Origins – DARPA/Navy Unmanned Combat Air Vehicle (UCAV-N)

- Navy Unmanned Combat Air Vehicle (UCAV-N) initiated in 1999
  - Defense Advanced Research Projects Agency/Department of the Navy program
  - Build upon the DARPA/Air Force UCAV program already underway

- Provide multi-mission capability
  - Persistent intelligence, surveillance, & reconnaissance (ISR)
  - Strike
  - Suppression of Enemy Air Defenses (SEAD)

- Wide trade space of designs investigated
  - Vertical Takeoff & Landing (VTOL) operations from air-capable ships
  - Conventional carrier catapult launch and arrestment

- Balanced design emerged as best tradeoff in capabilities
  - Long range/endurance
  - Large payload for sensors and weapons
  - Balanced survivability
The tailless “kite” planform was investigated for UCAV-N.

Well-suited to SEAD/strike missions.

Northrop Grumman initiated a company-funded program to demonstrate UAS technologies necessary for narrow dispersion carrier landings; later brought into UCAV-N as the X-47A.

Flown in February 2003 at Naval Air Weapons Station China Lake, CA.
“Cranked Kite” Planform Evolution

**Cranked Kite** Combines Best Features of Kite and Flying Wing Planforms

- **Kite**
  - Long Length for Propulsion & Weapons Integration
  - Moderate Aero Efficiency - Drives Vehicle Size

- **Flying Wing**
  - Short Body Length Drives Vehicle Size
  - Excellent Aero Efficiency
  - Sweep Limited by Vehicle Balance and Carrier Suitability Considerations

- **Cranked Kite**
  - Long Length for Propulsion & Weapons Integration
  - Excellent Aero Efficiency
  - Excellent Carrier Suitability
  - Outer Wing Panels De-coupled from Centerbody – Allows Planform Optimization
Initial Cranked Kite Configuration and Wind Tunnel Model

- Initial cranked kite UCAV-N configuration developed in Fall 2000

- 1/32 scale diagnostic wind tunnel model tested in the Northrop Grumman 7x10 low speed wind tunnel in January 2001
Carrier Compatibility Configuration Design Drivers - Examples

Deck Spotting

Maintenance & Servicing

Hangar Bay/Door Clearance

Catapult/JBD Clearances

Elevator Clearance

Arrestment Clearances

Carrier compatibility permeates every aspect of configuration design
X-47B configuration design developed in accordance with Navy SD-24M criteria
Cranked kite configuration favorable to carrier compatibility
### Comparison of UOS-N and UDS-N

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Transition to Joint Unmanned Combat Air Systems (J-UCAS)

- Air Force and Navy UCAV efforts combined into the Joint Unmanned Combat Air Systems (J-UCAS) program in Spring 2003

- Expand from pure technology demonstration to include provisions for mission capability

- Common Performance Objectives established for payload, range, endurance, field performance (land based), and launch/recovery performance for carrier-based operations

- UCAV-N redesigned and enlarged to address J-UCAS objectives
  - Metallic structure with mechanically fastened composite skins; A-6E landing gear retained
  - Twin internal weapons bays optimized to each carry up to one 2000-lb JDAM weapon
  - Dedicated sensor bays provided in front of weapons bays
  - Non afterburning Pratt & Whitney F100-PW-220U selected for combination of high thrust and moderate specific fuel consumption
  - Both Navy (probe) and Air Force (receptacle) refueling systems incorporated
  - Wing span increased from 58 to 62.1 feet
  - No fundamental re-design required to meet Navy objectives
Planform Comparison – Wing Tip Modification

Original Wing Tip

Modified Wing Tip

Wing tip modification:
• Provided shielding of aileron outboard tip
• Improved structural stiffness
• Enhanced lift and control power
• Improved wing loading
• Improved longitudinal stability margin
Transition to the Navy UCAS Program and UCAS-D

- In response to the 2006 Quadrennial Defense Review (QDR), the J-UCAS program was restructured, and the Navy Unmanned Combat Air System (N-UCAS) program was created
  - “...to provide greater stand-off capability, to expand payload and launch options, and to increase naval reach and persistence.” (Ref 2006 QDR report, Page 46)

- N-UCAS included a UCAS Carrier Demonstration (UCAS-D) program to develop and demonstrate key technologies for a future carrier capable UAS
  - Unmanned, autonomous capability
  - Tailless, low observable relevant planform
  - Seamless integration into the carrier environment
  - Autonomous Aerial Refueling demonstration

- X-47B design updated and simplified
  - Weapons bay actuated doors replaced with covers; bays retained
  - Simplified exhaust nozzle
  - Simplified auxiliary power generation system inlet and exhaust
  - Off-the-shelf antennas replaced conformal antennas for comm/nav/identification

- X-47B selected for UCAS-D in August 2007; first flight February 4, 2011
Configuration Evolution Summary: UCAV-N to UCAS-D

- Tech demo        operational assessment
- Performance        mission capability
- Provisions for LO, sensors, weapons, and aerial refueling
- CV suitability at
  - sea demo added
- TOGW = 42,209 lbs       47,500 lbs
- F100
  - PW
  - Off-the-shelf subsystems
- A
  - 6E landing gear       new landing gear
- J
  - UCAS UDS

