“Rotorcraft – Back to the Future”
A Discussion of the Past, Present, and Future of Rotorcraft

Presented by:

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Steve Glusman
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AHS Dinner Presentation
March 8, 2011 Towne House Restaurant, Media, PA
AIE Military Rotorcraft Conference
June 7, 2011 Washington, DC

Hal Rosenstein
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June 27, 2011 Munich, Germany
V/STOL Aircraft and Propulsion Concepts

- We have done it all before
- Except for helicopters, only a handful of V/STOL concepts have reached production
## Competition Decreasing -- Derivative Modifications Increasing

### Impact of increasing cost and complexity

### Impact of budget constraints

### New Starts

<table>
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<tr>
<th>1960s</th>
<th>1970s</th>
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<tbody>
<tr>
<td>CH-46D/F</td>
<td>CH-46E</td>
<td>OH-58D</td>
<td>CH-47F</td>
<td>VH-71A</td>
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<td>CH-47B/C</td>
<td>CH-53E</td>
<td>UH-60L</td>
<td>UH-1Y</td>
<td>ARH-70A</td>
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<td>CH-53D</td>
<td>CH-47D</td>
<td>MH-47E</td>
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<td>MH-60K</td>
<td>AH-64D</td>
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### Derivative Modifications

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<tr>
<td>XC-142A*</td>
<td>CH-46A</td>
<td>XH-59A*</td>
<td>CH-53A</td>
<td>CH-47D*</td>
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<td>CH-47A</td>
<td>XV-15*</td>
<td>AH-1*</td>
<td>MH-60K*</td>
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<td>UH-60M</td>
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### Program Cancelled
- COTS Commercial Off-The-Shelf
- Technology Demonstrator or Prototype

**Note:**
- X indicates cancellation.
- * indicates technology demonstrator or prototype.

**Date:** 11/24/2012
U.S. Jet Fighter vs. Rotorcraft Generations

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<td>4th Gen Fighters</td>
<td>5th Gen Fighters</td>
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- **1st Gen Rotorcraft**
  - Subsonic
  - Guns
  - No radar

- **2nd Gen Rotorcraft**
  - Supersonic
  - Radar
  - Air-air missiles

- **3rd Gen Rotorcraft**
  - Maneuverability
  - Adv. weapons integration
  - Survivability

- **4th Gen Fighters**
  - Maneuverability
  - Look down, shoot down capability

- **5th Gen Fighters**
  - Stealth
  - Fly-by-wire
  - Net centric
  - Thrust vectoring

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- **5th Gen Fighters**
  - Stealth
  - Fly-by-wire
  - Net centric
  - Thrust vectoring

- **1st Gen Rotorcraft**
  - Piston engine
  - Wood blades
  - Vc < 90kts

- **2nd Gen Rotorcraft**
  - Turbine engine
  - Metal blades
  - Vc ~ 130 kts

- **3rd Gen Rotorcraft**
  - Composite blades
  - Survivability
  - Adv. weapons integration
  - Vc ~ 150 kts

- **4th Gen Fighters**
  - Higher speed
  - Fly-by-wire
  - Composites
  - Signature reduction
  - Vc > 170 kts

11/24/2012 12-130 | 4
50 Years of DoD Aviation Investment
1960 – 2010

RDT&E

$321 B
(FY 2011 $)

Procurement

$926 B
(FY 2011 $)

83% / 17% investment split between fixed- and rotary-wing
US Army Aviation S&T Investment

Constant 2008 Dollars (Millions)

Technology Readiness Level (TRL) = 1 to 4

Downward trend in DoD rotorcraft investment over past 20 years!
A Look at Today

There hasn’t been this much excitement in the rotorcraft industry since the 1960’s

Piasecki X-49A SpeedHawk (2007)

Sikorsky X2 Technology Demonstrator (2008)

Eurocopter X3 (2010)

Boeing/DARPA Disc Rotor
Have we made progress?

Co-Axial Compound Helicopters

Sikorsky Light Anti-Submarine Attack Vehicle – LAAV Concept (1968)

Sikorsky XH-59A Advancing Blade Concept (ABC™) (1975)

Sikorsky LHX Concept (1982)

Sikorsky X2 Technology Demonstrator (2008)
Have we made progress?

Single Rotor Compound Helicopters

Bell UH-1 Model 533 HPH III – 274.6 knots (316.0 mph) (1969)

Eurocopter X3 – 180 knots (207 mph) (2010)
Have we made progress?
Piasecki Compound Helicopters with the Vectored Thrust Ducted Propeller

Piasecki 16H-1 Pathfinder (1962)

Piasecki 16H-1A Pathfinder II (1966)

X-49A SpeedHawk (2007)
Have we made progress?

Compound Tandem Rotor Helicopters

Chinook Compound Concept (1961)

Unloaded Lift Offset Rotor – ULOR (Ongoing Design Project)

CH-46 Tandem Wing Compound (mid-1960s)

Model 347 Tandem Compound (early 1970s)
Have we made progress?

