A NEW GENERATION OF AIR WARFARE

KEY PRESENTS

DRONES

UNMANNED BUT ON-TARGET

COMBAT AIRCRAFT JOURNAL

NEW

LATEST DRONES REVEALED

RAF Protector & MQ-25 Stingray

JOYSTICKS, KEYBOARDS, CONTROLLERS

Virtual Pilots on the Front Line

REMOTE WARFARE

Striking the enemy from a distance

DRONES
ISBN 978-1-913870-55-3
UK £8.99

TYPES | MISSIONS | DEVELOPMENT

DRONES:
UNMANNED BUT ON TARGET

US Air Force/Senior Airman Haley Stevens

What do you immediately think of when you hear the term drone? May be a small quadcopter used for recreational flying by growing numbers of people? May be a larger machine used by a government agency for surveillance of national infrastructure? Both are valid. There are numerous types of drone in operation around the world. The most impressive by way of the technology used and the capability provided are those flown by the armed forces.

Leading the pack is the United States which already operates some fascinating fixed wing and rotary wing drones, with new types yet to enter service.

The content of this beautifully illustrated publication is for the most part dedicated to America's most capable, including technology demonstrators and those serving with the US Air Force and the US Navy.

Drones don't tend to score highly in the good looks department. They are not meant to. Their design is dedicated to providing endurance, the carriage of hi-tech payloads and mission requirements.

Consider three notable types: the carrier capable X-47 demonstrator, the multi-mission MQ-9 Reaper, and the nascent MQ-25 Stingray - the first unmanned aerial refuelling tanker designed to launch and land on an aircraft carrier's flight deck. Impressive stuff, covered in full.

Whether you're an avid aviation enthusiast or somebody with a general interest in aviation, Drones: Unmanned on the Frontline is an essential read.

Mark Ayton

Mark Ayton Editor

CONTENTS

Main cover image: Northrop Grumman

Editor: Mark Ayton
Senior Editor Bookazines: Roger Mortimer
Email: roger.mortimer@keypublishing.com
Design: Daniel Hilliard
Head of Design: Steve Donovan
Advertising Sales Manager: Andrew Mason
Email: andrew.mason@keypublishing.com
Advertising Production: Rebecca Antoniades
Email: rebecca.antoniades@keypublishing.com

Subscription/Mail Order
Key Publishing Ltd, PO Box 300, Stamford, Lincs, PE9 1NA
Tel: 01780 480404 **Fax:** 01780 757812
Subscriptions email: subs@keypublishing.com
Mail Order email: orders@keypublishing.com

Publishing
Group CEO: Adrian Cox
Publisher: Mark Elliott
Head of Publishing: Finbarr O'Reilly
Chief Publishing Officer: Jonathan Jackson
Head of Production: Janet Watkins
Key Publishing Ltd, PO Box 100, Stamford, Lincs, PE9 1XP **Tel:** 01780 755131
Website: www.keypublishing.com

Printing
Precision Colour Printing Ltd, Haldane, Halesfield 1, Telford, Shropshire. TF7 4QQ
Distribution
Seymour Distribution Ltd, 2 Poultry Avenue, London, EC1A 9PU

Published by: Key Publishing Ltd • PRINTED IN ENGLAND

US Air Force/Senior Airman Elora McCutcheon


US Air Force/Sgt Joshua King


US Marine Corps/Sgt Michele Hunt

DRONES: A GENIE OUT OF A BOTTLE

Editor, **Mark Ayton** provides a brief evolutionary overview of military drones in a modern-day context.

An RQ-2B Pioneer unmanned air vehicle attached to the pneumatic launch truck before take-off. The Pioneer was used by the US Marine Corps for basic reconnaissance and was one of the first unmanned air vehicle systems to enter service with the US Department of Defense. US Marine Corps/Cpl Brandon Roach

Drones have been in operation in one form or another for decades. Placing a timeline to that statement depends on your judgement as to what constitutes a drone. There have been many types in operation including unmanned balloons, aircraft modified for unmanned missions and remote-controlled operation, purpose-built jet-powered air vehicles used as aerial targets, and of course those designed and built as remotely piloted air vehicles, usually flown by aircrew operating in a ground control station.

The term drone refers to an unmanned air vehicle (UAV), one that is controlled by an operator using either manual or autonomous flight control modes and information fed from GPS and sensors. The US Department of Defense, probably the largest drone operator in the world, uses a group classification system based primarily on the air vehicle's gross weight. In parallel, military drone manufacturers also class their air vehicles based on performance. Medium altitude long-endurance or MALE is one such example.

"Unmanned systems will continue being part of martime ops."

The core topic of this book is military drones, types that in general are designed to gather imagery and signals intelligence, and to strike targets with precision-guided munitions, but other mission sets are undertaken by specific types.

Given the technology built into military drones and the resultant capability there is a perception that unmanned air vehicles have started to transform armed combat and given the pace of technology advances they may continue to do so. According to Lynn Davis a senior fellow with the RAND Corporation, unmanned air vehicles are fundamentally misunderstood: "Their champions wrongly contend they are revolutionizing warfare...A number of policymakers and experts have described armed drones as revolutionizing the way nations conduct war, putting their development in the same category as the advent of air power or even the atomic bomb. If armed drones are indeed revolutionary, their

presence on one side but not the other would decisively tilt the battlefield in favour of their possessor. But this is not the case given the vulnerability of long-range armed drones to air defence systems. This conclusion could change with technological advances in automation, miniaturization, stealth, and other fields. Swarms of smart drones acting autonomously to overwhelm air defences could prove to be truly transformative weapons. But such capabilities, if they ever exist, will be transformative because of their autonomous systems more than the unmanned platforms that carry them.

"Armed drones are more transformative against insurgent movements or others that lack even basic air defences. In these cases, the greater precision and loiter time of armed drones, as well as lower cost, can change the battlefield in favour of the counterinsurgent by enabling targeting that would otherwise be too risky or too costly… The benefits and limits of long-range armed drones suggest they offer their users significant capabilities but are only transformative in rare circumstances. They are operationally attractive in the fight against al Qaeda and the Islamic State but are best viewed as conventional weapons such as aircraft."

Lynn Davis also points out that: "Some argue that armed drones are inherently destabilizing and illegitimate, and establishing standards for their use—norms—would create an aura of legitimacy where none should exist. Others argue that armed drones are just like any other weapon and attempts to develop norms will only tie the hands of the United States, while doing nothing to constrain others…Like it or not, this genie cannot be put back in the bottle. United States [drone] use is establishing precedents that other nations might follow. While they may not transform warfare, armed drones provide the ability to identify and kill an individual from a standoff distance in a way that is unprecedented and unsettling to many people… The challenge in establishing international norms will be to define rules that preserve the rights of countries to use these systems in legitimate ways against legitimate threats (senior al Qaeda or Islamic State terrorists) while constraining illegitimate uses (political dissidents)."

In reality, the US armed services and the Royal Air Force are procuring more drones with greater performance and capability as shown in this book's coverage.

On March 16, 2021, the US Department of the Navy released its Unmanned Campaign Plan. One of its five goals seeks to advance manned-unmanned teaming effects within the full range of naval and joint operations.

In a message, Chief of Naval Operations, Admiral Gilday said: "As the Navy adapts to an increasingly complex security environment, it is imperative that we understand what our future force will need to operate both in day-to-day competition as well as a high-end fight. Unmanned systems have and will continue to play a key part in future distributed maritime operations, and there is a clear need to field affordable, lethal, scalable, and connected capabilities. That is why the navy is expanding and developing a range of unmanned aerial vehicles, unmanned undersea vehicles, and unmanned surface vessels that will play key roles as we shift our focus toward smaller platforms that operate in a more dispersed manner. Unmanned systems will provide added capacity in our future fleet — in the air, on the surface, and under the water. The campaign plan will serve as the comprehensive strategy for realizing a future where unmanned systems serve as an integral part of the navy's warfighting team."

"The USAF is considering a fleet with more drones than manned jets."

Underscoring the need for unmanned systems, Commandant of the Marine Corps, General David Berger said: "The speed with which unmanned technology is available to US, allied, and adversary forces requires that we have both a vision and roadmap for maximizing this capability. The Marine Corps requires unmanned air, surface, and ground systems to fully exploit our inherent expeditionary nature and capabilities. Partnered with our shipmates in the Navy, we will provide a Joint Force Maritime Component Command that supports the Joint Force in the unique maritime domain we inhabit. When operating forward, in small groups, under austere conditions, the ability to maximize unmanned systems to create outsized effects for our allies and against our adversaries is a key element of our future success."

In mid-May, speaking at the McAleese Defence Conference in Washington DC, Air Force Chief of Staff General CQ Brown said the service is seriously considering building a fighter fleet equipped with more drones than piloted aircraft. He said: "Part of our analysis in a simulated war game was to take a look at the mixture of manned platforms and unmanned platforms. So, what does a future fighter squadron look like, how many aircraft versus how many unmanned platforms does it have? And then, how do you train differently as you do this? I don't currently have the answer to what that mix might be, but we are laying the groundwork today to guarantee the service has the ability to make such a shift in the future."

In terms of combat employment, US Air Force and Royal Air Force drones continue to play significant roles in combat operations in southwest Asia. While the US Navy and Marine Corps continue to deploy a variety of unmanned air vehicles in surveillance roles from ship and land bases. As Lynn Davis said, the military drone genie is out of the bottle. ●

MQ-1 Predator 03-123/CA assigned to California Air National Guard's then 163rd Reconnaissance Wing back in January 2012. US Air Force/TSgt Effrain Lopez

GLOBAL

In peacetime, new-production military aircraft are seldom removed from service because they are not considered worth the cost of operating and maintaining them. It was a surprise to many when the announcement came in early 2012 that the US Department of Defense' FY2013 budget request would terminate the planned production of 31 (reduced from 42 the year before) Northrop Grumman Block 30 RQ-4A Global Hawks. The request also provided for 18 of these high-altitude unmanned air vehicles (UAVs) with the US Air Force be withdrawn from service and stored. At the time 14 were built and four were in production at a cost $3.4bn. A further three already contracted for would also be cancelled. The Air Force estimated cancellation would save $2.5bn in the future.

Outperformed by the U-2

Apparent failure of the Block 30 was significant because it was the first UAV intended from the outset to take over an entire mission area from manned aircraft, that of high-altitude intelligence, surveillance, reconnaissance (ISR). Instead, the mission continued to be carried out by the Lockheed Martin U-2, the classic 60-year-old Kelly Johnson design. A further $1.1bn previously budgeted for the Global Hawk was re-allocated to the U-2. The ability of the U-2 to adapt better than the more advanced Block 30 suggested that the rise of the UAV was not to be as rapid or comprehensive as its advocates had believed.

The US Air Force and its credibility were damaged. Once again, the Air Force failed to effectively manage a major procurement programme. Given the concerns over the F-35 Joint Strike Fighter at the time, this could not be presented as an aberration. Generals and service secretaries that testified in favour of the Block 30 programme before the Congress and signed statements that it was vital to national security, year after year, were revealed, without apology, to be badly and expensively mistaken.

As anticipated, the news that the Air Force intended to pull its new high-capability and ➲

HAWK

David Isby and **Mark Ayton** detail the turbulent service life of the US Air Force RQ-4 Global Hawk.

RQ-4B Global Hawk at cruise altitude in airspace near to Edwards Air Force Base, California. US Air Force

Avionics specialists with the 12th Aircraft Maintenance Unit prepare RQ-4 Global Hawk 02-2010 for a runway taxi test at Beale Air Force Base, California. US Air Force

high-cost UAV from service went down badly with the Congress . On March 6, 2012, the House Appropriations Committee announced that it would conduct its own investigation of the decision. The House of Representatives passed the FY2013 appropriations and authorisation bills with language that prevented the Block 30's withdrawal from service and added funds to keep them operational.

The Senate Armed Services Committee did not act to block the cuts, but the appropriations committee approved a bill with language similar to its House counterpart. Other bill language required reports on the cost impact of the Block 30 cancellation. But, facing bitter political divisions in an election year, looming large-scale defence cuts, and its own inability to pass either a final defence authorisation or appropriation bill by the time the fiscal year ended on September 30, 2012, the Congress was unable to provide more money to keep the Block 30s flying permanently. But neither did they vote to approve the request to withdraw them.

On September 18, 2012, the Air Force announced it would keep the Block 30s in service until at least September 30, 2013 or until Congress voted for the service to do otherwise. Lieutenant General Larry James, the then deputy chief of staff for intelligence, surveillance, and reconnaissance, said at the annual Air Force Association convention in Washington: "The intent of Congress so far in general is they would like us to keep flying the Block 30 Global Hawk fleet, so right now we are planning to continue to fly them until we get definitive guidance from Congress ."

Compromise solutions such as retaining 18 Block 30s in service remained a possibility.

Meanwhile, though the future remained uncertain, Block 30 Global Hawks flew throughout 2012, with Northrop Grumman responsible for operations and maintenance under a contract with the Department of Defense. At the time, the objective was to deploy one orbit comprising three UAVs each at Naval Air Station Sigonella on Sicily, Anderson Air Force Base on Guam, and Al Dhafra Air Base in the United Arab Emirates. Air vehicles not being used for operational tasking were used for training at Beale Air Force Base, California or in maintenance or modification.

This shot of Block 40 RQ-4B Global Hawk shows the 319th Reconnaissance Wing tail flash applied to its assigned air vehicles. US Air Force/Senior Airman Elora McCutcheon

An Expensive Failure

Washington had no shortage of explanations for the failure of the Block 30 Global Hawk programme, which had been marked by multiple crashes. Three prototypes had crashed between 1999 and 2002 alone.

On August 20, 2011, one of two EQ-4B Block 20 Global Hawks modified for communication relay missions using the Battlefield Airborne Communications Node (or BACN mission payload) crashed in Afghanistan.

Stand-downs resulting from the accidents repeatedly delayed development.

But cost was the critical reason for the Block 30 cancellation given that the U-2 force was

seen as being available for the same mission. Ultimately, the Block 30 was cancelled because it lost the battle for scarce resources with the aircraft it was intended to replace.

When the then Deputy Secretary of Defense, Dr Ashton Carter made the announcement of the Block 30 termination on January 26, 2012, he said: "That's the fate of programmes that are too expensive."

Based on production quantities, the Block 30 per-unit cost was $215m.

General John Jumper ret'd, former Air Force chief of staff was quoted in the press as having said: "If we had to do it all over again, we would do it differently. ... We did not do a good job on controlling the requirements of making the Global Hawk a plug-and-play platform".

The then Secretary of Defense Leon Panetta said: "The cost of the Global Hawk programme would significantly exceed the cost of the U-2, so we cancelled Block 30 Global Hawk and extended the U-2 programme." In Congressional testimony, he explained: "When you look at cost effectiveness, actually the U-2 provides an even better picture at a lower cost and does the job."

General Norton Schwartz, then Air Force chief of staff said: "The Global Hawk system has proven to not be less expensive to operate than the U-2 and in many respects the Block 30 system is not as capable – from a sensor perspective – as the U-2."

On February 17, 2012, Air Force Lieutenant General Larry Spencer, told the House Armed Services Committee: "The Block 30 Global Hawk has fundamentally priced itself out of our ability to afford it when the U-2 gives in some cases a better capability and in some cases just a slightly less capable platform."

"Initially, the US Air Force planned to procure 22 Block 40 Global Hawks."

Making it possible for the U-2 to do the Block 30's planned roles, the Joint Requirements Oversight Council of the Joint Chiefs of Staff, which approves requirements for US forces and weapons, reportedly reduced operational requirements from six to three high altitude orbits. While these orbits had previously been required to be up to 1,200nm from base, under the reduction they could be 400nm away, important when the U-2 can remain in the air for some 12 hours, compared to 30 for the Global Hawk.

Fall of the Block 30

Perhaps the biggest factor of the Block 30 cut was how it reflected on the US Air Force's inability to contain costs over the life of the Global Hawk programme. A fact underlined by two previous cost overruns, in 2005 and 2011. These, under the provisions of the Nunn-McCurdy amendment, required the Pentagon to explain to Congress why the programme should not be cancelled and what steps it was taking to get better control of the cost growth. Air force explanations, which the Congress accepted, were undercut by the 2012 announcement to cancel the programme and store the existing Block 30s.

Block 30 payloads - the Northrop Grumman Airborne Signals Intelligence Payload (ASIP) along with the associated legacy RAS-1R signals intelligence collection system and the Raytheon Enhanced Integrated Sensor Suite (EISS) - failed to out-perform existing high-altitude ISR sensors. The Block 30's synthetic aperture radar (SAR) proved to be fully effective only at short range, ASIP proved to have limited geo-location capability and the EISS infrared sensor had a short stand-off range, which required the air vehicle to get close to its targets.

To this day, the gold standard high-altitude sensor remains the U-2's multispectral SYERS (Senior Year Electro-Optical Reconnaissance System), which simultaneously looks at the same scene in three visible light and three infrared frequency bands.

General Spencer testified that the imagery produced by the U-2 was far superior to that produced by the Block 30 and cheaper at $2,830 per flight hour for the U-2 compared with $6,710 for the Global Hawk, in 2011 dollars. These figures reportedly contradicted those supplied to congressional staffers in 2011, which showed the total cost per flight hour for both aircraft to be some $42,000.

The payload-limited Global Hawk design is less adaptable than the aging U-2. A considerable development effort was required to increase an early Block 10 air vehicle's 1,000lb payload to the 3,000lb available to Block 20 and Block 30 aircraft. But this is still less than a U-2's 5,000lb payload, which enables Lockheed's high-flying snooper to carry heavier sensor payloads and datalinks. Every pound devoted to fixing sensor limitations had to be found from a weight saving elsewhere. In military aviation, savings in weight are usually paid for through higher procurement costs and reduced performance.

Two major setbacks took place in the Block 30's test programme in 2011, as its termination was decided. The Department of Defense's director, operational testing and evaluation, reported the Block 30 was not operationally ➲

A US Air Force BACN-equipped EQ-4B Global Hawk waits for its take-off clearance at an undisclosed base in Southwest Asia. The Battlefield Airborne Communications Node or BACN functions as a persistent gateway, bridging diverse tactical data links and voice communications to improve battlefield communications. US Air Force/SSgt Eric Harris

effective nor operationally suitable; and Air Force operational testers declared significant limitations with the aircraft.

As part of its operational test programme, a Block 30 was tasked with narcotics interdiction missions over Latin America for US Southern Command. During this test phase, the Block 30 was giving a 41% mission capability rate, in part because of a troublesome electric generator (since replaced) and because Block 30 spares had been procured at an unsustainable low rate to save money. Despite this, on August 12, 2011, Air Combat Command (ACC) declared that the Block 30 had achieved initial operational capability (IOC), with four air vehicles and the ability to maintain a single persistent orbit with one spare aircraft.

Despite successful operational missions flown to survey areas of Japan devastated by the tsunami and support coalition air operations against Libya, the US Air Force came to see cancellation as the best solution for its Block 30 fleet.

Earlier in 2011, both BACN-equipped EO-4B Global Hawks provided communication relays for the raid that resulted in the death of terrorist leader Osama bin Laden.

The year finished with some decent statistics. On operations the type posted an 83% mission availability rate, 18% above the set requirement. That December, when an RQ-4 Global Hawk completed the type's last mission over Iraq,

"In FY2015 the Air Force continued to operate 18 Block 30 RQ-4s."

Northrop Grumman's high-flyer had flown 1,146 sorties, comprising 21,346 hours of combat time, without loss.

RQ-4 Global Hawk aircraft flew just 5% of the Air Force's high-altitude reconnaissance sorties but gathered more than 55% of time-sensitive targeting imagery used for strikes.

Block 40

Initially, the US Air Force planned to procure 22 Block 40 Global Hawks equipped with the X-band ZPY-2 modular, active electronically scanned array (AESA) radar system. The set was developed under the multiplatform-radar technology insertion programme dubbed MP-RTIP, with the capability to detect moving and fixed targets.

In 2011, an Air Force decision to cut Block 40 procurement from 22 to 11 triggered the programme's second Nunn-McCurdy breach. The statutory provision known as Nunn-McCurdy is a tool for Congress to use to hold the Department of Defense accountable for cost growth on major defence programs.

Block 40 received its airworthiness certificate in April 2012 and has been in operation with the 69th Reconnaissance Group based at Grand Forks Air Force Base, North Dakota since August 2012.

Annual reports by the DoD's director, operational test and evaluation, since FY2014 detailed the progress made during various Block 30 and Block 40 test events.

FY2014

The 2015 Presidential Budget fully funded the Global Hawk programme, resolving several years of programmatic uncertainty.

Block 30 activity: The Air Force continued to acquire and pursue upgrade programmes for the ASIP sensor. In addition, the Air Force planned to modify some Block 30 RQ-4B ASIP sensors for transfer and deployment on the U-2 Dragon Lady in FY2014.

Block 40 activity: The Air Force continued developmental testing of the Block 40 RQ-4B system in FY2014 in preparation for the planned IOT&E in FY2015.

The programme was supporting operational employment, with two systems in the US Central Command area of operations and two systems to the US Pacific Command area of operations. The operational capability of these systems was limited but supported the

"Despite successful operational missions in Japan and Libya, the US Air Force came to see cancellation as the best solution for its Block 30 fleet."

immediate requirements of the respective combatant commanders.

The Air Force completed six planned interoperability

test flights and three integrated system evaluation test events with US Air Force Distributed Ground Stations (AF DGSs) to demonstrate system maturity and improve the exploitation and dissemination of Block 40 RQ-4B data.

The Air Force also implemented a number of radar system and image processing changes intended to address synthetic aperture radar image quality problems observed during the FY2013 Block 40 RQ-4B Operational Utility Evaluation. The impact of the software and processing upgrades was subsequently demonstrated and fully evaluated during the Block 40's IOT&E in FY2015.

Previous acquisition strategies resulted in Block 30 and Block 40 being managed as separate programmes. Given the full funding awarded in the 2015 Presidential Budget, the US Air Force revised its acquisition strategy and worked to bring all Global Hawk variants into one cohesive programme. Block 30 and Block 40 had separate operational test requirements, so the Air Force developed a combined approach to codify the varied operational test requirements and identify test agencies and resources required to complete the evaluations.

Block 30: Since the combined RQ-4B Block 30/ASIP IOT&E in 2011, the Air Force corrected most RQ-4B air vehicle reliability and availability problems and implemented a limited number of previously planned system improvements. However, due to programmatic issues resulting from the previous DOD decision to retire the RQ-4B fleet, the Air Force had not conducted a comprehensive FOT&E to verify correction of all major IOT&E deficiencies.

Block 40: The Air Force continued to execute developmental testing which led to IOT&E in FY2015. Initial results from key integrated system evaluation events with the AF DGS showed improved maturity in ZPY-2 radar system stability and interoperability.

Field data from US Central Command indicated that software fixes and procedural workarounds had improved suitability in comparison to FY2013 Operational Utility Evaluation performance.

All sensor modes and the enduring Tasking, Collection, Processing, Exploitation and Dissemination system were rigorously tested and fully characterised during the IOT&E in FY2015.

