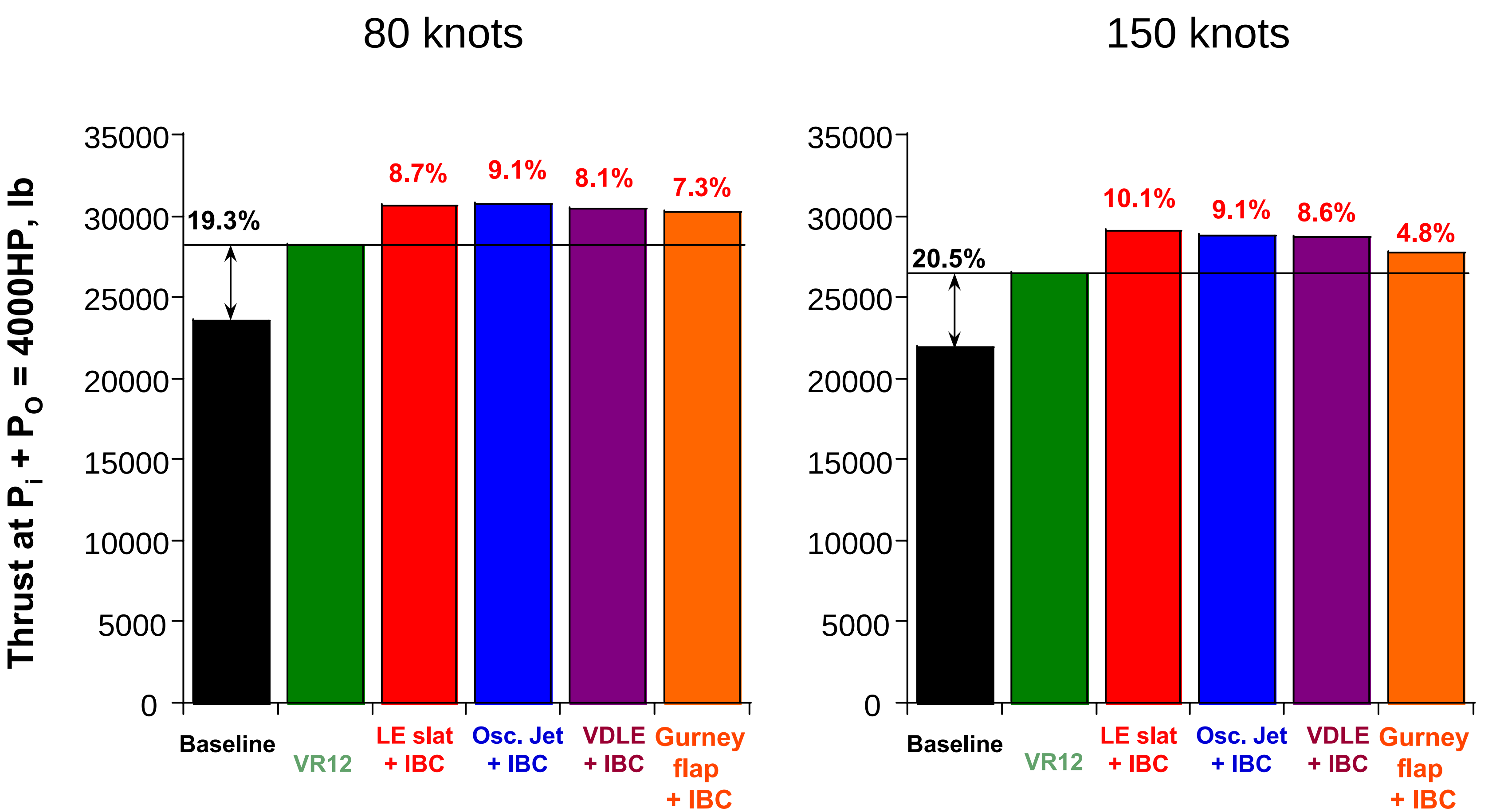
Blade Loading at 80 knots



Max. Blade Loading Improvement

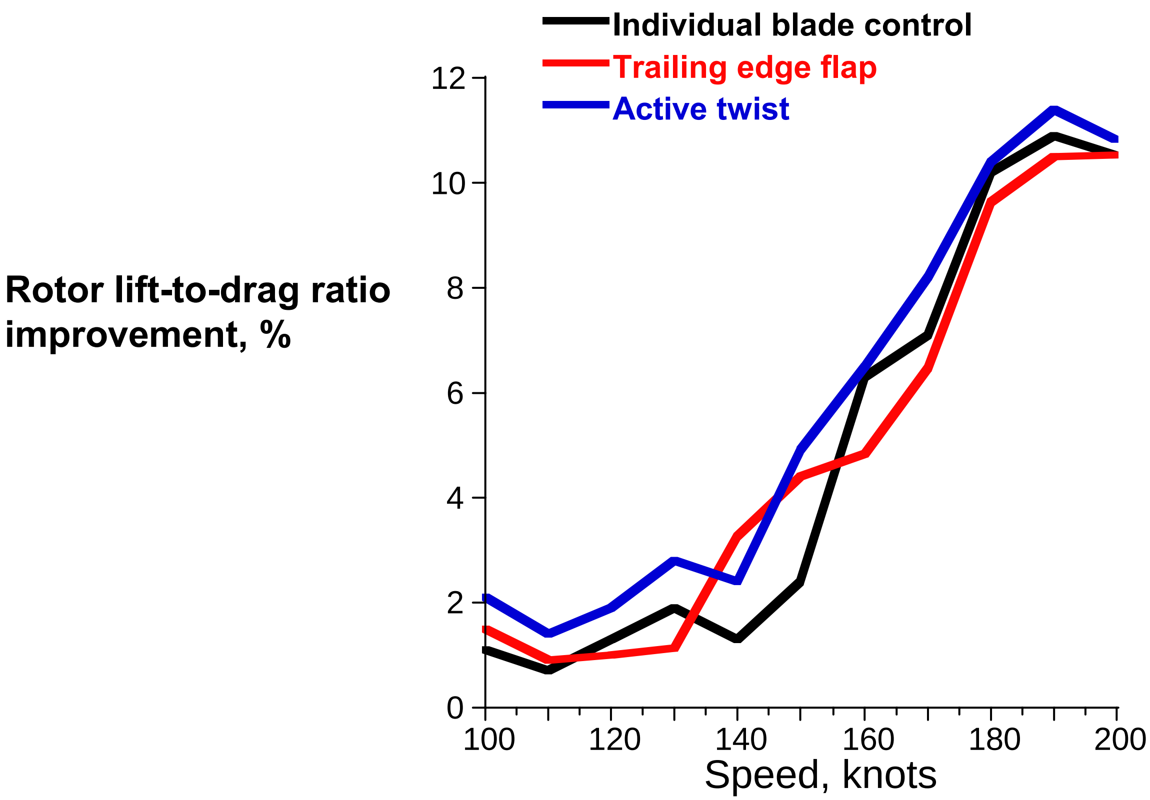


Max. Blade Loading Improvement (Multiple Controls)



Aero Efficiency Improvement