Navy UCAS
Mission Focus
Transition to Joint Tech Demonstration
Joint Mission Capability and Full LO Features Added

Configuration Refinement
- 2015 operational system concept configuration
- TOGW = 33,576 lbs
- PW800UOS turbofan
- Off-the-shelf subsystems

UOS-N
- Full scale demonstrator
- Scaled composites airframe
- TOGW = 25,555 lbs
- PW308C turbofan
- Off-the-shelf subsystems

J-UCAS UDS
- Improved wingtip
- Full LO configuration
- 440
- Non-LO exhaust
- LO planform only
- CV demo flight
- test air vehicle

441
- Initial configuration trade studies establish "cranked-kite" focus

J-UCAS UDS
- J-UCAS Common Performance Objectives Introduced
- J-UCAS Capability Objectives Finalized
- OA

UCAS-D demo vehicle
- Navy UCAS CV Integration Demo (UCAS-D) established

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UCAS-D X-47B Air Vehicle

**Design**
- Tailless, cranked-kite

**Planform**
- LO relevant features

**Structure**
- Carrier approved

**Take-off gross weight (demo)**
- 44,000 lbs

**Engine**
- P&W F100-PW-220U

**Twin Internal Weapons Bays**
- 4,500 lbs payload

**Aerial refueling provisions**
- USN / USAF style

**CV launch OPWOD**
- +2.2 knots

**CV recovery WOD**
- +7.2 knots

**Spot factor (F/A-18C)**
- 0.87
X-47B Major Components and Suppliers

**Avionics:**
- Vehicle Management Systems (GE)
- INS/GPS (Honeywell)
- Air Data (Goodrich)
- Flight Control Actuation (Moog)
- TTNT Data Link (GFE) (Rockwell Collins)
- Avionics S/W: (Wind River)

**Fuel and Hydro Systems:**
- Eaton

**ECS:**
- Honeywell (F-35, F/A-18, F-22)

**Internal Structure:**
- GKN

**Arresting Hook:**
- Lockheed Martin (New Design)

**APGS:**
- Honeywell (F-22)

**Wingfold System:**
- Parker

**Main Landing Gear:**
- GE Aviation (New Design)
- GE Aviation
- Hamilton Sundstrand (F/A-18)
- Wheels, Brakes, Tires (S-3)

**Lab IT Equipment:**
- Dell

**Nose Landing Gear:**
- GE Aviation (New Design)
- GE Aviation
- Wheels, Tires (F/A-18)

**AMAD:**
- Hamilton Sundstrand
- (F/A-18)

**Engine (F100):**
- Pratt & Whitney
- (F-16)

**Fuel and Hydro Systems:**
- Eaton

**Arresting Hook:**
- Lockheed Martin (New Design)

**APGS:**
- Honeywell (F-22)

**Wingfold System:**
- Parker

**Main Landing Gear:**
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- GE Aviation (New Design)
- GE Aviation
- Wheels, Tires (F/A-18)
X-47B Flight Test Activity

Modeling and simulation predictions proving to be highly accurate when compared to flight test data

• 23 Envelope Expansion Flights completed Feb 2011 - May 2012
  - Cleared envelope to 15,000 ft MSL altitude, 219 knots
  - X-47B system checkout
  - Validated:
    • Air vehicle aerodynamic performance;
    • Guidance, navigation & control models; mission planning and command/control functionality
  - Operations in all modes: ground, takeoff, cruise, approach
  - Validate X-47B PGPS/TTNT landing system functionality
UCAS-D Manned Surrogate Testing

• Autonomous Arrested Landing with a F/A-18D Manned Surrogate 2 July 2011

• An interim step to demonstrate landing technology and unmanned autonomous operations with the safety/redundancy of a man in the cockpit

• USS Eisenhower testing:
  – 36 approaches
  – 16 touch and go landings
  – 6 coupled approaches to arrested landings

Successful Testing Reduces Risks, Builds Confidence for X-47B Carrier Landings in 2013
Recent and Upcoming Testing

CV Suitability Testing
- Cats / Steam Ingestion
- EEE
- CDU Taxi
- Precision Approach / Flying Qualities
- Traps / Arresting Cable Compatibility

Hoist Aboard (CVN-75)
- EEE
- Deck Handling
- CDU Taxi
- CVN Compatibility

CV Demo
- CV Catapult
- CV Check-in
- CV Holding
- CV Approach
- CV Arrestment
- CV Touch & Go / Bolter

Autonomous Aerial Refueling
(Lear Jet Surrogate Only)
- Rendezvous
- Station Keeping
  - Basket and Boom
UCAS-D Technologies Applicable to Future Carrier-Based UAS

Aviation/Ship Integration

Tailless Low Observable Relevant Design

Autonomous Aerial Refueling

PGPS Landing System

Autonomous Functionality

AV-1 in Cruise Configuration

Photo Illustration

UCAS-D is the Essential First Step for Future CV-Based UAS

NAV AIR

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Summary

• X-47B configuration design evolved over 10-year period, from UCAV-N through UCAS-D

• Despite changes in program scope and objectives, cranked kite planform remained the preferred choice

• First flights of X-47B have confirmed aerodynamic benefits of the cranked kite configuration

• X-47B configuration design provides solid foundation for future potential carrier-based UAS alternatives