Completion of Block 40 developmental test events was delayed due to slower than expected maturation of AF DGS software necessary to receive and exploit ZPY-2 radar data.

NASA Global Hawk No.872 during an instrument checkout flight. Configured with yellow and black pods housing cloud particle probe instruments used during the ATTREX campaign of 2014 over the western Pacific Ocean. NASA/Tom Miller

FY2015

In February 2015, USD(AT&L) approved a multi-year $3.5bn upgrade and modernisation development programme to correct previous capability shortfalls identified during the 2011 Block 30 RQ-4B IOT&E; address emerging component obsolescence problems; and significantly upgrade system sensor, ground station, and communication systems.

Block 30 activity: The Air Force continued to sustain operations for 18 Block 30 aircraft at Beale Air Force Base, California, and at forward operating bases in US Pacific Command, US Central Command, and US European Command areas of operation.

In addition, the Air Force developed a test strategy that included re-evaluation of previously identified ASIP/SIGINT ➲

Block 40 RQ-4B Global Hawk 10-2044/GF is towed across the flight line at Grand Forks Air Force Base, North Dakota, home of the 319th Reconnaissance Wing. US Air Force/ Senior Airman Elora McCutcheon

mission capability shortfalls, interoperability deficiencies, MS-177 sensor integration, weather radar performance, and mission planning upgrades, all to be included in the Block 30 follow-on test and evaluation in FY2018.

Block 40 activity: In FY2015, the Air Force continued to employ two Block 40 RQ-4B development systems with limited operational capabilities in the US Central Command area of operations. Two additional systems were deployed in the US Pacific Command area of operations. All four systems were fielded in FY2013 and FY2014 to support combatant commanders' requests for additional airborne ISR support.

Following numerous developmental test delays, the Block 40 IOT&E ran between September and December 2015. Delays were caused by a number of factors that included synthetic aperture radar image quality and system stability problems encountered during the FY2013 Block 40 Operational Utility Evaluation, and a delayed delivery of AF DCGS system software changes necessary to support Block 40 operations.

Block 30 assessment: Since the combined Block 30/ASIP IOT&E in 2011, the Air Force had corrected most air vehicle reliability and availability problems and implemented a limited number of previously planned system improvements. However, due to the programme's uncertainty driven by the FY2013 DoD decision to retire the RQ-4B fleet, and the subsequent reversal of that decision, the Air Force had not conducted a comprehensive FOT&E to verify correction of all major IOT&E deficiencies.

During FY2015, the Air Force was planning to conduct FOT&E in conjunction with the initial phases of the RQ-4B modernisation programme in FY2018. FOT&E was expected to include a complete re-evaluation of the Block 30 SIGINT mission capabilities with the ASIP sensor, and assessments of previously identified ground station, air vehicle, communication system, interoperability, and cybersecurity shortfalls.

Block 40 assessment: Since FY2013, the Air Force implemented a series of software changes to improve the ZPY-2 radar's stability and performance. IOT&E began in September 2015, included 10 sorties, and concluded in October 2015. Additional data collection and analysis continued until the end of December 2015.

FY2016

Based on the Block 40 and ZPY-2 IOT&E staged in late 2015, the system demonstrated the capability to provide exploitable SAR and GMTI data. Both SAR and GMTI data met most operational requirements and provided actionable intelligence products to operational users.

However, inadequate training, procedures, tools, communication, and management hindered the ability of the AF DCGS to exploit GMTI data in near real-time.

The Block 40 was found to be operationally suitable, could generate and sustain the long-endurance missions necessary to support non-continuous operations representative of the then current combat tempo.

Despite initial requirements for a single Global Hawk orbit to provide near-continuous on-station coverage for 30 days, the Air Force adopted a combat tempo of three long duration (approximately 28 hours) sorties a week over 30 days or more.

> **"NATO accepted its fifth and final RQ-4D at Sigonella in November, 2020."**

FY2017

DOT&E discontinued oversight of the Block 40 programme in September 2016 since the IOT&E was complete and the Air Force did not plan to implement any major capability enhancements to the platform.

On February 8, a Block 30 aircraft equipped with a UTC Aerospace System's MS-177 sensor made the maiden flight: the start of a six-month integration, test and qualification phase at Edwards Air Force Base, California. The MS-177 is a high-resolution, long-range sensor used to precisely identify targets, day, or night, on land or sea.

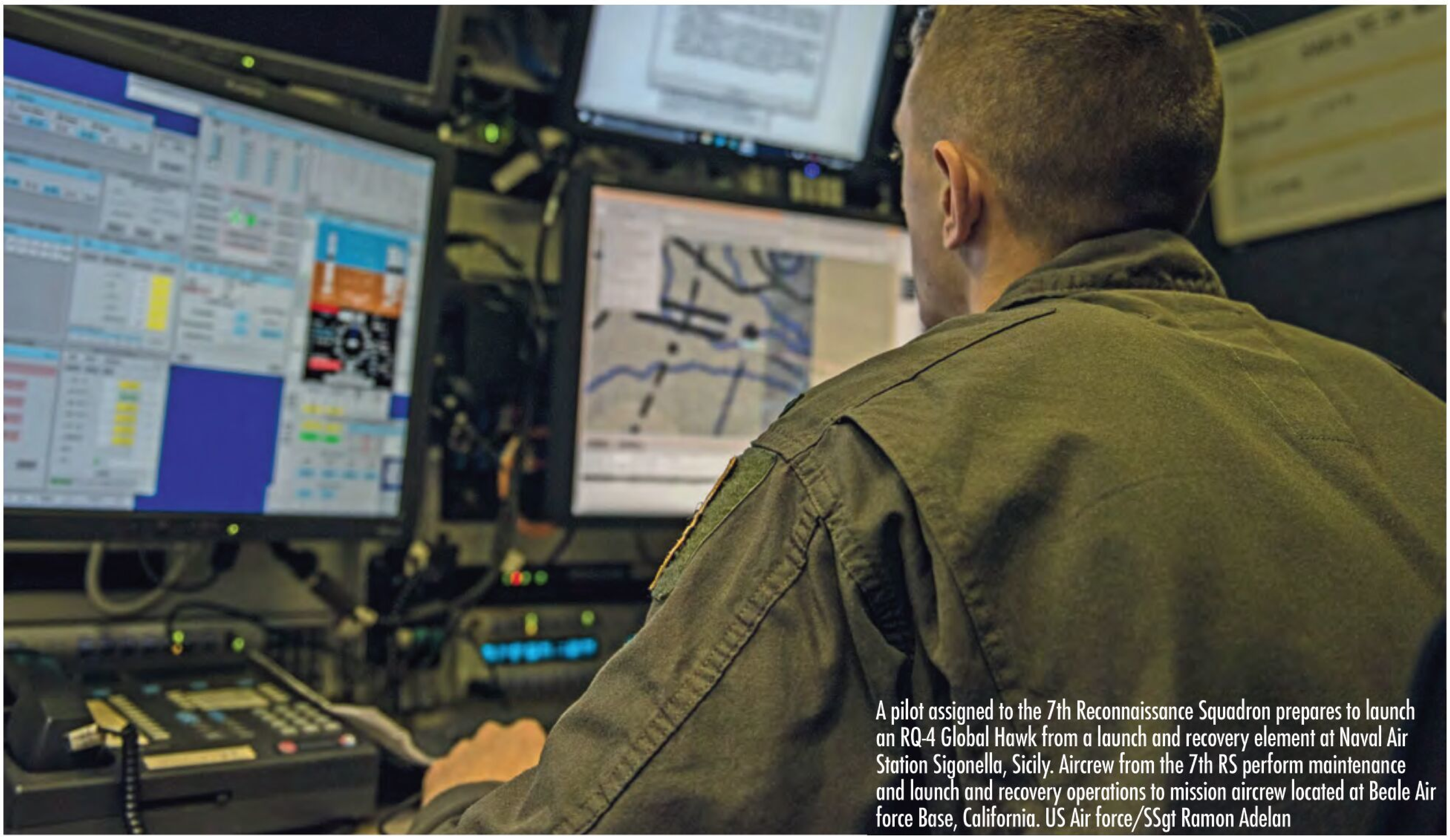
The MS-177 radiated high levels of EMI during Northrup Grumman developmental testing in an anechoic chamber, which could interfere with the ASIP system, producing false signal detection reports. During FY2017, the programme was evaluating the problem to determine an acceptable solution.

Significant delays were encountered when the RQ-4B platform transferred MS-177 sensor images to the DGS installation using the legacy system link. Although the RQ-4B is a strategic platform, the delays did not allow the operator to determine when to reacquire an image or allow the exploitation of imagery in near real-time to support operational intelligence needs.

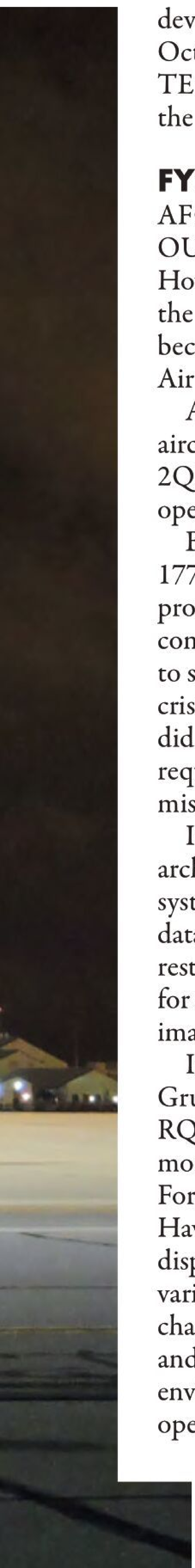
FY2018

AFOTEC originally planned to conduct an Operational User Evaluation (OUE) on the Block 30 MS-177 system in mid-2017. Delays to the start of the OUE occurred due to problems with weather radar testing, technical order development, and a software deficiency that could result in loss of air vehicle control while in flight. That software build was also used for the Block 30 MS-177 aircraft. Northrop Grumman modified the deficient software code, and Air Combat Command's 53rd Test and Evaluation Group observed

RQ-4 Global Hawk 02-2022/BB at Robins Air Force Base, Georgia, home of the Warner-Robins Air Logistic Complex where the air vehicle was the first of its type to undergo a repaint. US Air Force/Roland Leach



A pilot assigned to the 7th Reconnaissance Squadron prepares to launch an RQ-4 Global Hawk from a launch and recovery element at Naval Air Station Sigonella, Sicily. Aircrew from the 7th RS perform maintenance and launch and recovery operations to mission aircrew located at Beale Air force Base, California. US Air force/SSgt Ramon Adelan



developmental ground and flight tests in October 2018. Officers assigned to the 53rd TEG confirmed the deficiency was mitigated by the new software code.

FY2019

AFOTEC conducted the Block 30 MS-177 OUE between June and September 2019. However, AFOTEC did not accomplish all of the imagery testing documented in the test plan because it attempted to remain to schedule with Air Combat Command's early fielding schedule.

At the time, ACC planned to field two aircraft equipped with the MS-177 sensor in 2QFY2020 to support combatant command operations.

Based on preliminary analysis, the MS-177 system demonstrated the capability to provide EO and IR imagery data. The sensor completed long-endurance missions necessary to support operations at a peacetime or a non-crisis operational tempo. Although the system did not meet all of the joint interoperability requirements, it did not significantly degrade mission effectiveness.

Implementation of the Goshawk network architecture and Swift Broadband, which added system complexity and resulted in increased datalink outages. Any datalink bandwidth restriction could render the system unsuitable for some sensor modes, such as persistent imaging.

In early December 2020, Northrop Grumman successfully completed the first RQ-4 flight of the Global Hawk ground station modernisation programme at Edwards Air Force Base, California. A modernised Global Hawk ground station features new cockpit displays, the ability to fly all Global Hawk variants without software or configuration changes, simpler maintenance interfaces, and improved situational awareness and environmental conditions for pilots and sensor operators.

"A Block 30 aircraft equipped with MS-177 made the maiden flight on February 8, 2017."

Other Operators

At the May 2012 NATO summit in Chicago, a contract was finally signed for NATO's five (reduced from eight) modified MP-RTIP-equipped Block 40 RQ-4D Global Hawks for its Alliance Ground Surveillance (AGS) programme.

Some 13 NATO members contributed to buying and operating the Global Hawks. Total procurement cost, including the construction of a main operating base at Naval Air Station Sigonella, Sicily and buying 15 ground control stations and equipment was estimated at €1bn, while a 20-year operations period including maintenance was expected to cost a further €2bn.

NATO accepted its fifth and final RQ-4D at Sigonella on November 19, 2020 at the end of a 20-hour flight from Palmdale, California. NATO's AGS management agency and the Italian airworthiness authority have since completed their certification processes to complete hand-over of the system to its operators assigned to the NATO AGS Force.

On February 15, NATO's Supreme Allied Commander Europe, General Tod Wolters, declared initial operational capability for NATO's RQ-4D system.

Republic of Korea

On December 12, 2014, the US Air Force awarded Northrop Grumman a $657m contract to deliver four RQ-4 Global Hawk air vehicles, two spare engines and ground control stations to the Republic of Korea Air Force (RoKAF). The contract was awarded under the US foreign military sale programme.

Seoul's first aircraft arrived at Sacheon Air Base on December 23, 2019 and was subsequently assigned to the newly established 39th Tactical Reconnaissance Group. According to the South Korean news agency Yonhap, in June 2020, a military official said the RoKAF planned to start flying operational missions, rather than training flights local to Sacheon, during the latter part of 2020 once the fourth and final aircraft had been delivered. The fourth aircraft arrived at Sacheon in September 2020, two months before a TCPED ground system was commissioned. The ground system is used for tasking, collection, processing, exploitation, and dissemination of all data gathered by Global Hawk.

Japan

In November 2018, the Japanese government awarded a $489m contract for three Block 30i RQ-4 Global Hawk air vehicles, two ground control stations, spares, and support equipment. The Block 30i features an enhanced version of the Raytheon EEIS integrated sensor suite payload.

Tokyo's first RQ-4B made its first flight from Air Force Plant 42 at Palmdale, California on April 15, 2021. Jane Bishop, vice president and general manager, Northrop Grumman autonomous systems said: "The unarmed RQ-4B Global Hawk will provide Japan with on-demand intelligence, surveillance and reconnaissance information supporting the Japan Air Self-Defense Force's missions of protecting borders, monitoring threats and providing humanitarian assistance in times of need."

In May 2021, Northrop Grumman won a $58.6m contract to provide contractor logistics support services to include in-country ➲

personnel, mission planning, contractor field teams, contractor inventory control, reach back support and software maintenance at Misawa Air Base, Japan - the future home of the JASDF RQ-4 fleet. Air vehicles will be assigned to a squadron within the Teisatsu Kokutai or Air Reconnaissance Group

Germany

In May 2013, German Defence Minister Thomas de Maziere announced the cancellation of the Bundeswehr's Block 20 RQ-4E Euro Hawk programme, designed to conduct high-altitude signals intelligence (SIGINT) collection.

The first aircraft had arrived at Manching Airfield on July 21, 2011. After undergoing a period of modification which included the integration of an EADS-designed Isis SIGINT collection system, air vehicle 99+01 started ground testing with Wehrtechnische Dienststelle 61, the Bundeswehr's aircraft test centre at Manching in the summer of 2012. A contract for the four follow-on air vehicles was not signed, though the Bundeswehr reportedly spent over €500m of the estimated €1.2bn programme cost.

NASA

NASA's Armstrong Flight Research Center operates three Global Hawks. Acquired from the US Air Force, the three aircraft consist of a Block 2 Advanced Concept Technology demonstration model and two Block 10 initial production models.

Global Hawk aircraft operate autonomously and execute a flight plan loaded to the aircraft prior to flight. Although autonomous, the air vehicle's flight is managed, and systems are monitored via satellite and line-of-sight communication links using a ground control station. Dedicated satellite communication links provide NASA customers with direct access to their onboard sensor packages during missions. Customers have the ability to monitor sensor function and evaluate selected data in near real time from the ground control station or from their home station.

Between 2010 and 2017, Global Hawks served with NASA's Science Mission Directorate, the National Oceanic and Atmospheric Administration (NOAA), and the Department of Energy performing Earth observation research.

Examples of the science work undertaken by NASA Global Hawks include:

Airborne Tropical TRopopause EXperiment (ATTREX) to study moisture and chemical composition in the region of the upper atmosphere where pollutants and other gases enter the stratosphere and potentially influence climate. Flights were performed between 2011 and 2014.

The Sensing Hazards Operational Unmanned Technology (SHOUT) programme of 2015, in which NASA partnered with NOAA to investigate the use of a high altitude long endurance aircraft in sensing high impact weather-related hazards. NOAA discovered that entering the atmospheric data gathered from 60,000 feet to the ocean floor into their forecast models greatly enhanced storm track and storm intensity predictions.

The Hands-On Project Experience (HOPE) Eastern Pacific Origins and Characteristics of Hurricanes (EPOCH) field campaign of 2016 studied storms in the Northern Hemisphere to learn more about how storms intensify as they developed out over the ocean. Global Hawk proved itself to be a valuable asset for high altitude hurricane and severe storm research performed over the Atlantic and Pacific oceans.

"Japan ordered three Block 30i Global Hawks in November 2018."

Maintainers assigned to the 380th Aircraft Maintenance Squadron prepare an RQ-4 Global Hawk for launch at an undisclosed base in Southwest Asia.

Air Force vs Congress

In its FY2020 budget request, the US Air Force submitted a proposal to retire 24 of its 35 RQ-4 Global Hawks to the Office of the Secretary of Defense for review as part of annual budget negotiations. The air vehicles proposed for retirement were three Block 20 BACN-equipped EQ-4Bs and 21 Block 30 RQ-4s.

The proposal was driven by America's change of emphasis from fighting wars in the theatres around southwest Asia to meeting the threats presented by Russia and China. Given the precarious aspects of sustaining the Global Hawk fleet caused by a shortage of parts, and its vulnerability to threats, the Global Hawk was an easy target for Department of Defense cost cutting.

This proposal was not the first time the Air Force had targeted its Block 30 Global

On February 15, NATO's Supreme Allied Commander Europe, General Tod Wolters, declared initial operational capability for NATO's RQ-4D system. NATO

"The US Air Force wants to retire all three air vehicles in the coming years."

Hawk fleet for reduction, the service had tried the same tactic in its FY2014 budget proposal. Congress rejected the proposal and the alternate to chop the U-2, after which the Air Force left both types untouched. Congress would only agree to the proposal if the secretary of defense certified two things - that Global Hawk divestment would not prevent combatant commanders from completing their missions, and that the capability of a replacement system would be worth higher costs for operations and sustainment.

As a result of congress' rejection, the Air Force considered ideas for improving its older Block 20 EQ-4Bs and Block 30 RQ-4s and other proposals to extend the service life of its Block 40 aircraft assigned to the 319th Reconnaissance Wing based at Grand Forks Air Force Base, North Dakota.

The fate of the three EQ-4B BACN-equipped aircraft appeared to gain certainty on January 26, 2021 when Northrop Grumman was awarded a new support contract worth up to $3.6bn, to support the BACN-equipped EQ-4B and E-11A aircraft through 2026.

Despite the provision for support of the EQ-4B, the US Air Force wants to retire all three air vehicles in the coming years and replace them with a software system called gateway One capable of translating machine code transmissions between incompatible types, as developed as part of the broader Advanced Battle Management System.

But the FY2021 National Defense Authorization Act (NDAA) included the following warning to the Air Force in respect of the EQ-4B aircraft: "The conferees remain concerned regarding the potential decrease in airborne network communications capacity and capability resulting from the Air Force decision to divest EQ-4B platforms, and the impacts this could have on the geographical combatant commands, specifically US Central Command. Therefore, the conferees expect the Secretary of the Air Force, in coordination with the associated US air component commanders for each relevant geographical combatant command areas of responsibility, to provide equal or greater capability and capacity for battlefield airborne communications and networking, noting the Secretary's planned inventory quantity increases of manned E-11 aircraft systems that was similarly provided by both the unmanned EQ-4B and the E-11A aircraft systems combined."

Despite the warning, lawmakers approved the Air Force plan in the FY2021 NDAA, which became law on December 27, 2020.

But Air Force leadership was not done with its pursuit to retire its Block 30 Global Hawks as outlined by acting Air Force Secretary John Roth and Chief of Staff General Brown in written testimony to Congress, which cited the need to repurpose Block 30 RQ-4 funds for a new penetrating ISR capability. Roth and Brown stated that: "Tomorrow's conflicts will be contested. Moving beyond the RQ-4 would allow the Air Force to bring the ISR enterprise into the digital-age by using sensing grids and fielding advanced technology that includes penetrating ISR platforms."

The battle for Global Hawk continues. ●

RQ-4B GLOBAL HAWK CHARACTERISTICS

Primary function: High-altitude, long-endurance ISR
Power Plant: One Rolls Royce-North American F137-RR-100 turbofan engine rated at 7,600lb
Wingspan: 130ft 10in
Length: 47ft 7in
Height: 15ft 3in
Weight: 14,950lb
Max take-off weight: 32,250lb
Fuel Capacity: 17,300lb
Payload: 3,000lb
Speed: 310kts
Range: 12,300nm
Endurance: More than 34 hours
Ceiling: 60,000ft
Initial operational capability: 2011 (Block 30); 2015 (Block 40)
Source: US Air Force

LONG ENDURANCE MARITIME SURVEILLANCE

Mark Ayton spoke with MQ-4C Triton programme representatives based at Naval Air Stations Patuxent River, Maryland and Jacksonville, Florida to learn about this fascinating unmanned aerial system.

Early last year, launch, recovery, and maintenance teams for the MQ-4C Triton were deployed to Andersen Air Force Base, Guam in support of the type's Early Operational Capability (EOC). It represented a major milestone for PMA-262, the Persistent Maritime Unmanned Aircraft Systems Program Office based at Naval Air Station Patuxent River, Maryland.

The US Navy had defined the MQ-4C Triton's EOC requirement as having a main operating base and a forward operating base in operation, with two air vehicles at IFC 3 baseline configuration and deployed outside of the continental United States.

PMA-262 achieved that with a pair of MQ-4C Triton air vehicles, each configured with a software load named Integrated Functional Capability 3.2 (IFC 3.2) which represents the operational baseline standard for a vehicle without a multi-intelligence capability.

At Patuxent River, PMA-262 continues to develop the next software load standard, IFC 4, which will introduce an enhanced multi-intelligence sensor system in accordance with the Navy's maritime intelligence, surveillance, reconnaissance and targeting transition plan.

Developed and built by Northrop Grumman, the MQ-4C Triton is designed to acquire unprecedented situational awareness of the battle space to shorten the sensor-to-shooter decision loop (reaction time) in the maritime and coastal domains. The unmanned aerial system is also the first high altitude, long endurance aircraft that can conduct persistent intelligence, surveillance, reconnaissance missions to complement Boeing's P-8A Poseidon in the maritime domain.