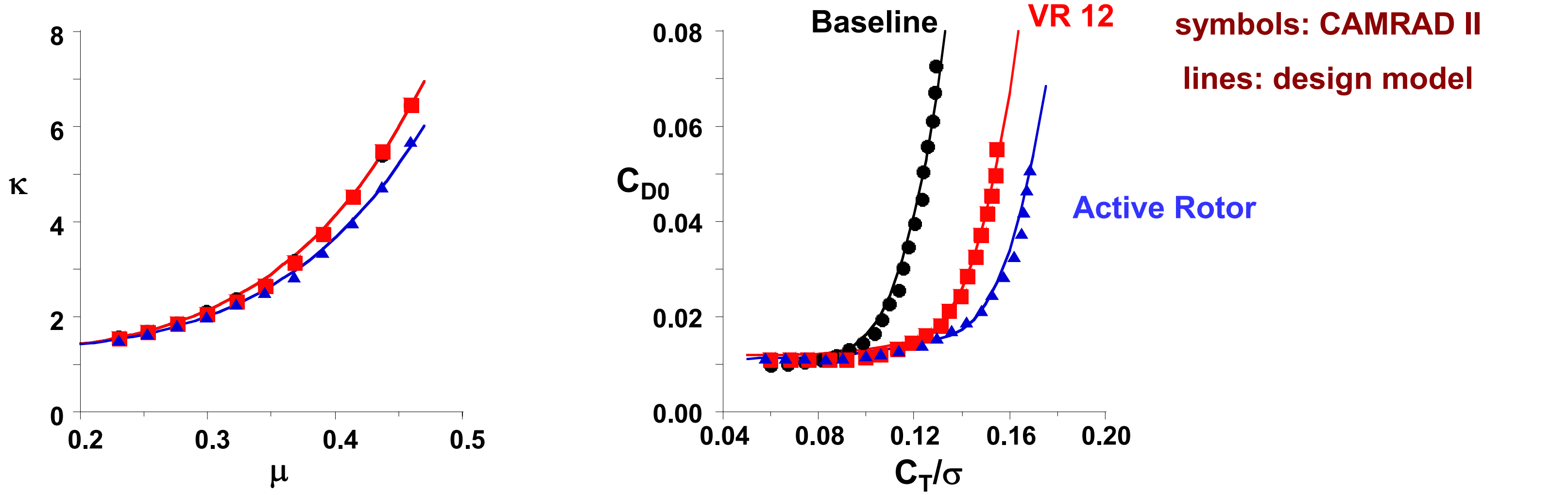
$C_T/\sigma = 0.075$



Control input	IBC	Trailing edge flap	Active twist
Low speed	1 deg cos (2ψ–210)	1 deg cos (2ψ)	1 deg cos (2ψ–210)
High speed	2 deg cos (2ψ–210)	4 deg cos (2ψ–30)	3 deg cos (2ψ–210)