Disc Rotors

Jacob Ellehammer – first ‘Disc-Rotor Helicopter’ concept to fly (1912)

Ellehammer – Disc-Rotor wind tunnel model and test (1935)

Jonathon Caldwell – ‘Disc-Rotor Plane’ (1934)

Boeing/DARPA Disc Rotor (Ongoing Design Project)

SOURCE: 100 YEARS OF DISC-ROTOR RESEARCH - A BRIEF HISTORY, ANGELO N. COLLINS and MICHAEL J. HIRSCHBERG, Presented at the International Powered Lift Conference, October 5-7, 2010, Philadelphia, PA
Have we made progress?

**Tilt Rotors**

**Baynes “Heliplane”**
(1938)

**Platt-LePage Tilt Rotor Design**
(1940s)

**Transcendental Model 1-G**
(1954)

**Transcendental Model 2**
(1957)

**Bell XV-3**
(1955)

**Bell XV-15**
(1977)

**USMC/Bell Boeing MV-22B Osprey**
(1989)

In production and operational with the U.S. Marine Corps and U.S. Air Force, the V-22 recently surpassed 100,000 flight hours!
What is going on?

“Recent” Technology Advancements

- For the most part, it is not the configurations that are advancing .... it’s the Technology Enablers

- All-composite rotorcraft

- Advanced airframe and blade tip shapes [1990s]

- Advanced crew stations [1980s]

- Optimal Speed Rotor [early 2000s]

- CFD and other Analysis Tools/Techniques

- Digital fly-by-light [1980s]

- Electric actuation [late 1990s]

- Higher harmonic control [1980s]

- What is going on?

- For the most part, it is not the configurations that are advancing .... it’s the Technology Enablers

- Active vibration control [1980s]

- Survivability enhancements [1980s]

- Computing Power

- What technology breakthroughs have been demonstrated in this decade?

HHC Off

HHC On

Analysis Techniques
A generational leap desired in range and speed – all at 6,000 ft/95°F.
Joint Multi-Role (JMR) Program
(continued)

Maximize commonality to improve affordability

JMR program appears to be the future of DoD Vertical Lift
Back to the Future – Prototyping
[e.g. Opportunity]

Model 347 → Fly-by-Wire
XH-59A → Advancing Blade Concept
X2 → Speed, maneuverability

XV-15 → V-22
Model 360 → V-22 composite airframe
X-49A → Speed

ARTI → RAH-66
S-76B Fantail → RAH-66 anti-torque system
X3 → Speed
**Hurdles**

- **Existing fleet modernization programs:**
  - Bell Boeing V-22 Osprey
  - Boeing AH-64D Apache
  - Boeing CH-47F Chinook
  - Sikorsky UH-60M Black Hawk

- **Fixed-wing emphasis**
- **Customers collaboration**
- **International competition**
- **Possible loss of critical skills**

The US Industry Faces a Precarious Future

**The US Gov't Rotorcraft Deliveries**

**Pre-MS B**  **Derivative Development**  **New Start Development**

Source: Boeing analysis of PB09
Exciting projects are already under-way

Unloaded Lift Offset Rotor – ULOR

DARPA Mission Adaptive Rotor – MAR

DARPA Disc Rotor
ULOR Configuration Features

Unloaded Lift Offset Rotor – ULOR

- High speed cruise > 250 knots
- More maneuverable than H-47
- Underfloor fuel (2,000 gal 7570.8 liters) in crashworthy cells
- Advanced 4-bladed rotor 60 ft [18.29m] diameter
- 8-ft (2.44m) diameter propellers
- Same internal cabin dimensions as H-47
  30 ft 2 in. [9.19m] Length X 6 ft 6 in. [1.98m] Height X 7 ft 6 in. [2.29m] Width
- Same payload as H-47 with greater range
- Retractable landing gear
- Similar external dimensions as H-47

ULOR Mission Scenario
Boeing/DARPA
Edgewise Mission Adaptive Rotor (eMAR)
Features on a Notional New Design Rotorcraft

- Variable rotor speed
- Swashplateless rotor system
- Active blade twist
- Active leading edge
- Active trailing edge
- Active tip sails
DARPA/Boeing/VPI
Disc Rotor Concept Study

- High-speed VTOL/troop assault
- (2) turboshaft engines or turboshaft/turbofan combination
- Unique 350+ knots speed capability
What will next generation rotorcraft look like?

Technology Demonstrators and Prototypes have worked very well in the past...

- Active drag reduction
- Mission Adaptive Rotor technologies
- Ultra-low vibration and noise
- Adaptive self-healing structures
- Next generation digital flight controls
- Single-pilot crew station
- Advanced engine and hybrid propulsion technologies
- Next generation advanced NOTAR
- Morphing wings
Parting Comments
Questions?

Thank you.