Integrated Test Team

Located in a purpose-built facility at Naval Air Station Patuxent River, the Triton Integrated Test Team (ITT) is equipped with three air vehicles, a hangar wide enough to house all three aircraft, wingtip to wingtip (an MQ-4C boasts a 130ft 10in wingspan) and each type of control station required for its ongoing flight test programme including those to be used at forward operating sites.

It's worth noting the Triton ITT comprises personnel from the both developmental and operational test authorities based at Patuxent River: Air Test and Evaluation Squadron 20 (VX-20) and Air Test and Evaluation Squadron1 (VX-1) 'Pioneers', respectively.

There are many aspects to the MQ-4C Triton and its missions. Some are fascinating. Based on the Northrop Grumman RQ-4 Global Hawk, the MQ-4C looks very similar, but looks can deceive. Under the skin, the MQ-4C has strengthened wing structures, an anti-ice and de-icing system, and a suite of systems all of which make the US Navy variant different from its US Air Force brethren.

MQ-4C Triton aircraft, BuNo 168457 and 168458, at Northrop Grumman's test facility in Palmdale, California. US Navy/Northrop Grumman/Chad Slattery

Northrop Grumman

Operational Assessment

Throughout the second half of 2015 the Triton ITT and PMA-262 were busy with the integration effort of software load IFC 2.2, the configuration required for the Triton system's first operational assessment (OA). This event was designed to provide the ITT and PMA-262 with information to help guide the focus of continued testing leading up to the operational evaluation period. Conducted between November 2015 and January 2016, the OA involved six flights, the longest of which was over 12-hours in duration, and about 60 hours of flight time to test Triton's envelope performance and its sensor suite comprising:

- A ZPY-3 multi-function active sensor active electronically steered array (MFAS AESA) maritime surveillance radar designed to detect, identify, and track surface targets and produce high-resolution imagery.
- A DAS-3 MTS-B electro-optical/infrared sensor to capture full motion video and still imagery of surface targets (the air vehicle's camera).
- A ZLQ-1 electronic support measures system which detects, identifies, and geo-locates radar threat signals.
- An automatic identification system (AIS) receiver which permits the detection, identification, geolocation, and tracking of cooperative maritime vessels equipped with AIS transponders.

Operationally representative in its construct, the OA also provided the Triton ITT with the opportunity to test the on board line-of-sight and beyond line-of-sight datalink and transfer systems. These provide air vehicle command and control and transmit sensor data from the air vehicle to the mission control stations for dissemination to fleet tactical operation centres and intelligence exploitation sites.

Over the course of the six flights, crews were able to get Triton on station effectively and provide real-time updates to the Navy end user. Crews also found ways to improve functionality for fleet operators using procedural changes and identified tweaks to the software that led to a better user interface. One example was the reduction in the number of command pushes required for a given function.

During the six flights, flight test crews looked at the stability of the sensors, the functional capability of the camera system, the full suite of communication systems (radio, line-of-sight, and satellite) and checked sensors, communications and interoperability with a simulated surface combatant generated by the Surface Aviation Integration Laboratory (SAIL) at Patuxent River. The SAIL was also used to simulate different types of US Navy aircraft – the P-8A Poseidon was one example – to simulate interoperability with Triton in the mission sets conducted during the six flights.

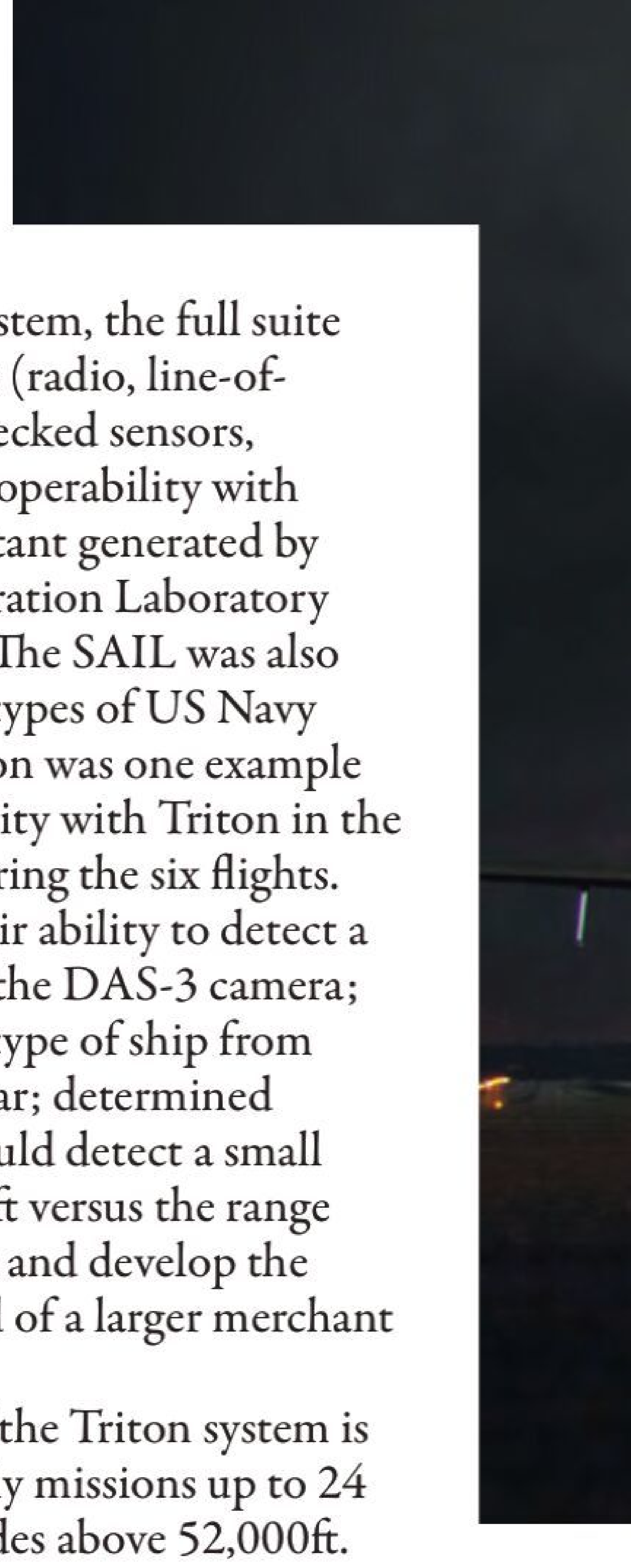
Test crews evaluated their ability to detect a certain size of vessel using the DAS-3 camera; to detect and identify the type of ship from range using the ZPY-3 radar; determined the range at which they could detect a small fishing boat or a patrol craft versus the range at which they could detect and develop the position, course, and speed of a larger merchant combatant ship.

A noteworthy aspect of the Triton system is its objective capability to fly missions up to 24 hours in duration at altitudes above 52,000ft. Such a sortie enables its mission systems to monitor two million square miles of ocean and littoral areas.

The 2016 OA demonstrated an initial assessment of the ability to get an MQ-4C Triton on station effectively and provide real-time updates to the Navy end user via the on board line-of-sight and beyond-line-of-sight datalink and transfer systems.

Post-OA, the ITT conducted an initial assessment in order to allow PMA-262 and Northrop Grumman to improve the system's functionality. Consequently, numerous upgrades have been made to the system including a better user interface with improved displays.

In June 2016, the ITT team undertook the first missions to increase Triton's heavy weight envelope to a full fuel payload - a critical requirement if the MQ-4C is to attain a 24-



MQ-4C Triton BuNo 168457 during an early test flight from Palmdale California. This image clearly shows the configuration of the aft fuselage, engine, and vertical stabilisers. US Navy/ Northrop Grumman/Chad Slattery

An MQ-4C Triton under tow at Andersen Air Force Base, Guam. US Navy/Mass Communication Specialist MacAdam Kane Weissman

hour flight duration. On the first mission, a Triton in heavy weight configuration, completed all test objectives while operating in a 20,000ft altitude band followed by a second flight operating in a 30,000ft altitude band. Since then, the ITT and PMA-262 successfully attained mission durations longer than 24 hours at altitudes above 52,000 feet in heavy weight configuration.

Ground test activity started with IFC 3.1 in January 2017. This software load included improvements to functionality of the ZPY-3 radar (temperature management), DAS-3 MTS-B sensor (control), ZLQ-1 electronic support measures system (interface), AIS and basic communications relay. The improvements allowed the MQ-4C to achieve EOC and deliver a capability to survey a huge swathe of sea surface coverage to operational commanders.

Operating Triton

The Navy's Triton concept of operations (CONOPS) is to have an air vehicle operating thousands of miles away from the control station, two of which are planned at two locations: Naval Air Station Jacksonville, Florida and Naval Air Station Whidbey Island, Washington.

At Patuxent River, things differ to the

"Like any other aircraft, a Triton mission starts with mission planning."

fleet's CONOPS simply because the control stations are co-located with the aircraft, which means the air vehicle operator (AVO) can operate as the local crew with the aircraft (UA) or as the remote crew. In fleet service there will be two disparate crews: one on detachment with the UA and a mission control station at the forward operating base (FOB) and one back at the main operating base (MOB).

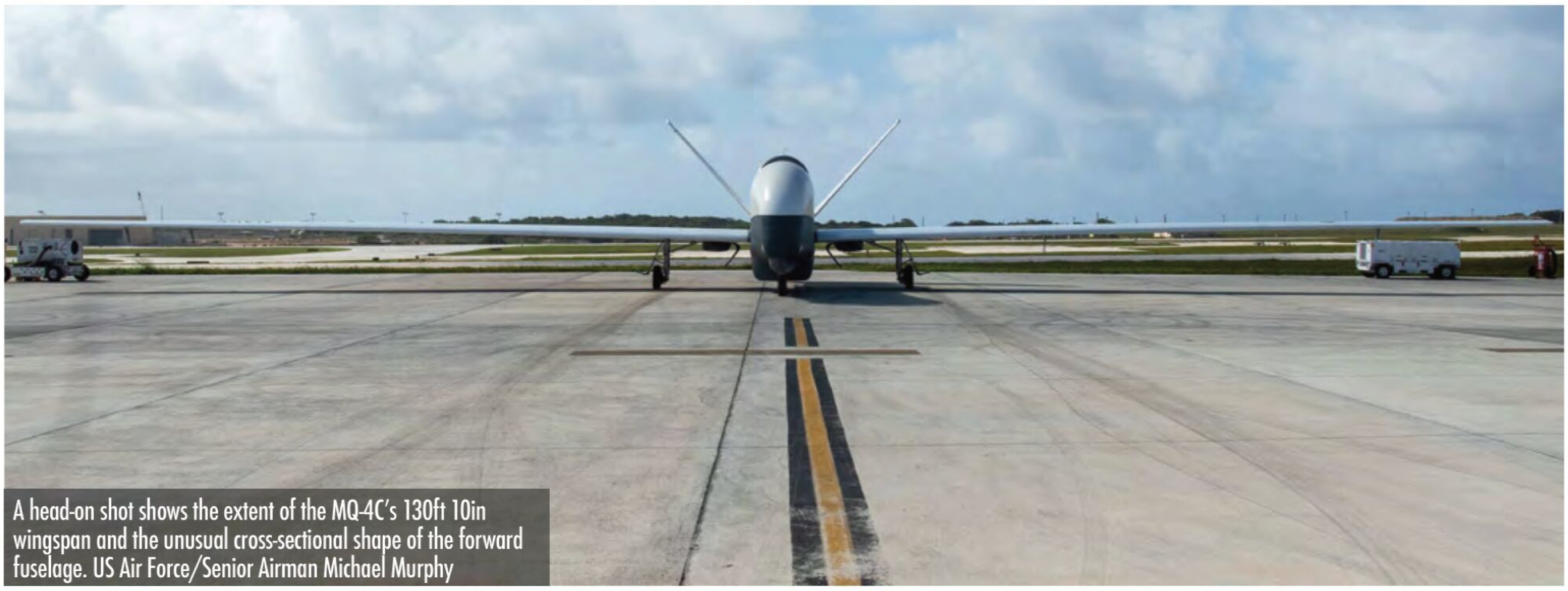
Like any other aircraft, a Triton mission starts with mission planning and preparation work between the crew, which comprises an AVO who is also the UAC (unmanned aircraft commander), a tactical coordinator (TACCO) and two mission payload operators (MPOs). The AVO has responsibility for the safe flight of the aircraft and its positioning for the tactical employment of the sensors. The TACCO is responsible for coordinating the tactical picture and the MPOs operate the sensors from their control stations. All members of the crew have pre-flight duties.

Before the aircraft is spotted (the colloquial term for parking the aircraft on a specific spot on the flight line) the crew start mission briefings covering the safety, specific items, tasks, and goals of the day as well as the particulars needed for the pre-flight.

Teams then start their respective duties whether at the aircraft or at their control station. At Patuxent River, the UAC goes to the aircraft to conduct a walk around for pre-flight. That's unique, because in the fleet the aircraft is at the FOB. The difference between operations at Patuxent River and the fleet's CONOPS is the UAC will be at the MOB and will have to delegate the walk around to the local AVO, someone who is qualified to do that at the FOB. At Patuxent River the UAC is with the aircraft.

Once the UAC has completed the walk around, the aircraft is handed over to the test controller, the person who ensures everything is buttoned up and secured on the aircraft. The UAC then goes to maintenance control to sign what's called the 'A sheet' - the flight release - and takes responsibility for the aircraft as released by the maintenance department.

As mentioned earlier, the Triton system differs to a conventional aircraft in several ways, not least its mission duration. Flying for over 24 hours requires the crew to swap ➲



A head-on shot shows the extent of the MQ-4C's 130ft 10in wingspan and the unusual cross-sectional shape of the forward fuselage. US Air Force/Senior Airman Michael Murphy

for each of the mission's multiple phases to ensure safe operation throughout. In fact, the Navy has had to adjust its operating procedures to allow for a change of the aircraft's commander in flight. The original or previous UAC, the original signatory for the aircraft, ensures the next UAC signs a new A sheet to take responsibility for the aircraft during his or her phase of the mission. This handover process continues until the aircraft lands. In fleet ops the handover process is not so straightforward because the UAC is at the MOB and the aircraft is at the FOB. Devising a procedure for such a handover is a detail the Triton fleet integration team continues to refine during the ongoing detached ops from Andersen Air Force Base.

Mission Control Stations

Two mission control stations (MCS) are used for all flight operations: a FOB MCS and a MOB MCS. The intent for the AVO at the forward base, who is within line-of-sight of the aircraft, is to control the aircraft on the ground, perform the take-off and the initial climb-out. He or she will then hand over control of the aircraft to the main base. All control stations have the ability to control the aircraft and maintain command and control of the aircraft simultaneously. The intent of the CONOPS is for the FOB operator to release command and control once it's under the control of the MOB whose crews fly the mission. Upon return to base, the aircraft is handed back to the forward-based AVO for the final descent, landing and ground taxi input.

"Projected Triton development costs had increased by 61%."

Autonomous Taxi

The operator controls the air vehicle using a keyboard, a mouse, and a mission plan. The latter is developed and built from the start spot to the shutdown spot, the so-called spot-to-spot. Commands given to the aircraft by the AVO are fairly straightforward: taxi execute, stop execute, and take-off execute. Once taxi execute is given, the aircraft taxies to the runway autonomously in accordance with the mission plan's route.

If the AVO commands the aircraft to taxi it will taxi. If the air vehicle loses control from the control station it will automatically stop, and the AVO can stop the taxi at any time. When the air vehicle takes to the runway it will not take-off unless it's given a direct command from one of the two control stations. Automatic logic is built into the air vehicle's control system and has most significance in the event of an aborted take-off. A manual abort command is also available to the AVO faced with such an incident.

A second crew driving a ground chase vehicle work with the air vehicle crew during taxi and take off. The crew in the vehicle watch for obstructions, and other aircraft or airfield traffic in the way, and remain in constant radio contact with the control stations. When the aircraft takes to the runway, the car follows. When the aircraft is commanded to release the brakes, the car driver accelerates as best they can to keep up with the aircraft, almost like a formation take off. When the aircraft lifts off which can be at just over 100kts depending on its weight, the car exits the runway. In the event of an emergency situation, the air vehicle crew can abort take off at speeds between 90 and 100kts.

For landing, the driver positions the car at the end of the runway holding short. As soon as the aircraft passes the car, the driver follows the aircraft in almost a formation landing. During take off and landing, the car crew run through data cards just like any other aircraft and know if the air vehicle has achieved enough speed and distance to attempt take off or abort, and enough distance in the event that take off is necessary for an immediate return to land.

"Once the aircraft has stopped on the runway, the operator selects the taxi command, and the aircraft autonomously taxies to the shutdown spot as programmed."

Control When Airborne

Once airborne, the aircraft follows its mission plan route. Local air traffic control (ATC) has details of the route because it can be close or different to the local departure and arrival patterns. What's more interesting about ATC coordination is manual flying. Because there is no one on board the aircraft, manual flying requires extra coordination to look out for other traffic. The air vehicle crew works with ATC just like any other aircraft and remain in communication with the controller to ensure the aircraft remains in a safe position, especially in the event of a malfunction.

The mission plan and its route are created for autonomous control such that the aircraft autonomously follows the route and executes all instructions within the plan. However, the crew can gain manual control of the aircraft at any time using different commands. Examples include limiting the altitude while the air vehicle continues to follow the mission plan or if air traffic control instructs the operator to climb and maintain an altitude, the operator manually enters a heading and the required altitude. Another example is the command for flying a left or right 360° orbit at a specific altitude. If the AVO is told to keep the aircraft within a certain sector of airspace, the operator can enter go-to waypoints that are different to those in the mission plan. These ensure the aircraft stays within the new area while continuing to fly to the next planned way points, and if required at a different altitude.


US Navy/Northrop Grumman/Chad Slattery

If the control station loses the link, the aircraft has built in logic to autonomously recapture the mission plan and execute one of many different contingencies. These include flying itself back to its base or in the event of an emergency, flying to a diversion field or to a ditch point where the aircraft will safely ditch away from areas of population. Contingencies are pre-programmed for emergency situations whether or not the aircraft is on the mission plan route.

The air vehicle operator is responsible for making sure the aircraft is tied to the correct logic point for the real time situation, however during the mission the operator can manually fly the aircraft using commanded airspeeds, altitudes, headings, tracks, 360° patterns in both directions to prosecute a target, or find, identify, and follow a target of opportunity as needed.

Once a target of opportunity is done with, the operator can command the ➲

At the final approach fix, the air vehicle's system switches to glide scope mode, and lines the aircraft up on the centre of the runway. US Navy/Northrop Grumman/Chad Slattery

aircraft to return to its programmed route. If the aircraft senses the AVO is no longer on the link, it autonomously returns to the mission plan and executes whatever contingency logic is appropriate for the situation.

Mission plan areas are wide because the Triton flies so high for so long such that a carrier strike group commander's request to check a potential target of concern may already be covered by the mission plan area.

Logic to autonomously recapture the mission plan and execute one of many different contingencies is already built-in to the system, but the Navy has a requirement to upload a new mission plan in flight. PMA-262 would not confirm if the latter capability is already integrated on MQ-4C air vehicles assigned to the fleet.

Recovery

When an aircraft is at the end of its on station time and/or fuel load, and must return to base, the CONOPS is to replace it with another Triton which should arrive on station to provide continuous coverage of the area of operation. Once close to its forward operating base, the aircraft descends into the terminal area, and is handed over to the FOB AVO (although either control station can control the aircraft) and sets up for one of a number of different approaches pre-programmed in the mission plan, each to suit weather conditions at the FOB. Upon arrival at the initial approach fix the landing gear is lowered, and if not already done, the sensors are switched off. At the final approach fix the system switches to glide scope mode, and lines the aircraft up on the centre of the runway. On approach, the aircraft uses radio altimeters and four different navigation controls, two of which are for air vehicle navigation (the aircraft and its logic know it's geospatial location and its energy state) which control its approach flight with standard spoilers and engine throttle commands. When the system senses the runway, the aircraft flares, touches down, engages the brakes, and stops on the runway centreline. If the system fails its own internal landing check, it waves itself off and climbs out and returns to the pattern to make another approach to land. A wave off can also be manually selected by the AVO who can also manually fly the aircraft around the pattern for another autonomous approach to land.

Once the aircraft has stopped on the runway, the operator selects the taxi command, and the aircraft autonomously taxies to the shutdown spot as programmed.

"The operator controls the Triton using a keyboard and mouse."

Milestone C and IFC 4

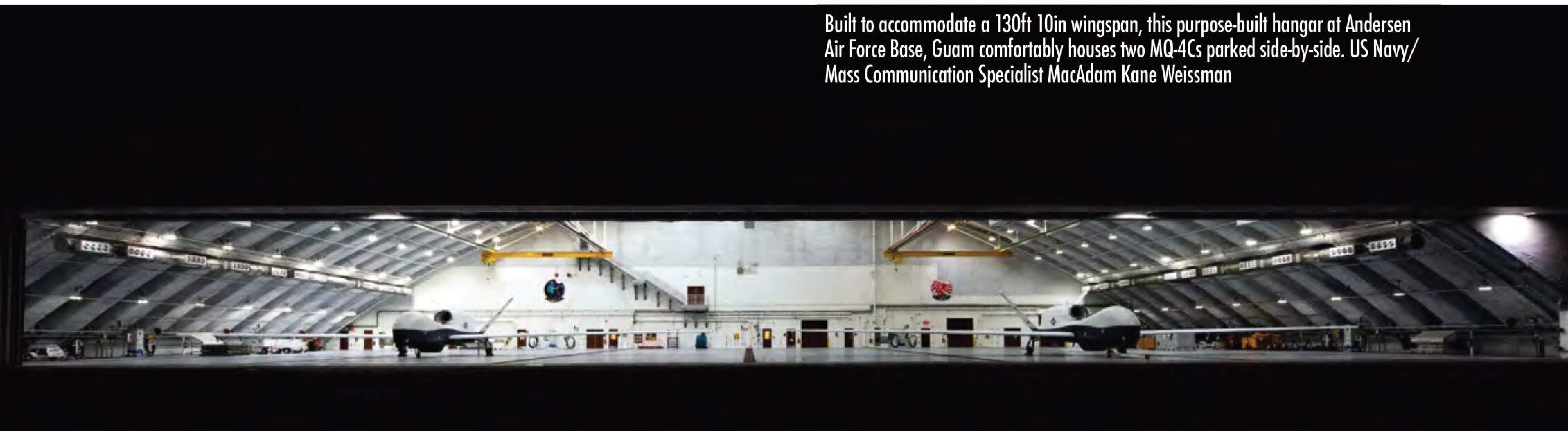
In conjunction with the MQ-4C Triton's Milestone C approval in September 2016, PMA-262 changed its acquisition strategy for the system by moving its initial operational test and evaluation (IOT&E) from Q4FY2017 to Q4FY2020. The change was made to align IOT&E with the development and fielding of IFC 4: the aircraft's all-important Multiple Intelligence (Multi-INT) capability and its full operational configuration.