Aircraft Design Analysis

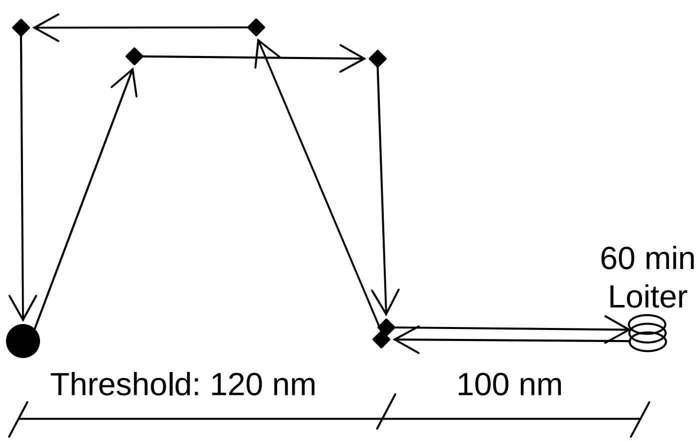
- Design single main rotor and tail rotor helicopter, to illustrate potential impact of active control in rotor performance improvement
  - Three designs: baseline, baseline with VR12, and active rotor technologies
- Design code rotor performance model calibrated to comprehensive analysis results for induced power ($\kappa=P_i/P_{ideal}$) and profile power (mean drag cd0)



- Sized aircraft for single mission using NDARC (NASA Design and Analysis of Rotorcraft)

Attack/Recon Profile

	Segment	Time	Distance	Speed	Atmosphere		Payload		Power	
					Alt	Temp	Wt	Δsq-ft	Eng. Spec	Margin
1	Warm-up	5 min			4k ft	95.0 ºF	3400 lb	10.0	100% IRP	
2	VTO	1 min		HOGE	4k ft	95.0 ºF	3400 lb	10.0	100% MRP	500 fpm VROC
3	Climb		Credit to 4	V_{CL}	ISA		3400 lb	10.0	100% IRP	
4	Cruise		120 nm	V_{BR}	Best	ISA	3400 lb	10.0	100% MCP	
5	Descent	No Fuel Burn Credit			ISA		3400 lb	10.0	100% MCP	
6	Ingress		100 nm	V_P	4k ft	95.0 ºF	3400 lb	10.0	90% MCP	
7	Loiter (Quiet Mode)	60 min		V_{BE}	4k ft	95.0 ºF	3400 lb	10.0	100% MCP	
8	Egress		100 nm	V_P	4k ft	95.0 ºF	0 lb	0.0	90% MCP	
9	Climb		Credit to 10	V_{CL}	ISA		0 lb	0.0	100% IRP	
10	Cruise		120 nm	V_{BR}	Best	ISA	0 lb	0.0	100% MCP	
11	Reserve (c)	20 min		V_{BR}	4k ft	95.0 ºF	0 lb	0.0	100% MCP	



V_{BR} – 99% Best Range Speed
V_P – Penetration Speed (90% MCP)
Loiter in Configuration for Minimum Acoustic Signature
Drop Ordinance at End of Loiter Segment

RDECOM

Aircraft Design Comparison

AMRDEC
STRENGTH THROUGH TECHNOLOGY

	Baseline	Baseline rotor with VR12	Active Rotor
Design C_W/σ	0.08	0.096	0.106
Design Gross Weight, lb	25284	22214	20994
Weight Empty, lb	15807	13420	12524
Rotor Weight, lb	2700	1977	1700
Installed Power, HP	2x2793	2x2429	2x2311
Disk Loading	8.1	8.1	8.1
Rotor Radius, ft	31.5	29.6	28.7
$V_{BR,}$ knots	126	130	135
$V_{P,}$ knots	142	142	145

Concluding Remarks

- Leading edge slat, variable droop leading edge, oscillatory jet, Gurney flap
  - Effective for increase of maximum blade loading when used over the retreating side
- Individual blade control, active twist, trailing edge flap
  - Effective for increase of rotor lift-to-drag ratio at $C_T/\sigma = 0.075$ with 2/rev harmonic control
- Integration of active rotor technology with airfoil design has potential for a significant performance improvement.