The Multi-INT system will provide Triton with an ELINT (electronic intelligence) and SIGINT (signals intelligence) capability, and includes sensors, supporting software and hardware, which permit processing of classified sensitive compartmented information.

The Multi-INT configuration will augment the maritime ISR capability currently provided by the P-8A Poseidon and will ultimately replace the EP-3E Aries II intelligence gathering aircraft for most missions - one of the main objective roles of the Triton system.

In September 2020, two of the three Triton aircraft assigned to the Pax-based ITT were

The first MQ-4C Triton made the type's inaugural cross-country ferry flight from Palmdale, California to Naval Air Station Patuxent River, Maryland overnight on September 17-18, 2014. Naval Air Systems Command/Erik Hildebrandt



Built to accommodate a 130ft 10in wingspan, this purpose-built hangar at Andersen Air Force Base, Guam comfortably houses two MQ-4Cs parked side-by-side. US Navy/ Mass Communication Specialist MacAdam Kane Weissman

MQ-4C Triton BuNo 168460/PE in the hangar at Andersen Air Force Base after arriving for the EOC deployment. The aircraft has the tail markings of Unmanned Patrol Squadron 19 (VUP-19). US Air Force/Senior Airman Ryan Brooks

being upgraded to the IFC 4 configuration along with an MOB and FOB modified in accordance with the Multi-INT mission. The first aircraft had commenced post-upgrade shakedown testing. Both aircraft are now being used by the ITT for the IFC 4 end-to-end flight test programme. According to PMA-262, there is no EOC planned for the Multi-INT configuration.

Initial operational capability declaration of IFC 4 will directly follow Triton's IOT&E and is planned for Q4FY2022.

MQ-4C production will be reduced in FY2021 and FY2022 based on the decision to strategically pause procurement of two air vehicles to focus on the development of SIGINT capabilities, part of the IFC 4 Multi-INT system. PMA-262 expects to resume production in FY2023.

A May 2019 US Government Audit Office report found the projected Triton development costs had increased by 61% from $3.5 billion in 2009 to nearly $5.7 billion in October 2018. This is in part due to the Navy's introduction of an advanced Multi-INT collection system to the programme of record - a major change to the system's original brief taken at the Triton Milestone C Baseline Requirements approval in September 2016. In addition, the programme experienced challenges associated with SIGINT integration and realised the risk of the required rework to improve passive and active collection thresholds. Both factors increased the time required to successfully incorporate the Multi-INT capability and delayed its initial fielding by approximately 22 months. The MQ-4C programme has been revised to deliver smaller increments of capability to flight test in order to reduce risk of additional cost growth and delay.

Northrop Grumman says it has been trying to reduce costs on the Triton programme. When asked by the author what steps had been taken to achieve cost reduction the company said: "The original requirements for the MQ-4C Triton did not include the multi-intelligence capability, which was added as a requirement in 2016 to enable the retirement of the EP-3E Aries II. Our partnership with the Navy has been critical in defining requirements throughout the evolution of the Triton programme, and Northrop Grumman has taken a number of steps to drive down programme costs. This includes building a new production site at our Palmdale facility, where we have implemented lean manufacturing processes to create efficiencies."

This image of MQ-4C Triton BuNo 168460/PE at Andersen Air Force Base shows the articulation of the engine air inlet on the top of the aft fuselage, the radome of the ZPY-3 radar on the mid under fuselage, and the DAS-3 MTS-B sensor below the forward fuselage. US Air Force/Senior Airman Michael Murphy

EOC, VUP-19 and Guam Ops

In June 2019, PMA-262 and the ITT concluded an operational assessment of the IFC 3 baseline configuration to support an early fielding decision of the MQ-4C Triton. According to the Director, Operational Test and Evaluation (DOT&E) FY2019 report, poor reliability, system immaturity, and weather prevented PMA-262 and the ITT from completing the test in accordance with the DOT&E-approved test plan.

Five test flights were launched between July 2018 and May 2019, accruing 58.6 flight hours; the planned test was nine flights totalling 192 flight hours over three weeks. DOT&E published a classified OA report in December 2019.

DOT&E's 2019 assessment of the MQ-4C Triton said that suitability deficiencies related to reliability, documentation, training, and human-system interfaces interfered with the execution of the OA. The report also stated that the deficiencies also contributed to the loss of MQ-4C BuNo 168461 in a gear-up landing at Naval Air Station Point Mugu, California on ➲

September 12, 2018. The aircraft, assigned to VUP-19 experienced an inflight mechanical issue during a test flight. As a precautionary measure, the AVOs shut down the engine and attempted to safely land the aircraft on the runway at Point Mugu. The aircraft's landing gear did not deploy, and the aircraft landed on the runway with its landing gear retracted.

MQ-4Cs used in the 2019 OA were configured with IFC 3.1, a standard that lacks the capability to disseminate maritime surface track data via Link 16 or the Global Command and Control System–Maritime. In September 2019, PMA-262 updated the air vehicle configuration to IFC 3.2 which provided the track data dissemination capability.

PMA-262 has also demonstrated a Due Regard Alternative Means of Compliance (DRAMOC) for the EOC, which alleviates, but does not eliminate, constraints on free navigation in the EOC area of operations. Naval Air Systems Command's Airworthiness Technical Authority certified the use of the Triton's sub-systems and NATOPS procedures to safely de-conflict from other aircraft from VUP-19's Tritons (employing the DRAMOC) during operations under due regard procedures in the 7th Fleet's area of responsibility. According to the DOT&E 2019 annual report, the DRAMOC is necessary because without it, employment of the MQ-4C will be tightly constrained until delivery of the air traffic collision avoidance radar system estimated for FY2024.

The Triton programme office has also exercised the TCPED (tasking collection processing exploitation and dissemination) process which delivers real time information about targets within the air vehicle's 360° field of view to both forward deployed naval forces and the US national intelligence community.

Unmanned Patrol Squadron 19 (VUP-19) 'Big Red', the Navy's first unmanned air vehicle squadron are currently operating two Triton air vehicles from Andersen Air Force Base, Guam. Flight operations for the EOC started in May 2020 with a mission tasked by the commander task force 72, the US Navy 7th Fleet's maritime patrol and reconnaissance command.

"The aircraft landed on the runway with its landing gear retracted."

Back-end mission crew, administrative and executive functions are performed from the squadron's facilities at Naval Air Station Jacksonville, Florida. Maintenance leadership and maintainers are stationed at Naval Air Station Point Mugu, California, and forward-deployed maintainers and aircrew are operating from Andersen Air Force Base, Guam.

At Andersen, VUP-19 is supporting current operations for various task forces across the Indo-Pacific, participating in advanced training events simultaneously interacting in multiple warfare domains. The squadron is also further developing a concept of operations, and fleet learning associated with operating a high-altitude, long-endurance system in the maritime domain.

No doubt, some missions are being flown to directly support P-8A Poseidon maritime surveillance aircraft operating around the Pacific to increase the capabilities available from the two aircraft in a manned-unmanned teaming concept.

A Triton can track a surface target using its DAS-3 MTS-B camera and download full motion video to a P-8 crew positioned some distance away via a common datalink, thereby helping to build situational awareness of the battle space. In an operational scenario, this capability enables the P-8 crew to familiarise with a target of interest and any surrounding vessels well in advance of the Poseidon's arrival on station.

Supporting this manned-unmanned cooperation between an MQ-4C and a P-8A, the Triton force comprises aircrew who are nearly all second or third tour personnel from the Maritime Patrol and Reconnaissance Force. That means each one has completed multiple operational tours with either a P-3, P-8, or EP-3 squadron before they transition to Triton operations. This experience enables them to quickly learn the Triton mission and tactics, and better integrate with P-8 crews on station.

EOC is specifically designed to develop concepts for incorporating the MQ-4C into the maritime domain mission set to augment the Navy's P-8A Poseidon and EP-3E Aries aircraft. Akin to a low earth orbiting satellite, the MQ-4C is a long-dwell system and a force multiplier within the family of aircraft flown by the Navy's Maritime Patrol and Reconnaissance Force (MPRF). The MQ-4C is designed to provide cueing data to any of the MPRF aircraft types and identify vessels and areas of interest that manned aircraft can further investigate with their respective sensor suites.

VUP-19, in coordination with Patrol and Reconnaissance Wing 11 and the Pacific theatre commanders, established a multi-phase approach to EOC. The teamed organisations devised a series of metrics to measure sensor performance, crew familiarisation, and fleet integration, until a point when the commander of the Pacific Fleet was comfortable with declaring EOC based on the squadron's successful and effective performance on station. A culmination test was set in which an MQ-4C was tasked to conduct operations for a dynamic problem set and provide commanders with real-time intelligence.

Throughout the EOC deployment, Combined Task Force 72 and the 7th Fleet are using opportunities ranging from direct support missions, exercise involvement, and real-world ISR operations in theatre to develop the CONOPS and fleet learning associated with operating a high-altitude, long-endurance unmanned air vehicle in the maritime domain. More specifically, each mission and integration event with any Navy or joint service asset deployed around the theatre provides ways for the fleet and joint services to understand and properly utilise Triton capabilities to meet the commander's requirements.

By October 1, 2020, the two aircraft had flown more than 765 hours from Andersen.

Despite the ongoing success achieved by

US Air Force/Senior Airman Michael Murphy

VUP-19, the Triton programme faced budget challenges last year. The Department of Defense's budget request for FY2021 contained a two-year production pause in 2021 and 2022, a Trump administration proposal designed to allow Northrop Grumman and PMA-262 to focus on the full development of the Multi-INT IFC 4 configuration. However, a production pause posed a significant risk to Northrop Grumman and PMA-262's ability to keep costs low, deliveries on track, and avoid negative effects on the MQ-4C production line and supplier base.

Northrop Grumman estimated that stopping and restarting the line alone would cost roughly $150 million and $20 million more for each subsequent aircraft produced. The company held talks with the Congress and Naval Air Systems Command about sustaining the production line, protecting suppliers, and supporting the programme long-term.

Under the MQ-4C Triton Development, Production and Sustainment Cooperative Program, the RAAF will retain Cooperative Project Personnel (CPP) embedded within the Navy team for the next decade. Australian personnel are working with teams dedicated to engineering, research and development, and flight test.

Concurrent discussions were held with the Australian Department of Defence about filling FY2021 and FY2022 slots to prevent a production pause, and the resultant cost savings for both the US Navy and the Royal Australian Air Force.

The Australian National Security Committee (NSC) approved acquisition of the first Triton aircraft in June 2018; a second in March 2019, a third in June 2020 and finalisation of contracts for the remaining three, the acquisition approvals were expected to follow. Production of the first Australian aircraft was due to begin in October 2020.

"Production of the first Australian aircraft was due to begin in October."

The Triton programme avoided an MQ-4C production freeze thanks to a US Navy contract awarded to Northrop Grumman for one air vehicle in low-rate initial production (LRIP) Lot 5 valued at $98.9 million announced on March 26, 2021. The air vehicle is currently in production at Northrop Grumman's facility at Air Force Plant 42 in Palmdale, California.

Back at Patuxent River, in mid-April, PMA-262 organised the airlift of a deployable trailer housing a Forward Operating Base (FOB) from the Maryland base to Andersen, Guam. The move is designed to provide the Maritime Patrol and Reconnaissance Fleet with additional capability for operations this summer. According to PMA-262, the new FOB will enable VUP-19 to support operations from nearly any US facility in the world. ●

MQ-4C Triton BuNo 168460/PE taxis at Andersen Air Force Base. US Air Force/Senior Airman Michael Murphy

ON THE PERCH

Mark Ayton details the Northrop Grumman MQ-8B Fire Scout, the first rotary unmanned air vehicle to serve with the US Navy.

An MQ-8B Fire Scout assigned to Helicopter Maritime Strike Squadron 35 (HSM-35) Detachment 1 ready for flight operations aboard Littoral Combat Ship USS Fort Worth (LCS 3). US Navy Mass Communication Specialist Antonio Turretto Ramos

I watched an MQ-8B approach its landing spot moving quietly and slowly, the Rolls-Royce-powered, unmanned helicopter remained perfectly level and visibly stable. It was in the hover 50ft above the ground, a position commonly known as the perch and under the control of an air vehicle operator sitting in a control room housed in a nearby trailer. As I continued to watch, the 30ft-long Fire Scout effortlessly descended to touch down. What seemed like a perfect landing was executed by the pilot with the click of his mouse and to this observer, it was an amazing sight.

The aircraft, one of 30 in the US Navy fleet, was assigned and operated by Naval Air Systems Command's Air Test and Evaluation Squadron 24 (UX-24), previously the Unmanned Aircraft Systems Test Directorate. The squadron is based at Webster Field, an outlying airfield to Naval Air Station Patuxent River, the home of Naval Air Systems Command (NAVAIR).

MQ-8B Fire Scout

The MQ-8B Fire Scout is a vertical take-off and landing tactical unmanned aerial vehicle system built by Northrop Grumman and based on the Schweizer 333 civilian helicopter. Commonly referred to as an air vehicle, the MQ-8B measures 30ft long, 9ft 4in high, has a rotor diameter of 27ft 6in, a top speed of 110kts, operates to a service ceiling of 20,000ft and a max take-off weight of 3,150lb.

George Vadoulakis, vice president and program manager of tactical unmanned systems for Northrop Grumman Aerospace explained when we spoke back in 2013: "The modular architecture accommodates a variety of electro-optical, infrared, and communications payloads that provide ground- and ship-based commanders with high levels of situational awareness and precision targeting support.

"The system has been in development for about 10 years and is well suited to support LCS missions such as drug interdiction, anti-piracy, search and rescue, and reconnaissance operations."

What's clever about the Fire Scout is its ability to take off autonomously and land on any warship equipped with a landing deck, or on prepared and unprepared landing zones.

Fire Scout's ground control system encompasses the tactical control system (TCS) software developed for US Navy ships, tactical data links and a communications relay system.

An MQ-8B's baseline payload includes a FLIR Systems BRITE Star II electro-optical/infrared (EO/IR) sensor and laser rangefinder/target illuminator.

Northrop Grumman lists the Fire Scout with an endurance of up to eight hours, which allows an MQ-8B to provide more than six hours' time on station with a standard payload at 110nm from the launch site or warship. The company also lists that a system of two Fire Scouts can provide continuous coverage at the same 110nm range. The 30ft-long unmanned helicopter can detect, identify, and provide accurate targeting data to Navy strike aircraft and helicopters, perform battle damage assessment, and downlink full motion digital video.

The Fire Scout system provides fully autonomous operation of the air vehicle and its payload, with the flexibility of having a wide variety of override commands available to the operators through the control system (CS). The CS also displays payload imagery, air vehicle status and situational information to the operators. Payload information can be disseminated via the C4I (command, control, communications, computers, and intelligence) architecture of the GCCS-M (global command and control system - maritime) and other C4I nodes.

All data is available through the Fire Scout's signal entry panel, including RS-170 video, fibre optics, ethernet, fibre optic ethernet and two data transfer protocols called asynchronous transfer mode and fibre distributed data interface.

The air vehicle operator (AVO), a mission payload operator (MPO) and a mission computer (MC) are all seated in the CS, equipped with the US Navy's TCS and tactical common datalink (TCDL). The crew can use the control system to undertake pre-mission planning for the air vehicle and payload, and also enables them to upload new missions in real-time and perform override control of both the air vehicle and its payload.

The US Navy purchased 30 MQ-8B Fire Scout air vehicles. The last two aircraft were delivered in 2013 after which production ceased.


Aviation specialists run checks on the maintenance status of an MQ-8B on the flight deck of USS Gabrielle Giffords (LCS 10). US Navy/Mass Communication Specialist Brenton Poyser

Operations

The MQ-8B's operational use began in 2010 while embarked on the guided-missile frigate USS *McInerney* (FFG 8) operating in the 4th Fleet area of operations. During the drug interdiction mission, an MQ-8B Fire Scout helped confiscate 130lb of cocaine from a fast boat. The next operational mission was flown from the frigate USS *Halyburton* (FFG 40) underway in the 5th Fleet area of operations. An MQ-8B Fire Scout provided overland ISR for special forces operations in Somalia.

Captain Patrick Smith, NAVAIR's program manager for the MQ-8B Fire Scout at the time of the author's visit to Webster Field highlighted the operational achievements, when four Fire Scouts were deployed aboard the USS *Klakring* back in 2012. This was particularly noteworthy because it was the first time that as many as four MQ-8Bs were embarked on board a US Navy ship, with the added innovation that

"The MQ-8B Fire Scout is a vertical take-off and landing tactical unmanned aerial vehicle system built by Northrop Grumman and based on the Schweizer 333 civilian helicopter."

US Navy/Mass Communication Specialist Anderson Branch

An MQ-8B Fire Scout assigned to Helicopter Sea Combat Squadron 22 (HSC-22) 'Sea Knights' takes off from the flight deck of Littoral Combat Ship USS Milwaukee (LCS 5). US Navy/ Mass Communication Specialist Nathan Beard

"MQ-8B's baseline payload includes a FLIR Systems BRITE Star II."

there was no MH-60R Seahawk to accompany them. While Fire Scout and the MH-60R can both provide over the horizon capability to a ship and can complement each other, an MQ-8B cannot perform the medical evacuation or airlift roles undertaken by a Seahawk.

Another first in the deployment was dual air vehicle operations involving two Fire Scouts flown simultaneously while on station. "Additionally, we provided a half orbit capability, up to 12 hours or more continuous watch on targets of interest," Captain Smith explained.

Commander Darrell Canady, the then commanding officer of the guided missile frigate USS *Klakring* (FFG 42) fleshed out some operational details: "To conduct dual air vehicle operations you need more than two operational aircraft embarked. For the majority of the deployment, we typically had three out of the four fully mission capable at any given time. On a typical mission we had two aircraft operating and one ready as a spare. Our team perfected the art of managing maintenance requirements and crew rest in proving 12-hours-a-day operations could be sustained almost indefinitely."

Lieutenant Commander Jay Lambert, the then officer-in-charge of the Klakring's aviation detachment cited another major accomplishment: "providing 24 hours of continuous orbit for the theatre commander required a lot of effort both from the Fire Scout operators and coordination with the ship to maintain flight quarters. This was a new single-day endurance record for the MQ-8B. Completing the milestone required ten separate flights, refuelling aircraft eight times, and the ship setting flight quarters for launch or recovery 20 times. It took everyone on the air detachment and ship working together to make it happen."

The aviation detachment embarked on the Klakring, logged more than 500 flight hours in the US Africa Command area of responsibility. Its role was to provide real-time intelligence, surveillance, and reconnaissance (ISR) in support of the combatant commanders. Commander Canady spoke of the mission value given by Fire Scout to the ship: "Fire Scout greatly expanded the ship's over the horizon ISR capability. We used it on several occasions to gain a visual identification on a contact on the ship's radar but with no other way of identifying. This represented our first orbit capability when forward deployed."

On November 17, 2014, the Littoral Combat Ship USS *Fort Worth* (LCS 3) departed its homeport of San Diego, California for a 16-month rotational deployment to Singapore. The ship deployed with the first composite aviation detachment comprising one MQ-8B Fire Scout and one MH-60R Seahawk helicopter, part of the ship's surface warfare mission package which also included two 36ft rigid-hull inflatable boats and two six-man boarding teams. Assigned to Helicopter Maritime Strike Squadron 35 (HSM-35) 'Magicians' based at Naval Air Station North Island, California, it was the Navy's first composite expeditionary helicopter squadron deployment.

In August 2015, the MQ-8B was used in an operational context during two Cooperation Afloat Readiness and Training or CARAT events, one with Indonesia and one with Singapore.

BUILDING AN MQ-8B

The MQ-8B Fire Scout is a highly-modified variant of the Schweizer 333 helicopter. Schweizer was acquired by Sikorsky in August 2004 and the MQ-8B airframes were produced by Sikorsky's Schweizer Aircraft subsidiary at its military aircraft completion centre in Elmira, New York.

Each MQ-8B airframe, fitted with a Rolls-Royce 250-C20W turboshaft engine, was delivered from the Elmira facility to Northrop Grumman's production facility in Moss Point, Mississippi. The Moss Point facility installed the autonomous flight systems and completed all electrical and ground checks. From Moss Point, each air vehicle was delivered to either Webster Field in Maryland for flight -testing with NAVAIR or to the Navy fleet at Naval Air Station Jacksonville, Florida and Naval Air Station North Island, California.

During CARAT Singapore, the Fire Scout provided over-the-horizon imagery and video of opposing warships and streamed video back to the Fort Worth. The details provided would not have been obtainable by a radar picture.

The LCS crew also used the Fire Scout's BRITE Star II camera and a payload called VORTEX to gather and stream video back to a handheld tablet used by a crew member on board the Fort Worth. This provided an outlook of the battlespace at the Fire Scout's forward position.

At the time of the USS *Forth Worth* deployment, the US Navy was bullish about the advantages of its two classes of new LCS ships. The Navy cited a shallow draft, speed, agility, and mission-focus as credentials for operating in near-shore environments configured with a modular mission package for either surface warfare, mine countermeasures or anti-submarine warfare.

However, in December 2015, the then US Secretary of Defense, Ashton Carter instructed the Navy to reduce its planned procurement of LCS ships and to select just one class - a cost saving measure to enable budget re-allocation to other higher-priority Navy weapon systems. Consequently, on June 20, 2020, the Navy announced it would place the first four of its LCS-class ships, USS *Freedom*, USS *Coronado*, USS *Forth Worth* and USS *Independence* in reserve status.

MQ-8B Fire Scouts continue to deploy as part of aviation detachments on other LCS ships.

Flight Deck Crew

Manning and on station time requirements are two of the primary determinants in allocating composition of a ship's aviation detachment. Experiences gained from previous deployments had determined that the number of flight deck crew required to support the MQ-8B was about half that of the MH-60R Seahawk. One example is in crash recovery, fewer personnel are required for an unmanned Fire Scout with no one on board.

For USS *Klakring's* deployment, the maintenance manning posture was increased because of the four air vehicles on board. Lieutenant Commander Lambert explained that the flight deck crew was divided into two sections, to ease the workload on the ship. This proved effective during periods of flying that lasted for 24 hours and required flying off flight quarters 20 times, which was spread over the crew day.

"MQ-8B flight operations were suspended on two occasions."

According to LCDR Lambert, "the art of managing the flight deck, managing the maintenance of the four aircraft on board, creating the flight plan, and turning over [switching] pilots when required were the most difficult parts of dual vehicle operations."

The officer-in-charge continued: "The actual mechanics of take-off, landing and flying are not all that challenging. The hard part always remains with the single spot ship when you have two aircraft in the air. If you have a maintenance delay or if you have a problem with one of the aircraft, and in particular if you have an end user that is receiving your data on a specific target that he does not want interrupted, when do you hold [on station] and when do you fold [return to the ship]? Clearing the deck of one aircraft to recover another and refuel it or pulling one off station as things get delayed. That's the hard part."

An engineman assigned to USS Gabrielle Giffords (LCS 10), connects the fuel nozzle to an MQ-8B Fire Scout assigned to Helicopter Sea Combat Squadron 23 (HSC-23) 'Wizards' underway in the 7th Fleet area of operations. US Navy/Mass Communication Specialist Brenton Poyser

An MQ-8B Fire Scout on the perch over the flight deck of USS Milwaukee (LCS 5) underway in the Atlantic Ocean. US Navy/ Mass Communication Specialist Anderson Branch

An MQ-8B Fire Scout with its engine running on the flight deck of USS Milwaukee (LCS 5) with an MH-60 hovering to the aft of the ship. US Navy/Mass Communication Specialist Nathan Beard

Mission Data

Captain Smith explained the three ways in which the Fire Scout's integration to the frigate is tied in: "Fire Scout provides full motion video to the combat information centre [CIC], the bridge and the captain's cabin. It also provides a reach back capability to the ship's satellite communication system [a search and seizure boarding operation is one example]. The full motion video is available to different users who can link into the ship's satellite mission systems; and we also provide that capability to ROVER [remote operations video enhanced receiver] equipped units."

Users are those who analyse the video for intelligence purposes, information then utilised by theatre commanders to decide on the appropriate action. Additional AIS data, that can only be gained by the Fire Scout at altitudes above sea level, is also fed to the ship CIC and the bridge.

MAGICIANS

Helicopter Maritime Strike Squadron 35 (HSM-35) 'Magicians' became the first composite expeditionary helicopter squadron to operate the MQ-8B Fire Scout and the MH-60R Seahawk when it was re-established at Naval Air Station North Island, California on March 5, 2013.

As the Navy's first operational squadron with both manned and unmanned aircraft, HSM-35 heralds a new era for naval aviation while adopting the former number plate from the SH-2 Seasprite-equipped HSL-35 which was decommissioned at North Island in 1992.

The Magicians' first task was to train with the MQ-8B and develop a concept of operations with the type.

Glitches

USS *Klakring* was specifically tasked to deploy to the African AOR to support maritime security operations with an ISR capability provided by MQ-8B Fire Scouts. Maritime security operations comprise everything from visual identification of surface contacts, and therefore ensuring that vessels are not being used for trafficking drugs or people, to developing a recognised maritime picture for the operational commander.

During USS *Klakring's* five-month deployment, MQ-8B flight operations were suspended on two occasions due to component failures inside the control station within the CIC.

Because the Fire Scout back-up kit on board did not hold spares of the components that failed, the aviation detachment suffered downtime while waiting for the parts to arrive in theatre.

On both occasions the ship had to find a port from which it could pick-up the spares. Captain Smith said PMA-266 was looking at single point failures and sparing posture, "what components we place inside our back-up kit and the reliability of components to make sure that we can keep the fleet flying in the appropriate manner."

CDR Canady added: "By procedure the crew is not allowed to fly until both the primary and the back-up components are operating. Even if the back-up fails, the crew can still fly the air vehicle, which was the case when one component failed on board the Klakring."

Incidentally, the suspension of MQ-8B flight operations on board the Klakring was not connected to two accidents in 2012 each of which caused the loss of an MQ-8B: one on board the USS *Simpson* and the other when operating from a land base in Afghanistan where the Navy had a permanent Fire Scout detachment.

The incident on USS *Simpson* resulted from the crew deciding to terminate the flight. The engineering investigation on the recovered aircraft pointed to a fault within the auto landing system, called UCARS (unmanned air system common air recovery system). The fault was associated with UCARS components, so corrections were implemented that allowed the deployment on board the USS *Klakring* to take place.

The engineering investigation on the MQ-8B lost in Afghanistan focused on a navigation fault within the air vehicle that caused a departure from flight. Corrections in the air vehicle to prevent the suspected navigation mode failure were also made.

Upgrading Fire Scout

In January 2013, NAVAIR's PMA-266 awarded aerospace and defence company Telephonics a $33m contract to supply nine ZPY-4 multimode maritime radar systems for the MQ-8B Fire Scout including integration and testing.

In the surface search mode, the X-band ZPY-4 can detect and track up to 200 surface targets at various ranges and displays the target data selected by the operator. In terrain mapping mode, the ZPY-4 can detect and display surface objects such as land masses, land/water transitions and large prominent objects. Using the radar's weather mode, the ZPY-4 provides continuous information on the rate of rainfall, thunderstorms, wet hail, or wet snow to determine the relative density of the ➲

rainfall areas.

For imaging targets, to aid in their identification, the ZPY-4 can operate in three modes: inverse synthetic aperture radar (ISAR), strip-map and spotlight SAR. Each mode generates high-resolution images of targets or terrain, in both range and cross-range, using pulse compressed waveforms and Doppler processing techniques. ISAR imaging uses target rotational motion to provide cross-range resolution and stretch-pulse compression to provide 3ft range resolution.

By the spring of 2014, NAVAIR was underway with testing the ZPY-4 radar at Webster Field and subsequently demonstrated that the system greatly extended the MQ-8B's ISR range out to 80nm.

The MQ-8B was also upgraded with a mine-detection sensor called the Coastal Battlefield Reconnaissance and Analysis or COBRA, designated the DVS-1.

According to the Director, Operational Test and Evaluation's FY2018 annual report, PMA-266 completed COBRA Block I initial operational and test evaluation (IOT&E) test periods 2 through 5 between October 2017 and September 2018.

In March 2018, during test period 2, fleet sailors operated the system in the Southern California Operational Area from USS *Coronado* (LCS 4). Equipped with a COBRA payload, an MQ-8B completed four missions to assess its shipboard performance at sea. After each flight, trained fleet operators completed post-mission analysis of COBRA data. Also, that month, during test period 3, fleet sailors conducted a maintenance demonstration, which included five simulated system faults.

The annual report stated that COBRA Block I provided an organic, remotely operated, beach reconnaissance capability for detecting and localising minefields and obstacles during amphibious assault operations. The report also stated that the system performed reliably during IOT&E with four minor operational mission failures, though troubleshooting and repairs required significant maintenance and technical support. Because the Navy acquired the MQ-8B Fire Scout in response to an urgent operational need, a full assessment of its operational performance or suitability was not conducted during the IOT&E.

Arming Fire Scout

During the spring of 2013, PMA-266 worked on an urgent operational request to arm Fire Scout as a rapid deployment capability effort with $17m of funding. To meet the requirement, NAVAIR selected a 2.75-inch rocket made by BAE Systems, designated the WGU-59/B Advanced Precision Kill Weapons System or APKWS.

The rocket's mid-body guidance and control section is compatible with existing and new types of 2.75-inch rocket motors, warheads, and launchers. Using a plug-and-play, point-and-shoot design, the APKWS guidance and control section transforms an unguided rocket into a laser-guided variant with no modifications required to the rocket, firing platform or launcher system.

APKWS is a weapon designed for use in urban areas against soft or lightly armoured targets. Its guidance and control section comprises an M151 or M282 warhead, an M423 fuse, wings that provide control, wing-mounted laser-seeker optics, an Mk66 rocket motor and folding fins. Up to six rockets can be carried in two three-round launcher pods, one carried on each wing pylon fitted to the fuselage sides.

An aviation electrician assigned to Helicopter Sea Combat Squadron 23 (HSC-23), performs maintenance on a MQ-8B on the flight deck of USS Gabrielle Giffords (LCS 10). US Navy/Mass Communication Specialist Brenton Poyser

"Up to six rockets can be carried in two three-round launcher pods."

In March 2013, NAVAIR undertook a quick reaction assessment of the WGU-59/B APKWS at Naval Air Weapons Station China Lake, California. Work involved fit checks and flight-testing to evaluate vibration frequencies during flight to determine how vibration might affect the rockets, the launcher and the air vehicle and the potential for vibration-induced damage. Later in the year, PMA-266 conducted live firing of WGU-59/B rockets from an MQ-8B. The assessment involved both developmental and operational testing and was the first time the US Navy had armed an MQ-8B.

By June 2014, PMA-266 had successfully demonstrated the MQ-8B's ability to designate and shoot WGU-59/B APKWS rockets in response to the urgent operational request which had originated from the type's deployment to Afghanistan.

Discussing the Fire Scout during a presentation at the Navy League's Sea Air Space 2018 exposition, PMA-266 programme officials said the MQ-8Bs armed with WGU-59/B APKWS rockets were ready for deployment following a successful demonstration of Fire Scout to operate with weapons aboard a Littoral Combat Ship earlier in the year. According to Captain Jeff Dodge, the then MQ-8 programme manager with PMA-266, the weapons testing was successful from the airframe standpoint. "However, because the WGU-59/B is based on an unguided rocket, it's designed to be built up in an armoury and the LCS armoury doesn't have the space required to conduct the build-up," he said. "It's used to store all of the ship's weapons, including any that would be used for aircraft. There's been a lot of studies to determine what the right weapons mix would be between aircraft weapons and ship weapons."

The issue was not resolved and to this day, MQ-8B Fire Scouts deploy on Littoral Combat Ships without WGU-59/B rockets carried on board.

Flight Control and Mission Payload

The MQ-8B has a fully autonomous flight system with manual override via a keyboard and mouse used by the air vehicle operator (AVO).

During ship borne deployment the AVO's operator station is in the ship's combat information centre (CIC). Fire Scout uses a two-man operator workstation for the AVO and mission payload operator (MPO) who sit next to each other.

Flight operations are conducted from the landing deck at the aft of the ship. When the air vehicle is on the deck and prepared for launch, it is colloquially referred to as 'spotted'.

The person responsible for clearing the deck immediately prior to engine start is the Navy plane captain and he or she will give the AVO a green light to start engines.

Engine start is simple, just a keyboard command on the AVO workstation. Once the Fire Scout's engines are running, the AVO works through the checks undertaken with the UHF/VHF command and control link between the air vehicle and the ship. All commands to control the MQ-8B are sent over the UHF/VHF link

Just like the engine start, the launch command is also a simple keyboard command. From the point of take-off from the deck, the Fire Scout flies a pre-programmed mission through a series of waypoints. That's the pre-planned mission, but the nature of the Fire Scout's role requires dynamic re-tasking to be able to identify any surface contact of interest to the battlespace commander. Re-tasking is easy to implement. The AVO simply enters the co-ordinates of a series of new waypoints using the keyboard and mouse to re-programme the air vehicle's flight.

Interestingly, none of the commands sent to the air vehicle by the AVO are done by touch screens.

So that's the flight control, what about controlling what's referred to as a mission payload, which currently comprises a FLIR Systems BRITE Star II EO/IR turret and its digital video camera?

This is the responsibility of the MPO who has a choice of the type of controller he or she wants to use to steer the turret's ball: either a single-handed joystick-like option or a two-handed game console-like version. Video is sent back to the ship via a system called the TCDL.

The ZPY-4 radar commences scanning the ocean surface for contacts shortly after the air vehicle is airborne. The BRITE Star II sensor is interfaced with the ZPY-4 radar which enables the BRITE Star II turret ball to be autonomously slewed to any contract of interest. Alternatively, the MPO is able to slew the ball manually to the required position.

"The MQ-8B has a fully autonomous flight system with manual override."

Training Centre and Fleet Replacement Squadron

On July 10, 2012, Northrop Grumman and the US Navy's Helicopter Maritime Strike Wing Atlantic (HSMWL) hosted a ribbon-cutting reception for a new MQ-8B Fire Scout training facility at Naval Air Station Jacksonville, Florida.

The facility has two training systems: one for maintainers and one for AVO and MPO training. It is equipped with four mission simulators, an instructor's station, and classrooms.

Nearly three months after the training centre was opened at Jacksonville, Unmanned Helicopter Reconnaissance Squadron 1 (HUQ-1) 'The Hydras' stood up at Naval Air Station North Island, California on October 1, 2012.

HUQ-1 serves three roles; as the MQ-8 Fleet Replacement Squadron to train new AVOs and MPOs for the MQ-8B and MQ-8C; to supply Perry-class frigates with 32-man UAS detachments or UDets, for ISR missions in support of conventional and special operations forces; and to provide unmanned aviation detachments (AV Dets) to Littoral Combat Ships. ●

ZPY-4 RADAR SYSTEM FEATURES

Radar
Multi-Mode operation
- Surface search
- Terrain mapping
- SART/beacon detection
- Weather avoidance

Programmable digital waveforms
Digital demodulation
Digital pulse compression
Target tracking

General system description
System weight: Typically, less than 75lb
Power required: 28V at 22A and 115V, 400Hz at 100mA
Special features: Sector blanking, PRF jitter and frequency agility

Antenna
Bandwidth: 300MHz
Gain: 26 to 31dB (antenna dependent)
Sector scan: 45° to 300° or continuous 360° scan (operator selectable) 28, 45, 90°/sec
Stabilisation: +/- 30°
Searchlight for ISAR/SAR antenna steering

Optional modes and resolutions
ISAR: 3ft
Strip map: SAR (3, 6, 13 and 26ft)
Spotlight: SAR (3, 6, 13 and 26ft)

Performance
Detection: 10.7ft^2 beyond 15nm in sea state 3
Max radar range: 120nm
Display range resolution: 0.01nm
Reliability: 2,000 hours mean time between failure

Display and processing
Track-while-scan with automatic track initiative.
Range scales: short, 30, 60, 120nm.
Weighted digital compressed pulse width.
Standard interfaces available to allow integration/operation with onboard display and control systems.
Standalone consoles available using TDMS GUI with colour display.
Data supplied by Telephonics

An MQ-8B Fire Scout assigned to Helicopter Combat Squadron 21 (HSC-21) 'Blackjacks' hovers over the flight deck of the USS Tulsa (LCS 16). US Navy/Mass Communication Specialist Colby Mothershead

UNDERWAY

The Northrop Grumman MQ-8C Fire Scout is the latest rotary unmanned air vehicle to serve with the US Navy. **Mark Ayton** examines the type.

Northrop Grumman

With an airframe based on the commercial Bell 407 helicopter, the MQ-8C Fire Scout is the US Navy's next-generation autonomous helicopter.

It is fitted with Northrop Grumman's autonomous systems architecture to meet the Navy's requirements for autonomous take-off and landing on any aviation-capable ship, and from prepared and unprepared landing zones.

Compared to the Schweizer S333-based MQ-8B, the MQ-8C provides more than double the range and endurance, and more than three times the payload capacity.

Following 255 flights and around 330 hours of flight testing at Naval Air Station Point Mugu, California, the Navy's MQ-8C Fire Scout completed its first period at sea in December 2014. Embarked onboard Arleigh Burke-class guided missile destroyer USS *Jason Dunham* (DDG 109), MQ-8C BuNo 168455/'VX' completed 32 take-offs and recoveries and three flights during a five-day period underway off the coast of Virginia.

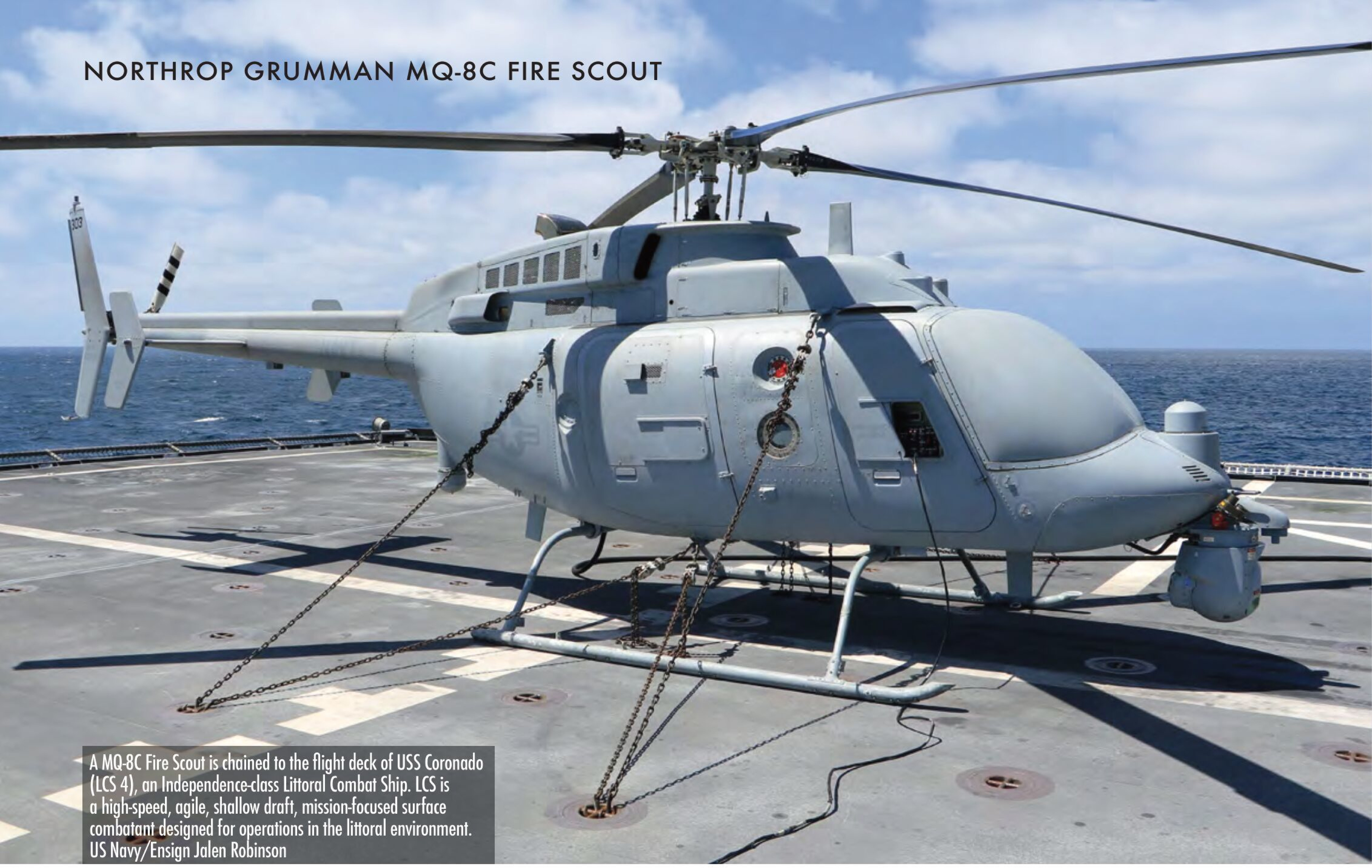
Point Mugu

The land-based testing conducted at Point Mugu involved flight envelope expansion and verification of the navigation, control, and auto landing systems. The joint test team, comprising personnel from Northrop Grumman and Naval Air Systems Command (NAVAIR), also undertook initial shipborne compatibility testing. This involved landing the air vehicle in different approach attitudes onto a sloped deck at different angles of tilt.

Simulation and analysis of the ship's characteristics and the key margins in the navigation and control laws formed a major part of this phase of the programme. This was required to assess the responsiveness of the air vehicle and ensure that it could withstand the rigours of the shipborne environment, most notably the turbulent air blowing over the moving flight deck.

Such high-fidelity simulation also demonstrated that an MQ-8C can safely operate from a DDG-class ship without colliding with or damaging any equipment fitted to, or near, the flight deck.

Captain Jeff Dodge, NAVAIR's then program


A MQ-8C Fire Scout is chained to the flight deck of USS Coronado (LCS 4), an Independence-class Littoral Combat Ship. LCS is a high-speed, agile, shallow draft, mission-focused surface combatant designed for operations in the littoral environment. US Navy/Ensign Jalen Robinson

"Based on the Bell 407 helicopter, the MQ-8C Fire Scout is the US Navy's second autonomous helicopter."

An MQ-8C Fire Scout sits on the flight deck of USS Montgomery (LCS 8) during a test period at sea to verify launch and recovery procedures and test interoperability between the air vehicle and the ship. US Navy/Command Master Chief Jacob Shafer


Two MQ-8C Fire Scouts in the hangar bay of USS Montgomery (LCS 8) during April 2017. US Navy/ Command Master Chief Jacob Shafer

manager for multi-mission tactical unmanned aerial systems: "The sloped landing piece was critical because we wanted to double-check the rotor blade and aircraft clearances for any kind of behaviour encountered when autonomously landing the air vehicle on the flight deck. We installed UCARS [unmanned common automatic recovery system], our UAV auto recovery system, on the tilt-deck, and evaluated all of the landing profiles to see how the air vehicle stepped through it."

Another big component involved testing wind across the azimuth to determine how the air vehicle flew with wind coming at it from different directions and various speeds. Captain Dodge said: "It was particularly important because at sea you can't always turn directly into the wind, so we defined optimal wind envelopes for flight operations. This was the first step to seeing what the air vehicle is capable of.

"Once on the ship we looked at how the air vehicle flew through the turbulent air over the deck, and how it responded to touching down or moving off from a moving flight deck. We also looked at the effects of wind across the azimuth and determined if there were any big issues when recovering the air vehicle."

Ship's Preparation

Prior to the five-day test period, the USS *Jason Dunham* underwent two phases of equipment installation. The first involved UCARS and calibration of the data link to ensure ship-to-air vehicle communications were functioning correctly. The second phase included fitting data recording equipment for use by the test team to capture ship speed and motion and data downlinked from the Fire Scout.

During the week before the ship got underway from its homeport of Norfolk, Virginia, the air vehicle was craned aboard and used by the test team to train members of the ship's company in basic air vehicle handling. The time was also used to evaluate the ship's hangar deck and its support systems to ensure ground power and fuel was available to the aircraft.

According to Captain Dodge, the test period

was a risk reduction exercise that used the ship's availability to enable the test team to go to sea and operate the air vehicle in the shipborne environment. It should be noted that the MQ-8C is not scheduled to deploy on DDG-class ships but Littoral Combat Ships (LCSs). The first available test period for the C-model onboard a LCS was later in 2015.

Captain Dodge told the author: "We only had one week to develop the whole envelope – we would usually take three or four, so this was a limited scope of tests using an envelope with basic ship motion and airspeed to ensure we had the correct control and weren't drifting during the landing phase at the ship.

"We were very pleased with the MQ-8C given the burble and deck environment. It is a very stable platform and held its intended flight path well."

Back at Point Mugu

After five-days underway, MQ-8C BuNo 168455 returned to Point Mugu where the test team continued work on verifying payload functionality and data transmission to ensure data generated by the BRITE Star II sensor downlinked properly and without any disturbance from the airframe.

Because the MQ-8C's turret is the same model as the one used on the MQ-8B, the test team neither expected nor encountered any problems using the new system. According to Captain Dodge, payload testing, including time at sea, was a prelude to the start of operational test.

"By October 2020, Northrop Grumman had delivered 34 MQ-8Cs."

The MQ-8C Fire Scout programme included two other capabilities: weapons, the follow-on and larger version of the BAE Systems WGU-59/B Advanced Precision Kill Weapon System rocket, and integration of the ZPY-8 maritime search radar.

By using one of the most proven commercial helicopters on the market, the Bell 407, with the systems already in service on the MQ-8B which had thousands of combat flights hours to its name, Captain Dodge was right to be confident of the new Fire Scout: "We had no issues with integration or with the capability of the air vehicle."

MC-8C IOT&E

According to the FY2018 annual report from the director, operational test and evaluation, the US Navy's Operational Test Force (OPTEVFOR) and Air Test and Evaluation Squadron 1 (VX-1) completed land-based and sea-based testing for the MQ-8C's initial operational test and evaluation (IOT&E).

IOT&E consisted of 192 hours of system operating time and 35 flight sorties conducted between April 2018 and March 2019 at Webster Outlying Field, Maryland, and on board the USS *Coronado* (LCS 4), underway on the Point Mugu Sea Range.

The land-based phase focused on overland surveillance and intelligence gathering, the ability of the MQ-8C to detect, classify, and identify overland contacts of interest, and provide accurate target location data for further action. The sea-based phase focused on independent operations from an LCS with an emphasis on ISR and surface warfare mission areas. OPTEVFOR designed the test events to evaluate the ability of MQ-8C to detect, classify, and identify maritime targets.

During flight operations, the MQ-8C baseline variant demonstrated a significant improvement in endurance over the legacy MQ-8B.

The MQ-8C routinely transited through cloud layers and operated in light rain with no adverse effects. The air vehicle demonstrated effective UHF communication relay capability and consistent, reliable, and effective command and control with no lost-link recoveries required during IOT&E testing.

Although there were marked improvements in endurance over the MQ-8B, the Navy and DOT&E assessed the MQ-8C system as not operationally effective, not operationally suitable, and not cyber survivable.

Primary degraders that led to this assessment ➲

Sailors unchain and unhook a cable from an MQ-8C Fire Scout during final flight preparations from the USS Jackson (LCS 6) underway in the Pacific Ocean on April 12, 2021. US Navy/ Ensign Alexandra Green


HCO TOWER
RECORD

Flight crew monitor flight operations from the USS Coronado's helicopter control tower as maintainers prepare to launch an MQ-8C Fire Scout. US Navy/Ensign Jalen Robinson

included the overall air vehicle reliability, image quality and system performance of the BRITE Star II EO/IR system, and the poor reliability and inconsistency of the Tactical Common Data Link (TCDL). The TCDL is the conduit for payload video and control. Excessive operator workload coupled with an immature supply support system also contributed to the assessment of not operationally suitable.

The PMA-266 programme office established a Tiger Team with fleet representation to increase readiness and reliability of the MQ-8 system of systems. The team's focus was to address the three primary deficiencies TCDL, BRITE Star II, and cyber survivability.

DOT&E recommended the Navy correct all TCDL and BRITE Star II operational deficiencies and gain OPTEVFOR verification of the deficiencies during follow-on test and evaluation.

Further details released by NAVAIR about the sea-based IOT&E testing, which took place between June 15-29, 2018, listed two main capabilities had been proven. The ability to operate with a Littoral Combat Ship (LCS) by gathering intelligence and identifying targets for the ship to prosecute, and the development of

"MQ-8C has double the range and endurance of the MQ-8B."

procedures for simultaneous flight operations with the MQ-8C Fire Scout and the MH-60S Seahawk, and their respective maintenance. During the period at sea, different mission scenarios were flown in the Point Mugu Sea Range off the coast of southern California including simulated engagements with enemy warships.

The IOT&E results confirmed that dual operations can be conducted but required extensive planning and coordination across the ship.

Change of Core Mission

Despite the relatively successful IOT&E outcome, the US Navy changed the MQ-8C's core mission from LCS protection against a swarm attack by fast attack boats to one of providing targeting information for a nascent long-range strike weapon launched by the LCS. The decision was driven by an intent to employ the LCS with long-range strike weapons to counter threats in operation within the Indo-Pacific AOR. Officials determined that the MQ-8C provides greater capability to an LCS when equipped with a multi-function radar, a passive targeting capability and a robust network link, and future weapon integration.

NAVAIR identified the Leonardo ZPY-8 active electronically scanned array (AESA) radar and the Link 16 datalink as two of the systems required on the MQ-8C to accomplish the new core mission. This system combination will enable the air vehicle to distribute air-to-air and surface targeting information to all ships operating in distributed maritime operations, a concept of operation that involves multiple spread over ➲

ZPY-8 MULTI-MODE SURVEILLANCE RADAR

Leonardo's ZPY-8 multi-mode surveillance radar provides second generation active electronically scanned array surveillance capability as the primary sensor on the MQ-8C. Leonardo's house name for the radar is the Osprey MM.

The ZPY-8 radar set brings together wide azimuth and elevation electronically scanned (E-Scan) fixed antenna(s) with a compact, state-of-the-art processor and multi-channel receiver.

Key Benefits

- Class-leading maritime surveillance capability.
- AESA-enabled small target mode (STM).
- Very high resolution, wide swath SAR Mapping.
- Small radar cross section, low minimum detectable velocity, multi-channel moving target indication (MTI).
- Air-to-Air surveillance, track, and intercept.
- Instantaneous multiple mode interleaving.
- Difficult target detection from higher altitude.
- High reliability for persistent operations.
- Flexible configuration, installation, and integration.
- Multiple fixed antennas, choice of antenna sizes.
- Belly-free, obscuration-free 360° coverage.
- Open standards interfaces.
- Compact, lightweight LRUs.

Key Features

ZPY-8 provides a genuine multi-domain capability, with high performance sea surveillance, notably against difficult targets, land surveillance with wide swath, very high resolution ground mapping, small and low speed ground target indication, high performance air-to-air surveillance, tracking and intercept. These capabilities, combined with the radar's ability to rapidly interleave modes and provide scan- independent beam steering, make the ZPY-8 ideally suited to mixed environment operations, such as in the littoral.

Radar Set

The ZPY-8 radar set is a small size, weight, and power (SWaP) radar system, offered with a range of antenna sizes that may include up to four fixed antennas, depending on the azimuth coverage requirement, and which leave the belly of the aircraft free for operation to and from unprepared surfaces: or for other antennas, sensors, or weapon systems.

The ZPY-8 is well suited to unmanned air system operations, with very high reliability for persistent surveillance, and difficult target detection capability from high altitude, facilitating platform line of sight communications and improved platform fuel efficiency. The ZPY-8's flexible configuration, with antenna size and installation options, its low SWaP, air cooled line replaceable units, and its open standard interfaces simplify its integration.

Performance Benefit of AESA Radar

E-Scan enables simultaneous multi-domain wide area search and Target of Interest focus, and ultra-fast beam scanning to provide vastly improved clutter cancellation and superior detection performance. This performance is maintained from high altitudes typically encountered by UAS operating at the full extent of line of sight data links.

Superior Reliability and Operational Availability

At the core of the AESA radar design is the ability to tolerate individual element failure. Component failures within the array result in graceful performance degradation rather than complete system failure, delivering high operational availability when compared with conventional radar systems.

Its high reliability and availability result in a reduced maintenance requirement and provides the option to reduce spares holding, resulting in significant cost benefits over the life of the system.

ZPY-8 Radar Characteristics

Frequency: X-band
Scan coverage: Installation dependant
Maximum range: 200nm
Mean Time Between Critical Failure: >2000 hours
Cooling: Unconditioned air
Weight (Approximate installation dependent): 62lb (includes single antenna, processor, and receiver LRUs, and IMU)
Interface standards: Ethernet, RS422, ARINC 708, ARINC 429
Video outputs: Multiple options for Mission System and display compatibility

Dimensions (H x W x D)

Processor: 8 x 5 x 9in
Receiver: 8 x 10 x 7in
Antenna: 8 x 20 x 6in

Functions

Track While Scan: Up to 1,000 tracks, with Automatic Track Initiation (ATI)
Track Identification: AIS and Inverse Synthetic Aperture Radar (ISAR)
Mode Interleaving: Simultaneous multi-mode operation

Capabilities

Maritime Surface Surveillance Maritime surveillance small target mode
Strip and Spot SAR Ground Mapping High resolution wide area ground mapping
Moving target detection Ground, Maritime, and Air MTI Air-to-Air Intercept
Navigation

- Land mass discrimination
- Weather detection
- Turbulence detection
- Beacon detection
- Search and Rescue Transponder
- Target imaging/classification
- ISAR
- Range profiling

An MQ-8C Fire Scout lifts away from the flight deck of the USS Jackson (LCS 6). US Navy/ Ensign Alexandra Green

Air Test and Evaluation Squadron 1 (VX-1) sailors prepare an MC-8C Fire Scout to launch from the USS Coronado (LCS 4) during the type's initial operational test and evaluation. US Navy/Ensign Jalen Robinson

broad areas of ocean.

According to NAVAIR, a ZPY-8-equipped MQ-8C will acquire targeting information at greater range and operate as a force enabler linked with all of the warships in a broadly spread group, able to feed its over-the-horizon picture to those warships via its Link 16 datalink for engagement by strike weapons launched by the warships or aircraft.

On July 9, 2019, the US Navy announced that the MQ-8C had achieved initial operational capability (IOC) and was ready to deploy aboard Littoral Combat Ships. Achieving IOC allowed squadrons to commence training and operational missions with the MQ-8C in preparation for its planned maiden deployment during FY2021.

The declaration was made 17 months after the decision to change the type's core mission.

NAVAIR commenced an MQ-8C flight test programme for the Leonardo ZPY-8 radar operating from Webster Field on February 27, 2020. Weeks of ground testing preceded the first flight and continued in earnest as part of the test team's evaluation of other possible roles.

Based at Naval Station Norfolk, Virginia, Helicopter Sea Combat Squadron 22 (HSC-22) 'Knighthawks' received its first MQ-8C on September 15, 2020 and became the first Atlantic fleet to operate the type. In addition, it is the first squadron to operate the MQ-8B and the MH-60S Seahawk. Squadron pilots are certified to operate all three types and since Q3 2019 had conducted manned-unmanned teaming operations with the MQ-8B and MH-60S combo. Similarly, HSC-22 maintainers work on all three types.

HSC-22 began its work-up to safe-for-flight certification with the arrival of its second and third air vehicles and planned to deploy its MQ-8C aircraft to NASA's Wallops Island facility in Virginia to conduct land-based ops. This included development of tactics, techniques, and procedures.

Maintainers assigned to Air Test and Evaluation Squadron 1 (VX-1) 'Pioneers' inspect the flight deck of the USS Coronado (LCS 4) for foreign object and debris in preparation to launch an MQ-8C Fire Scout for underway testing. US Navy/Ensign Jalen Robinson

Training and pre-deployment work-ups on board an LCS is planned to follow.

On board the sprawling Norfolk Naval Station, HSC-22 is located near to a training facility run by the Center for Naval Aviation Technical Training Unit. The first squadron personnel completed their courses on August 29, 2019. They were instructed using a composite maintenance trainer or an avionics maintenance trainer throughout the eight-week MQ-8C Airframes and Power Plants Organizational Maintenance Course. By comparison, an MQ-8 pilot takes five weeks to train to fly on a course run by the dedicated training centre at Naval Air Station Jacksonville, Florida.

"MQ-8C's new mission is targeting for long-range strike weapons."

As of October 2020, Northrop Grumman had delivered 34 of the 38 MQ-8Cs ordered by the Navy, all of which will be retrofitted with the ZPY-8 radar. Additionally, six MQ-8Bs were assigned to two Atlantic Fleet HSC squadrons and eight to equivalent Pacific Fleet units. ●

REAPER:

Mark Ayton spoke with members of the US Air Force's 432nd Wing about maintaining, flying, and operating the MQ-9 Reaper.

AMERICA'S MULTIROLE UAV

A nose-on shot of MQ-9 Reaper 08-050/OT assigned to the 556th Test and Evaluation Squadron at Creech Air Force Base, Nevada. US Air Force/Senior Airman Haley Stevens

Based at Creech Air Force Base, Nevada, the 432nd Wing is the original home of US Air Force MQ-1 Predator and MQ-9 Reaper unmanned air vehicles. Today, the 432nd is a Reaper-only unit equipped with Block 1 and the upgraded Block 5 aircraft.

Today's wing structure includes at least seven MQ-9-equipped attack squadrons and one formal training unit. Creech is also home to the RAF's 39 Squadron which has been in residence at the Nevada drone base since January 1, 2007.

According to Major Troy, an experienced Reaper pilot who currently serves with the 432nd Wing's headquarters, Reaper operations are split between those classed as conventional and those classed as unconventional. Conventional operations being those flown to support troops with overwatch and strike capabilities, while those classed as unconventional involve the targeting of high value individuals.

Split Operations

An MQ-9 aircrew comprises a pilot and a sensor operator. The many aircrews assigned to the 432nd fly either the launch and recovery element (LRE) or the mission control element (MCE). Take-off and landing training is undertaken by the LRE squadron, who also deploy aircrew to combat theatres to perform launch and recovery ops, while the MCE squadrons fly combat missions from Creech, linked to the air vehicle via satellite.

"Most flying is done using a head-up display and two consoles."

Explaining the primary reason for splitting operations between LRE and MCE elements, Major Troy said: "When you're flying via satellite here in the States, you have to encrypt the satellite signal. That way hostile forces cannot hack into the signal and take command of the air vehicle. Encryption causes a delay in your input when you're flying via satellite. For example, if I command the aircraft to make a right turn via satellite, it suffers from a one second delay to respond to the command. You input right and wait for a second, and then it turns right. You input left and wait for a second, and it turns left. That would not be conducive for a take off or a landing where your control inputs need an immediate response. To mitigate that, 432nd Wing personnel deploy to forward operating locations where they use a different architecture for aircraft take off and landing. A ground data terminal beams the input direct to the aircraft via line of sight with an instantaneous response. That allows the pilot to take off and land more smoothly.

"A ground data terminal is limited by range. Once range is exceeded, you can no longer control the air vehicle via line of sight. So, we divvy up the operations by using a concept known as remote split ops. Personnel deployed to a forward operating location launch the aircraft and fly it to a safe location. And aircrews operating from ground control stations at Creech will turn on the satellite link, grab the aircraft, and fly their mission. Once the air vehicle is at its return-to-base fuel state, the MCE fly it back to a safe area from where the deployed LRE turn on the ground data terminal, grab the aircraft and land it.

An LRE pilot starts his launch process with an aircraft parked on the flight line. The pilot starts the engine, taxies out, ensures the systems, including the line of sight connection, are functioning correctly and conducts the take-off. Designated areas are used for the hand over. Major Troy explained how the pilot flies the MQ-9 to a safe altitude and location, and with a simple mouse click command, places the air vehicle in a pre-planned orbit. "We then advise the MCE crew we're going to shut off the aircraft's LRE connection, which always has precedence. If two elements are both trying to grab the aircraft, one via satellite and one via the ground data terminal, the line of sight connection always trumps the satellite connection. The LRE pilot has to turn off the connection before the MCE can grab the

Maintainers assigned with the 386th Expeditionary Aircraft Maintenance Squadron wing walk with an MQ-9 Reaper under tow on its way to an engine test at Ali Al Salem Air Base, Kuwait. US Air Force/TSgt Michael Mason

A crew chief uses a laptop for diagnostic work on an MQ-9 Reaper at Kandahar Airfield. US Air Force/SSgt Sean Martin

aircraft which is why the LRE pilot tells the MCE of the dis-connection. At the time, the MCE has their satellite link ready to grab the aircraft. Similarly at the end of the mission, the MCE flies the air vehicle to a safe area of airspace and advises the LRE of the air vehicle entering its pre-planned orbit. The MCE severs the connection, and the LRE grabs control of the air vehicle using the ground data terminal for recovery to the base."

Mission Elements

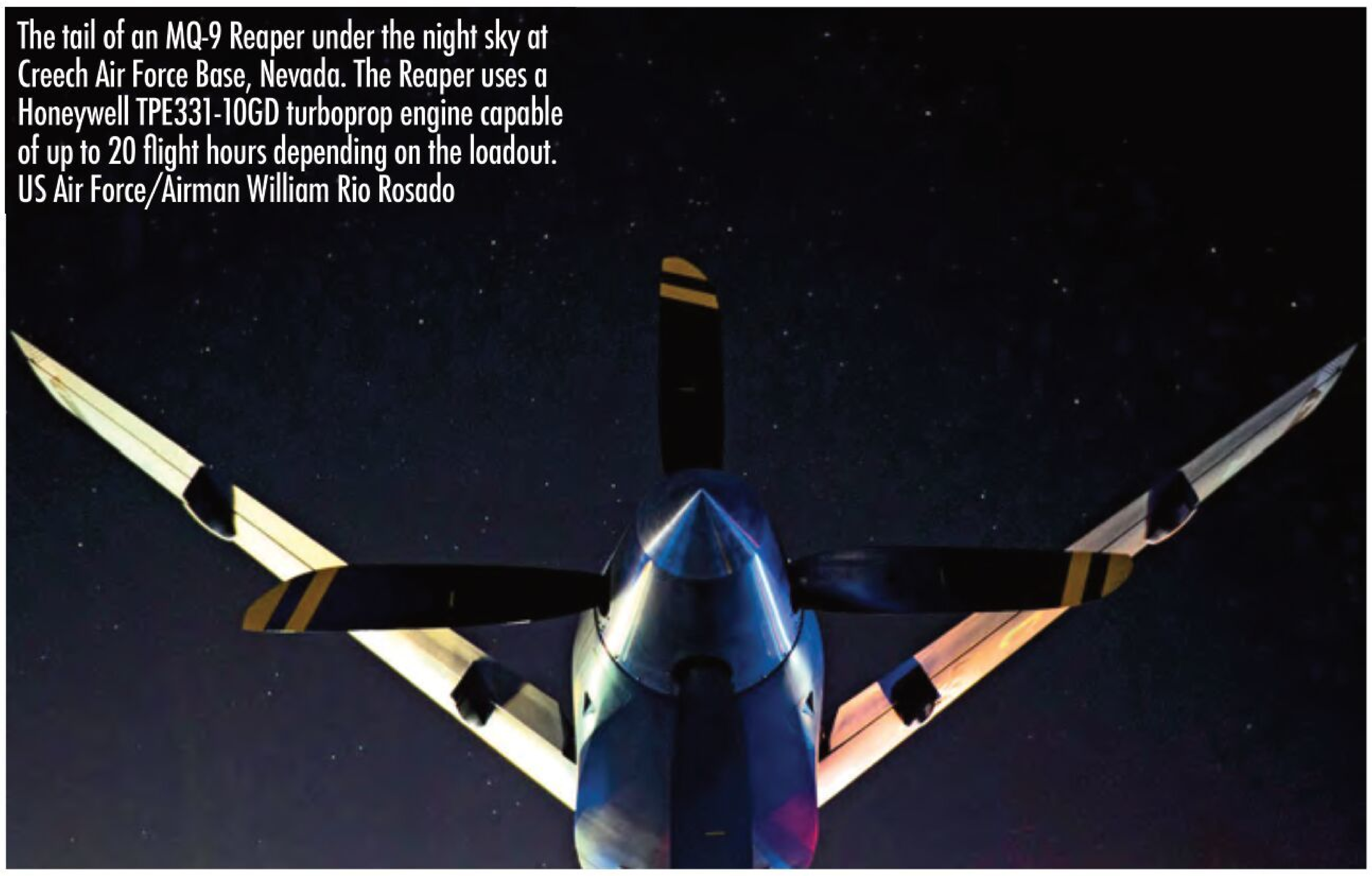
All Reaper flight operations, from take off to landing, are controlled by a pilot sat at a console inside a ground control station.

During the take-off run, the pilots use a forward-looking nose-mounted camera for visual reference to make sure the aircraft is tracking straight down the runway. The pilot can choose to use either a daytime electro-optical or night-time infrared camera, or the Multi-spectral Targeting Sensor (MTS) sensor mounted under the forward fuselage.

Pre-programmed or manual flight control is dependent on the mission itself. Sometimes pre-programmed control is used to transit the legs to the area of interest, but in some areas this mode is not possible due to the finesse required to climb, descend, and turn, especially to avoid international borders or threat zones. This requires hands-on flying, though some automation is involved. Commanding the air vehicle to climb to an altitude or fly at a specific airspeed is automated because it takes workload from the pilot. That allows the pilot to focus on terrain and threat avoidance and communicating with the agencies involved in the mission. Major Troy said the 432nd tries to avoid over-reliance on automation because aircrew get lax from using the mode saying: "When you force the pilot and the sensor to keep performing crosschecks, they are fully in control of the aircraft, you touch the stick, and it will respond so you have a heightened sense of awareness."

"A Reaper aircrew comprises a pilot and a sensor operator."

Most flying is done using the head-up display and two console displays. One called the tracker display which shows the air vehicle's geographical position on a map, and one called the tacit display which shows the positions of friendly and enemy forces and threats relative to the air vehicle. Additionally, aircrew use the MTS camera to look at the ground and targets. Once again this requires the aircrew to perform constant crosschecks.



The tail of an MQ-9 Reaper under the night sky at Creech Air Force Base, Nevada. The Reaper uses a Honeywell TPE331-10GD turboprop engine capable of up to 20 flight hours depending on the loadout. US Air Force/Airman William Rio Rosado

About 98% of the MQ-9's tasking is dedicated to protect troops on the ground with defensive overwatch looking for threats. If a threat is spotted, the Reaper crew can bring munitions to bear on the threat. A so-called conventional operation.

Non-conventional ops involve watching enemy forces for extended periods of time to determine patterns of life and understand what individuals are regularly doing. American commanders benefit from this type of information to avoid or minimise innocent civilians getting hit during a strike.

Strikes are usually conducted in contact with a Joint Terminal Attack Controller (JTAC) who briefs the Reaper crew on the target or insurgent activity. As a Reaper pilot, Major Troy said he has the option of sending the MTS feed of what the aircrew is looking at, to the JTAC so he can see exactly the same feed. This allows the JTAC to determine if that feed shows a threat and a legal target. The JTAC then passes a 9-line brief (as per DoD Joint Publication 3-09.03) to the pilot that allows a legal strike to be executed. Once the pilot has covered the nine lines, the JTAC gives the pilot clearance to employ a weapon on the target. "We call it cleared hot, and once given, the sensor turns on the MTS laser designator which will guide a Hellfire missile to the target. Hellfire is part of a standard combat loadout," said Major Troy.

"MQ-9 is powered by a single Honeywell TPE331 turboprop engine."

During the process described above, the sensor operator is using the air vehicle's MTS camera to watch the target. Sensor operators are experts in how to maximise the fidelity of an image and make it as clear as is possible. But range, altitude, and atmospheric conditions such as fog, dust, and clouds all affect the task. Knowledge of what to look for and what to focus on is all covered in the mission briefing, provided by intelligence personnel. They provide the aircrew with a full brief about what to expect in the operating area. Before the mission, the aircrew has time allocated to talk through the mission plan, discuss flight aspects, methods, agencies involved, and how to achieve the mission objective. In-depth preparations are undertaken to ensure the aircrew is best familiarised with the plan so that every minute is used appropriately to maximise camera and image time.

One interesting fact about the video feeds generated by an MQ-9 MTS camera is that they can be watched by the president and anyone else in the US government and Department of Defense. That is quite common among combatant commanders who, individually, may have a constant of 50 feeds up at a time, enabling that individual to watch whatever they want to watch.

In most of the combat zones in which MQ-9 has deployed in recent years, airspace control was in place. For a Reaper aircrew, radio communications with the control agency provided the operating altitudes of other aircraft which helped build their situational awareness. In situations when fighter aircraft were the primary strikers, MQ-9 aircrew would generally operate at altitudes above the fighters so the fighter aircraft could conduct strikes while the MQ-9s provided overwatch for the manned aircraft. In another type of scenario, the MQ-9s would operate below fighter aircraft and designate their targets using the MTS laser. Displays used by the aircrew in the ground control station provided full situational awareness of all aircraft operating around their Reaper, not least surface-to-air threats. Avoidance was the primary means used to counter the threat.

Local Ops at Creech

Flight operations at Creech are predominantly conducted by the LRE squadron and are used to teach pilots and sensor operators how to take off, fly the pattern, and land with the MQ-9. This is a common activity with fixed-wing aircraft but takes a different form with the MQ-9. A pilot may fly up to 20 touch and go landings during their training flight before flying to a safe area of airspace, enter the air vehicle into an orbit, from where the next crew assumes control and flies back to Creech for more touch and go landings until it's time to land the flight.

The LRE squadron also launches aircraft from Creech for handover to students assigned to 26th Weapons Squadron, a component squadron of the US Air Force Weapons School at Nellis Air Force Base. These missions are generally flown in the extensive Nevada Testing and Training Range from ground control

An MQ-9 Reaper on a training mission over the Nevada Test and Training Range. US Air Force/Airman William Rio Rosado

Crew chiefs remove panels on an MQ-9 Reaper loaded with three live AGM-114 Hellfire air-to-ground missiles on Kandahar Airfield, Afghanistan. US Air Force/SSgt Sean Martin

stations at Nellis via a satellite connection.

During the devasting wildfires in California in 2020, the 432nd Wing worked with the California Air National Guard's 163rd Attack Wing based at March Air Reserve Base, which did not have enough aircraft or manpower to support the fire fighters. The 432nd Wing gained Federal Aviation Administration agreement to fly MQ-9s into California airspace and work with fire fighters to spot fire lines, flare ups, and spreads of fire.

Deployed Operations

Captain Kyle is an experience MQ-9 instructor and evaluator pilot who has led teams at forward operating locations. While deployed, his duties included ensuring the LRE generated all of the missions required each day and handed each one over to the MCE in the States.

As a flavour of daily routine for an LRE, Captain Kyle said the team attends a daily morning brief to discuss the local conditions affecting the airfield and its surrounding airspace. Safety drills include working through practice emergency procedures and the pre-flight risk matrix to make sure all aircrew are safe to fly. Administrative aspects include

discussing which aircrews are flying the day's missions, how the flight schedule will work and if there are any deviations from the normal schedule.

Out in the ground control stations, individual aircrews start working through their check list to ensure the air vehicle, sensors and weapons are correctly set up for a launch or a land and start communications with the MCE back at Creech.

Ammo personnel load the weapons and as part of the aircrew's pre-flight, they check that weapons are correctly loaded and set-up for the MCE.

Reflecting on his combat experience flying the MQ-9 Captain Kyle referred to two examples of the MQ-9's capability on the front line. He said: "If a pop up threat appears somewhere near to a base, with the MQ-9's drawn out loiter time we can often be overhead before another aircraft and immediately have eyes on the situation, with the capability to strike and protect people much quicker. In terms of ISR, the MQ-9 is one of the most requested assets for the role. Any time a situation is developing we can be overhead, providing overwatch and reassurance to the troops on the ground."

When not deployed, Captain Kyle has two primary roles in the LRE squadron at Creech. Wearing his instructor hat, Kyle's job is to watch over a new pilot and get them to a level where he or she can fly in a combat zone by themself, effectively operate the mission and potentially employ a weapon. Captain Kyle explained how he watches over the shoulder of the student or upgrade pilot during instruction because there is not a seat with controls available. He said: "We have to be on the spot and make sure the student knows, that if I give them a direction they need to react immediately, rather than me being able to jump in and take control from them."

Secondly, Kyle ensures all squadron pilots are current in any flight activity that they have not done in a while. Key to the instructor's role is their ability to properly convey their tactics, techniques, and procedures to the most inexperienced pilot to ensure they are ready to fly in combat.

"Flight operations at Creech are predominantly by the LRE squadron."

Wearing his evaluator hat, Kyle gives squadron pilots and instructors a check ride to make sure they are up to scratch with everything that is expected of them to operate in whatever role they're assigned.

Sensor Operator

According to Sergeant Mikelyn, an experience sensor operator assigned to one of the MCE squadrons at Creech, her main role is to find threats or targets and track them using the MTS camera, the bread and butter of the MQ-9's mission set.

Sgt Mikelyn explained the range of cameras integrated on an MQ-9: "We use a daylight TV camera to show colours and different materials which helps with identification. We also have an IR camera, which can tell the difference in thermal radiation. This camera is used at any time of day to maintain custody of a target we're tracking. Lastly, we use a low light TV ➲

A crew chief marshals an MQ-9 Reaper to its parking spot on Kandahar Airfield, Afghanistan. Maintainers have to conduct brake checks before shutdown and temperature checks post shutdown. US Air Force/SSgt Sean Martin

camera to acquire and track targets in times of darkness.

"Managing the camera is a huge part of what the sensor operator does to ensure an optimal picture. We use a focus button to get a clearer picture and bring out certain characteristics of the target. Alternatively, we can focus manually. We manipulate the zoom function in order to satisfy the task. We can zoom out a long way to give us a big picture of the area we're looking at, and we can zoom in to see small details."

The sensor operator performs slightly different procedures when conducting ISR tasking compared to a weapon launch. Explaining, Sgt Mikelyn said: "We're trying to find threats and targets, so we move the camera around and zoom in and out to get the best picture, and we also scan areas trying to figure out potential threats. During a strike, our job is to make sure the camera is stable enough, so we get a better look at the target for employing weapons. We identify and confirm the target, back up the pilot who is the main authority for a strike and remain in contact with other agencies. We also provide back up to the pilot during any emergency."

Maintenance

Master Sergeant Brandon is an 11-year veteran of the MQ-9 Reaper. He is a trained crew chief and currently serves as a maintenance superintendent at Creech.

It's a crew chief's responsibility to conduct all engine and landing gear maintenance, and the overall health of the airframe and structures. Avionics specialists, electricians and ammo troops support the crew chief with their respective specialist trades.

MSgt Brandon reckons the MQ-9 is just like any other aircraft as far as inspections and preparing the aircraft for flight. Explaining, MSgt Brandon said: "We do a basic post flight pre-flight inspection, which includes inspecting the aircraft for damage, checking tyres for wear and tear, and the propeller for damage. The props are pretty sturdy but they're also susceptible to damage from dust and rocks encountered in the desert environment. If a propellor is damaged my job is to undertake a repair on the flight line."

The types of inspection undertaken on the MQ-9 are pretty standard by comparison to any other aircraft. There are however different components and different inspection criteria, for example, an inspection for damage to the carbon fibre surfaces. All inspections performed on the MQ-9 are either periodic or time-based, but there are no phase inspections. Given the number of hours flown by MQ-9 aircraft, the 200 and 400-hour inspections come around much faster than other Air Force types.

"With future upgrades, the MQ-9 will become a more dynamic system."

The MQ-9 is powered by a single Honeywell TPE331-10GD turboprop engine, which is a very dependable motor and one that is fairly easy to maintain. Explaining Reaper engine maintenance, MSgt Brandon said: "We actually don't do a lot of engine maintenance, but when we do it's usually an engine swap which is straightforward. To change an engine, we remove the diagonal tails, the lower vertical tail, and some panels. We disconnect and remove fuel lines and electrical connectors and unfasten the four bolts that fix the engine to the airframe. The diagonal tails have to be removed at an angle, which requires a team of three, two on a stand and one on the ground. Using a hoist to take the engine's weight, we remove the bolts and pull the hoist such that the engine rolls out. We transfer the engine to a maintenance stand where we remove any accessories required for fitting the next engine and reverse the process for engine installation."

MSgt Brandon reckons everything on an MQ-9 is accessible and fairly straightforward to work on. He said: "When General Atomics designed this aircraft, they did so logically and with a lot of help from maintainers to make it maintainer friendly."

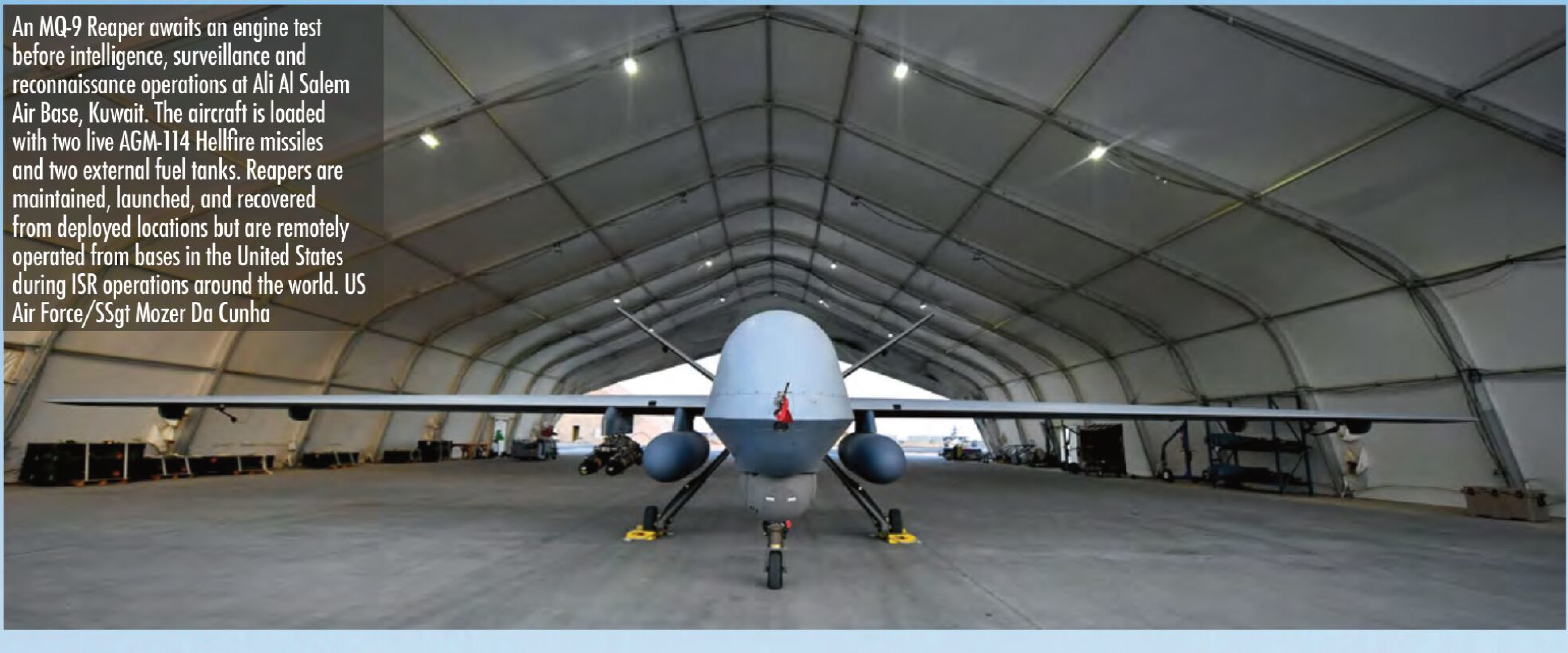
A good accolade for an aircraft that does not have a health monitoring system.

An MQ-9 Reaper on the flight line at Creech Air Force Base, Nevada. US Air Force/Senior Airman Haley Stevens

A crew chief checks the propellor of MQ-9 Reaper 11-136 on Kandahar Airfield, Afghanistan. US Air Force/SSgt Sean Martin

Maintainers get information from the aircrew as MSgt Brandon explained: "If an aircraft is coming back with a code 2 or code 3 maintenance status, my specialists go to the ground control station and work the problem with the aircrew. Sometimes we fix an aircraft before it even lands because something in the ground control station might be switched incorrectly. On occasions when we can't fix the problem while airborne, information from the ground control station helps with our troubleshooting because we can see first-hand what the pilots see. Once its back on the flight line, we hook up our aerospace ground equipment, maintain aircraft power so we can see the faults, and work through them on the ground. They're usually not tremendously challenging but require reprograming software or a straight part swap. The MQ-9 is a very avionics and electrician-based plane, so the avionics specialists and electricians are the heavy maintenance hitters."

The MQ-9's aft-mounted propellor presents airmen with a danger that's different to those presented by most other Air Force types. Comparing to his previous type, the F-16, MSgt Brandon said: "On an F-16 you can walk up behind the exhaust and duck down underneath the fuselage and remain out of harm's way. The MQ-9's propellor is quite the opposite and makes me very wary even though there are no checks required on the aircraft when the engine is running. There's no


An MQ-9 Reaper awaits an engine test before intelligence, surveillance and reconnaissance operations at Ali Al Salem Air Base, Kuwait. The aircraft is loaded with two live AGM-114 Hellfire missiles and two external fuel tanks. Reapers are maintained, launched, and recovered from deployed locations but are remotely operated from bases in the United States during ISR operations around the world. US Air Force/SSgt Mozer Da Cunha

MQ-9 Reaper 11-150/CH assigned to the 432nd Wing on a training mission over the Nevada Test and Training Range. MQ-9 aircrew provide persistent attack and reconnaissance for combatant commanders and coalition partners across the globe. US Air Force/Airman William Rio Rosado

"Sometimes an aircraft can be fixed when airborne by using the GCS."

reason for any maintainers to be near the dangerous area, and during launch procedures on the flight line, all maintainers stand forward of the wings for safety reasons."

MSgt Brandon explained the flight line launch and recovery procedures; "Once the aircraft has left its parking spot it belongs to the tower. We don't conduct any further checks at the end of runway ramp, those procedures are all done on the flight line parking spot. When the aircraft recovers to its parking spot, the crew chief and his team marshal the aircraft into the flight line spot. We perform a brake check before engine shutdown and temperature checks post engine shutdown, all while communicating with the LRE aircrew. During marshalling they watch us through the cameras, and we usually have wing walkers out to the side who signal the aircrew to show the wing tip is clear of obstacles."

Improving Reaper

Discussing future improvements for the MQ-9 Reaper, Major Troy said Air Combat Command and the 432nd Wing is pushing for an automatic take-off and landing capability. One of the manpower requirements of the MQ-9 Reaper is the need for a large, deployed presence comprising maintenance personnel to fix and repair, launch, and recover aircrew and ground data terminals. He said: "With the advances in automatic take-off and landing capability, we cannot eliminate that presence, but we can definitely minimise it. That would release more personnel from being deployed and assigned to the mission control element."

Based on the technology available, the ability to operate an MQ-9 autonomously from engine start to engine shutdown is possible, as per the Northrop Grumman MQ-4C Triton. However, because the MQ-9 carries weapons, the Air Force is hesitant with allowing a fully automated artificial intelligence system to take on that risk. Major Troy believes technology is improving such that some commanders are more comfortable with the small risks associated with fully autonomous systems.

Commenting on the 432nd Wing's current emphasis, Major Troy said the wing is keen to let the Air Force community at large know the MQ-9 is not just a counter-terrorist platform. He said: "It is our bread and butter work in operations and is in demand because the MQ-9 is so good at conserving gas and staying in uncontested airspace for a long time. But with future upgrades, the MQ-9 will become a more dynamic threat against near peer competitors." ●

MQ-9 REAPER CHARACTERISTICS

Primary Function: Intelligence collection in support of strike, coordination, and reconnaissance missions
Power Plant: Honeywell TPE331-10GD turboprop engine rated at 900shp maximum
Wingspan: 66ft
Length: 36ft
Height: 12ft 6in
Weight: 4,900lb empty
Max take off weight: 10,500lb or 11,700lb for extended range
Fuel Capacity: 4,000lb or 6,000lb for extended range
Payload: 3,750lb
Max Speed: 240kts
Range: 1,000nm or 1,400nm for extended range
Ceiling: Up to 50,000ft
Armament: Combination of AGM-114 Hellfire missiles, GBU-12 Paveway II, GBU-38 Joint Direct Attack Munitions, GBU-49 Enhanced Paveway II, and GBU-54 Laser Joint Direct Attack Munitions

STINGRAY:

Mark Ayton details the US Navy's nascent MQ-25 Stingray unmanned aerial

A team of aerospace specialists led by Naval Air Systems Command and Boeing's Phantom Works is currently developing a new weapon system, one that's set to change many of the established cultures of military aviation. Designated the MQ-25A and named Stingray, this 51-foot long non-experimental unmanned air vehicle is the world's first designed for carrier-based operations. In addition to catapult launch and arrested landing capabilities, the Stingray will perform autonomous aerial refuelling in support of all fixed wing aircraft assigned to the Carrier Air Wing (CVW).

Secondary to that, the MQ-25A has an intelligence, surveillance and reconnaissance (ISR) role afforded by an electro-optical and infrared sensor. Data will be transmitted at appropriate classification levels to other aircraft, naval vessels, ground forces, and to exploitation nodes afloat and ashore, specifically the Navy's Distributed Common Ground System.

In official Department of Defense parlance, the MQ-25 extends CVW mission effectiveness range, partially mitigates the current Carrier Strike Group (CSG) organic ISR shortfall and fills the future CVW-tanker gap, mitigating strike fighter shortfall and preserving F/A-18 Super Hornet fatigue life for fleet defence and strike missions.

As the first carrier-based, Group 5 unmanned aircraft system (UAS), the MQ-25 will pioneer the integration of manned and unmanned flight operations, demonstrate mature sea-based UAS command, control, communications, computers, and intelligence (C4I) technologies, and pave the way for future multifaceted, multi-mission unmanned air vehicles to keep pace with emerging threats.

The latter is a pointer to follow-on roles for the MQ-25. Certainly, the MQ-25's ➲

THE UNMANNED, CARRIER-BASED TANKER

vehicle designed for autonomous flight deck operations and aerial refuelling.

This shot shows the fuselage cross section form, the bulges of the wing joints housing the actuators and hydraulically-actuated pins that lock the wings in place, and the pitch of the tail surfaces of the V-tail.

low-observable, stealthy configuration points to the air vehicle being used to drag aircraft in CVW strike packages further from the carrier than ever before: most importantly supporting F-35C Lightning IIs into non-permissive environments.

This likelihood was not denied by Captain Chad Reed, MQ-25 program manager, unmanned carrier aviation with PMA-268 who said: “Right now, even though its configuration is stealthy, there is no low-observable requirement for the MQ-25. Our requirement was for Boeing to use mature technologies in accordance with the accelerated programme goals. It is designed to operate in permissive environments when it enters the fleet, while concepts of operation are explored, and it’s meshed with manned operations. Manned-unmanned teaming is a notable aspect of the programme, one that’s on the cutting-edge simply because other aircraft are not designed to

The test team followed standard procedures by keeping T1’s landing gear extended during its maiden flight on September 19, 2019.

“Stingray is the world’s first drone designed for carrier operations.”

The Phantom Works logo was removed from the forward fuselage on each side when T1 entered its initial flight test programme.

operate in such close proximity to and with manned aircraft: Stingray has a configuration and a new capability unmatched in a current air wing.”

MQ-25 requirements are aligned with the initial capability documents for the Unmanned Carrier Launched Airborne Surveillance and Strike (UCLASS) programme, and the Next Generation Air Dominance (NGAD) family of systems. Both documents highlighted the need for carrier-based refuelling and persistent ISR capabilities.

The Joint Requirements Oversight Council’s (JROC’s) guidance set out a requirement for a versatile platform that supports a myriad of organic naval missions such as aerial refuelling and ISR to support the CSG. On July 21, 2017, the JROC validated the capability development document for the MQ-25 Carrier Based Aerial Refueling System or CBARS.

“PMA-268 is preparing for Stingray testing at Pax River.”

Designed to be sustainable on board an aircraft carrier and from shore bases, the MQ-25 system is comprised of three major architectural segments.

- The air segment includes the MQ-25A air vehicle and associated support and handling equipment including the deck handling system, spares, and repair materials.

- The control system and connectivity (CS&C) segment includes the Unmanned carrier aviation Mission Control System (UMCS) and its associated communication equipment: mission support functionality of the Distributed Common Ground Station-Navy (DCGS-N), the US Navy’s primary intelligence, surveillance, reconnaissance and targeting system; all network based interfaces and routing equipment required to control the Stingray; and all required modifications to existing networks and C4I system infrastructure.

- The CVN (aircraft carrier) segment comprises the ships’ spaces allocated to unmanned carrier aviation, installed ship systems and modifications necessary for interface with the air and CS&C segments. CVN systems important to the MQ-25 include aircraft launch and recovery, data dissemination systems (including radio terminals and antennas), and deck operations systems. Ship installation requires considerable work to re-

model nearly $900ft^2$ ($84m^2$) of space on board the carrier to house the UMCS.

As Lead Systems Integrator (LSI), PMA-268 manages all three.

In terms of its operating envelope, the MQ-25 adequately meets the fleet's current operational needs and achieves the two primary roles. Driving that performance is a relatively low air vehicle empty weight and the fuel-efficiency of the Rolls-Royce AE3007N engine.

Components integrated on the air vehicle to meet mission requirements include a long wingspan for flight stability and endurance; a Héroux-Devtek landing gear system; redundancy systems for safety of flight; Raytheon ALR-69A(V) all-digital radar warning receivers providing 360° coverage; a Raytheon AAS-52 MTS-A multi-sensor imaging system equipped with infrared and CCDTV sensors, laser rangefinder, designator and illuminator; and one Rolls-Royce AE3007N turbofan engine rated at 9,000lb (40kN).

Systems specific to carrier flight deck operations include a tail hook for arrested landings; foldable wings to minimise the air vehicle's parking footprint on the flight deck; design features that ease maintenance; and on-deck control systems that integrate with systems currently used on Nimitz and Ford-class carriers.

CBARS Competition

Based on the US government's acquisition strategy approved in April 2017, the MQ-25 programme is an evolution from the previous UCLASS programme.

Concepts for the now defunct UCLASS programme were deemed too difficult and challenging given the number of new technologies involved, all of which required evaluation. Consequently, NAVAIR's PMA-268 implemented a restart to evaluate the possibilities for introducing something so new as the MQ-25, and to explore concepts of operation.

"Testing with T1 includes envelope expansion and aerial refuelling."

In 2016, the US Congress appropriated PMA-268 a congressional plus-up award for four contractors, each capable of developing an UAS suitable for the CBARS requirements: Boeing, General Atomics, Lockheed Martin and Northrop Grumman.

Each contractor presented PMA-268 with ideas about how they were to mature their own technologies and concepts prior to receiving their share of the congressional plus-up award - a means of funding their respective concept development programmes through mid-2018. At that point with details, including the giveaway fuel load and ranges of each of the concepts submitted, PMA-268 conducted a tanker trade study which help conclude its requirements for the CBARS programme.

PMA-268 released the draft air system Engineering, Manufacturing, and Development (EMD) Request for Proposal (RFP) in July 2017 and released the final EMD RFP in early October 2017. Shortly after, Northrop Grumman dropped out of the competition citing an inability to meet the Navy's specification and deliver a profit.

Less than eight months after receiving qualified proposals, PMA-268 awarded the EMD contract to Boeing in August 2018. This was the fastest Acquisition Category 1 (ACAT-1) EMD award in the past ten years.

Under the EMD contract, the first seven aircraft procured by the Navy are four Engineering Development Model (EDM, not EMD) test air vehicles (AV-1, AV-2, AV-3 and AV-4), and three System Demonstration Test Articles (SDTA). In addition, Boeing will also build two more airframes – one for fatigue testing and one for static loads testing.

Part of the requirement was to have a considerable amount of the design already complete prior to contract award; each company had either a prototype or a developmental article ready.

PMA-268 staff conducted a thorough review of each proposal over the next eight months. Boeing's bid was determined to offer the best value for the government, first and foremost because of its ability to meet the schedule, and the ability to meet the key performance parameters (KPPs). It's notable that the MQ-25 had just two KPPs. This a consequence of a pilot programme launched by the chief of naval operations, Admiral John Richardson in 2017 that sought to limit the number of KPPs for a new weapon system to no more than three. PMA-268 opted for two: the capability to give away a set amount of fuel to a CVW strike package hundreds of miles away from the

"Stingray has a configuration and a new capability unmatched in a current air wing."

The Navy-Boeing joint test team flew T1 with an aerial refuelling store loaded on the left side under wing pylon for the first time on December 9, 2020. Boeing/Dave Preston

T1 marked with the Phantom Works logo on the side of the forward fuselage while undergoing initial ground testing on an imitation catapult at Boeing's St Louis, Missouri facility.

carrier, and full integration with Nimitz and Ford-class carriers as they currently operate.

MQ-25 is designated a maritime accelerated acquisition programme because the chief of naval operations, Admiral John Richardson and the assistant secretary of the Navy for research, development and acquisition, James Geurts saw the importance of getting the system to the fleet quickly. More specifically to reduce the amount of flight time used up by F/A-18 Super Hornets when conducting the aerial refuelling role. The 6,000-hour Super Hornet service life is being depleted at much faster rates than anticipated. This has forced the Navy to develop a new weapon system to conduct its tanker mission. This is a primary reason why the US Navy switched its plan for a carrier-borne UAS from one programme, UCLASS, to another; CBARS (see below).

The CBARS concept also addresses other tactical aspects of carrier aviation; it helps to counter emerging threats now fielded by potential adversaries. That capability almost certainly points to a need for the MQ-25's stealthy, low-observable configuration.

T1 and Phase One Testing

Phantom Works, Boeing's advanced prototyping division, started building air vehicle T1 in 2012.

The design features a blended wing-body-tail air foil with folding, high-aspect-ratio wings and a V-tail. Its configuration reflects the long-endurance mission requirements of the UCLASS programme, particularly the long thin wings. Phantom Works finished the first iteration in 2014 as part of its design proposal for the UCLASS programme.

Air vehicle T1 has the same outer mould line and the same engine to nascent production standard MQ-25s. Consequently, some aspects of testing already undertaken with T1 will not require repeating with a production standard air vehicle.

The objective of the MQ-25 test programme is to evaluate system maturity and technical performance of the aerial refuelling role; both mission and recovery tanking.

Initial ground testing with T1, including communications integration, towing, combined system and taxi, began almost immediately following award of the contract at Boeing's facilities in St Louis, Missouri. In April 2019, Boeing trucked T1 to MidAmerica St. Louis Airport in Illinois to conduct the first phases of flight testing. T1's maiden flight took place there on September 19, 2019. The company chose MidAmerica (the commercial side of Scott Air Force Base) because of hangar, runway, taxiway and air space availability.

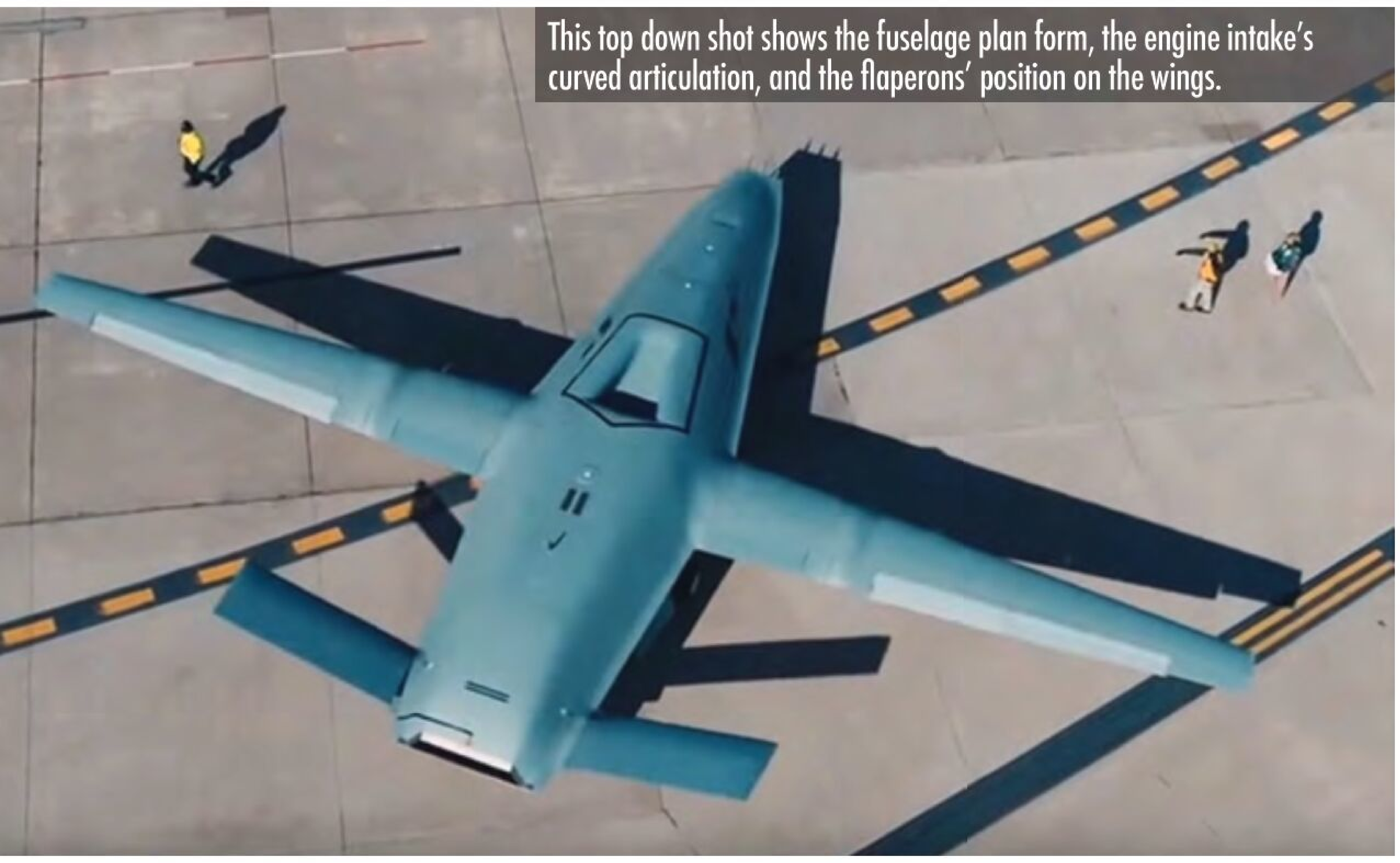
"MQ-25 will pioneer manned and unmanned integration."

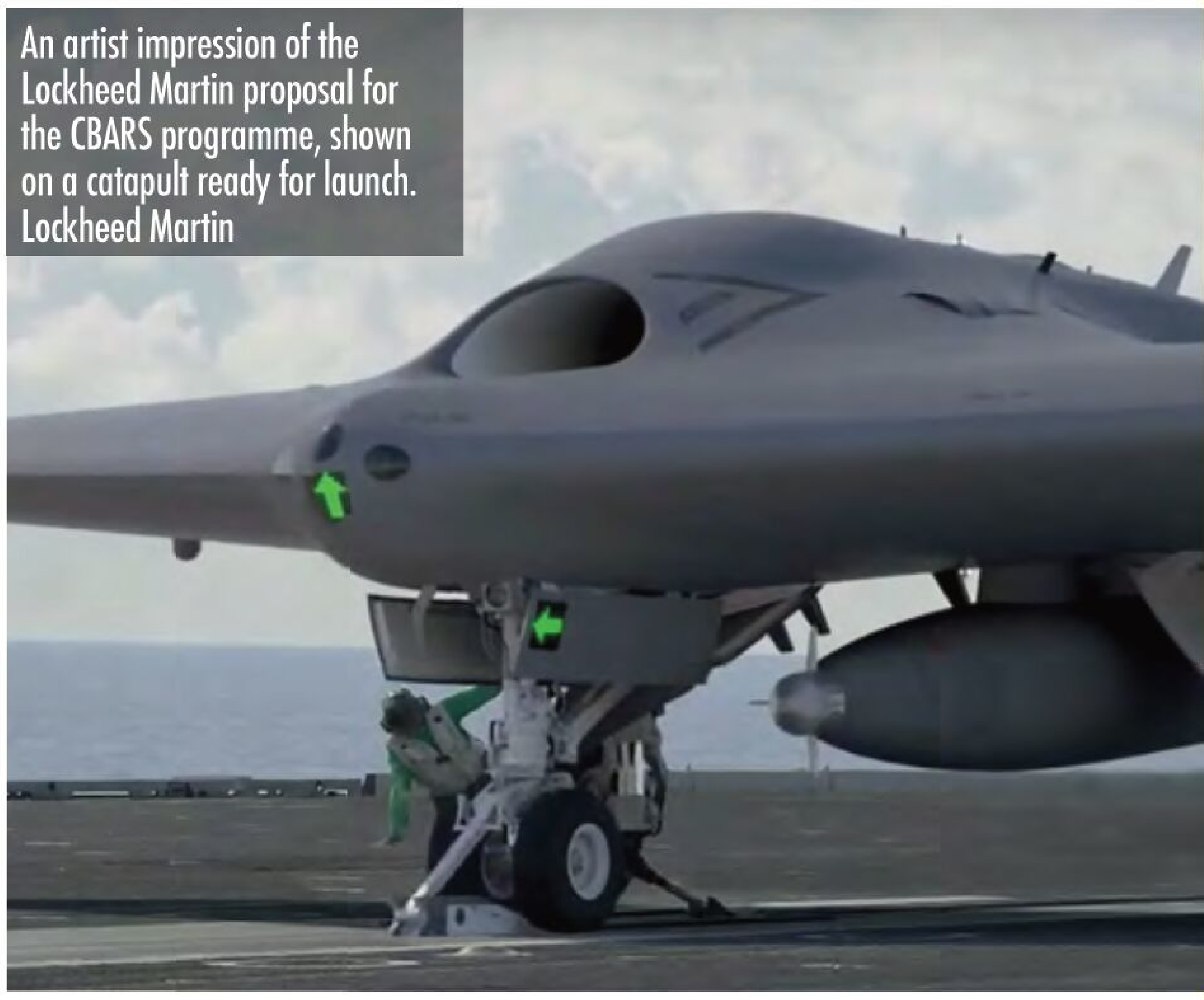
As of November 2020, T1 had flown 12 flights and amassed nearly 30 hours during which the team worked through test points designed to evaluate the aerodynamic performance of the air vehicle, altitudes and air speeds, and the performance of the engine. T1 is fully instrumented for capturing flight test data used to evaluate flight and aerodynamic performance.

T1 is currently undergoing a planned modification for the installation of an aerial refuelling store underneath the left wing, specifically a Cobham 31-301-7 buddy store. The modification is required because T1 was originally developed without pylons to carry stores which were not a requirement of UCLASS. The first series of aerial refuelling flight tests will follow later this year.

Testing with T1 will continue over the next few years to include envelope expansion, engine testing, aerial refuelling store operations, and testing of the Joint Precision Approach Landing System (JPALS).

The Navy-Boeing joint test team flew T1 with an aerial refuelling store loaded on the left side under wing pylon for the first time on December 9, 2020. Boeing/Dave Preston


This top down shot shows the fuselage plan form, the engine intake's curved articulation, and the flaperons' position on the wings.


An artist impression of the Lockheed Martin proposal for the CBARS programme, shown on a catapult ready for launch. Lockheed Martin

The latter will require T1 to undergo a second modification period to enable the air vehicle to land using the JPALS, a differential, GPS-based precision landing system that guides aircraft onto carriers in all weather and surface conditions up to the rough waters of sea state 5. It's an important mod which will evaluate functionality and identify any issue with JPALS before the FY2021 delivery to Naval Air Station Patuxent River of the first EDM test-configured air vehicle AV-1.

T1's involvement in the test programme will culminate with its hoisting aboard an aircraft carrier to test the deck handling and control station systems.

Risk Reducer and Later Test Phases

T1 has already proven beneficial as a risk reducer during initial ground and flight testing. According to PMA-268, T1 is performing as the models projected to give the programme confidence as it moves to EDM standard air vehicle production and test.

Having T1 available for testing years before the first EDM comes off Boeing's St Louis production line leads to the discovery of any issues much earlier than is typical. Lessons learned and any issues identified can be applied and corrected during the development of the EDM air vehicles. For example, an icing susceptibility problem with the air data probe system has already been identified. To correct the issue, a different air data probe has been designed and will be fitted to all four EDM air vehicles AV-1, AV-2, AV-3, and AV-4, during their production. Without T1, the test team would not have been able to identify the problem for several years.

Initial testing of each EDM air vehicle will take place at Boeing's MidAmerica St Louis Airport facility by an integrated Navy-Boeing test team before delivery to Naval Air Station Patuxent River, Maryland. The Air Test and Evaluation Squadron 23 (VX-23) 'Salty Dogs' will lead testing of MQ-25.

Part of the air vehicle's catapult launch and arrested landing equipment testing will take place at Naval Air Engineering Station Lakehurst, New Jersey, followed by cold soak trials in the McKinley climatic laboratory at Eglin Air Force Base, Florida.


An artist impression of General Atomics' proposal for the CBARS programme, shown aerial refuelling an F/A-18 Super Hornet from a single ARS mounted under the left wing. GA-ASI

AV-1 will undergo all aspects of a standard flight test programme followed by catapult launches and arrested landings at both Patuxent River and Lakehurst.

Boeing is conducting T1 flights in partnership with PMA-268, whereas EDM flight testing will be conducted by an integrated Navy-Boeing test team led by VX-23.

PMA-268 is overseeing all preparations for the MQ-25's test programme at Patuxent River. A hangar and laboratory facility are under construction, support equipment is being acquired, and personnel recruited.

AV-1 and AV-2 will be dedicated to flight sciences testing and fitted with similar instrumentation to T1. AV-3 and AV-4 will be dedicated to mission systems and carrier suitability testing, and the air vehicle's effectiveness to the aerial refuelling role, all planned for the second phase.

The air vehicle's all-up weight is an incredibly important design parameter for carrier suitability. The MQ-25 must be capable of fulfilling its tanking role despite the constraints imposed by maximum catapult shot weights and arrested recoveries from Nimitz-class and Ford-class carriers. All-up weight was also constrained by the requirement for a fuel giveaway of 16,000lb (7,257kg) at 500 nautical miles (925km) from the carrier. By comparison, a Super Hornet holds a giveaway fuel load of 12,000lb (5,443kg) on a two-hour cycle, 15,000lb (6,803kg) on a normal cycle and 25,000lb (11,339kg) on a short cycle.

"An AVO uses mouse and keyboard controls to operate MQ-25."

The MQ-25 will also be tasked with recovery tanking, which involves having a tanker airborne in orbit close to the carrier while aircraft recover. A critical capability at night or when the weather conditions are bad with a pitching deck in heavy seas, such that pilots need to top up the tanks to afford further attempts to land on the flight deck.

Initial Operational Test and Evaluation (IOT&E) is the final phase.

Control System

Designated the MD-5 A/B (ship/shore), the Unmanned Carrier Aviation Mission Control System (UMCS) is an MD-5 A/B control station comprising open architecture software, six OJ-845 common display systems, two UYQ-122 common processing systems, one

network processing group, one integrated communication system, and network connectivity.

Both the MD-5 and its operating software are being developed by PMA-268, which is also responsible for all modifications required to shore-based and CVN infrastructure. The latter includes integration of NAVAIR-developed software with Boeing's air vehicle OFP, the network, and the command, control and communication systems that will enable both CVN and shore-based control of the air vehicle.

A PMA-268 team demonstrated the first build of the UMCS using representative shipboard equipment and a simulated air vehicle at Patuxent River on April 11, 2017.

During the demo, the UMCS communicated with a Surface Mobile Aviation Interoperability Lab truck, simulating an air vehicle, and verifying command and control. Connectivity between the UMCS and shipboard network systems was tested and voice trunking (internet protocol to serial) between the air vehicle operator (AVO) and the simulated UAV was verified.

Limited control and data dissemination between the UMCS and simulated air vehicle to include automatic identification system detection, electro-optical/infrared camera operation, and full motion video, pre-planned and dynamic mission re-planning, was also performed.

UMCS 1.0 demonstrated that third party software can coexist with the common control system (CCS) framework, thereby proving the architecture is viable. This demonstration was the first of a series to demonstrate UMCS capabilities as development of the system progresses.

"Software is designed to handle unexpected events."

Integration testing is ongoing at Patuxent River as part of the programme's first test phase.

UMCS hardware builds on Naval Sea Systems Command's common display and processing systems from the DDG-1000 Zumwalt-class destroyer and other Aegis-equipped ships.

It also incorporates the Navy's CCS, a software architecture that features a common framework, user interface, and components designed for use with a variety of unmanned systems.

US Navy documentation lists a requirement for 12 UMCS sub-systems for assembly and delivery to installation sites between September 2020 and October 2027.

Air Vehicle Control

Using mouse and keyboard controls, the AVO commands the air vehicle where it needs to go and what it's required to do then the system determines how to get there in the most safe and efficient way.

Typical operation involves the AVO maintaining positive control of the air vehicle, including the ability to change speed, direction and altitude, and continuously monitor the machine while in flight.

Flight control software is designed to handle unexpected events such as bad weather or when a change of altitude or the position of its tanking pattern is required.

The AVO, a warrant officer, will use the MD-5 control station housed within the carrier's Unmanned Carrier Aviation Warfare Center throughout all stages of the mission from the catapult launch to the arrested landing.

Prior to launch and landing, a deck handling operator will use a deck control device to taxi the Stingray around the flight deck. Once the air vehicle is on the catapult, the deck handling operator will hand-off to the AVO. After landing, the deck handling operator will assume control to taxi the air vehicle to its parking spot. This is a similar method to the one used for the Northrop Grumman X-47B demonstrator.

During aerial refuelling ops, the AVO will have the ability to communicate with the receiver aircraft's pilot. PMA-268 is currently developing a concept of operations for aerial refuelling which will follow the same procedures as currently used by Super Hornets.

Milestone C and Beyond

Since the award of the contract to Boeing, PMA-268 is following a non-standard version of the rigorous Systems Engineering and Technical Review (SETR) process to finalise the design. The US Department of Defense tasked PMA-268 to tailor out elements of the standard SETR process as part of the MQ-25's Military Airworthiness Authority distinction in order to achieve a six-year schedule. MQ-25 milestone names and requirements differ from the traditional convention because of the focus on accelerating development and delivery to the fleet. Work will continue through to the ➲

T1 positioned with the forward launch and aft holdback bars lowered over the imitation catapult's shuttle track.

MQ-25 system design review (SDR) later this year to set its baseline design. This will allow production of the EDM air vehicles to begin. SDR is similar to a critical design review used by other Department of Defense programmes.

PMA-268 is pursuing a Milestone C decision for low rate initial production in FY2023 to procure up to a dozen MQ-25A air vehicles. Following successful IOT&E, PMA-268 will pursue a full rate production decision for an estimated total of 76 vehicles. Stingray is expected to achieve its initial operational capability with the fleet in 2024.

In the spring of 2020, T1 entered a period of modification to install the previously mentioned stores pylon under the left wing and integrate a Cobham 31-301-7 buddy Aerial Refuelling Store (ARS). Work undertaken included software updates for operation of the ARS, and an upgrade of the ground control station (GCS) to support the MQ-25's aerial refuelling mission.

T1 made its first flight loaded with the ARS on December 9, 2020, controlled by Boeing test pilots from a GCS located at MidAmerica airport, and completed a 2.5-hour mission to gather data about aerodynamic effects of the ARS at various points in the air vehicle's flight.

"MQ-25 Stingray has a secondary reconnaissance role."

The Cobham 31-301-7 buddy ARS is already in US Navy service with F/A-18 Super Hornet squadrons. According to Cobham, the ARS is mounted on an ejector rack by two lugs spaced 29.9in apart, has an internal capacity of 250 gallons and can pump fuel to a receiver aircraft at the rate of 180 gallons per minute. A ram air turbine drives a variable displacement hydraulic pump when the store is activated. Hydraulic power generated by the pump provides the power to drive the hose reel and fuel pump motors. The ARS provides hose guillotine, jettison, and sealing; pod jettison; and fuel dump emergency provisions.

Prior to November 2020, US Navy air vehicle operators (AVOs) had participated in multiple test pilots while occupying the third seat in the GCS. Following a training course with Boeing at its St Louis, Missouri facility during October, Navy AVOs assigned to VX-1 and VX-23, NAVAIR's operational and developmental test squadrons, participated in subsequent test flights as the co-pilot of T1. The course was designed to train them how to operate the MQ-25 using a GCS from start-up to shut-down.

Lieutenant Venus Savage, VX-1's MQ-25 assistant operational test director, said the training was a unique opportunity to learn about the command and control processes used to interface with and operate the MQ-25 long before the first aircraft is delivered to the Navy. Discussing the course Lt Savage said: "We were able to ask detailed questions and get clarification on what the checklists and commands are, and Boeing personnel let us know what to expect from the air vehicle."

The joint US Navy-Boeing test team is currently focussed on the guidance and control of the air vehicle with the ARS installed, checking functionality of extending and retracting the hose from the ARS, and determining the behaviour of the hose and basket in T1's wake. Once the necessary flight clearances and procedures required to engage the ARS basket, dubbed plugs, have been issued and devised, the joint test-team will conduct the first plugs with one of the Navy's MQ-25 EDM test air vehicles. PMA-268 is currently developing a concept of operations for aerial refuelling from the MQ-25. This will involve single drogue refuelling, and follow the same procedures currently used by Super Hornets.

As of mid-January 2021, T1 had flown 14 flights and amassed nearly 35 hours.

As a new unmanned, carrier-based weapon system, once its flight test and carrier suitability trials have been completed, the MQ-25 Stingray looks set to change well-established cultures of military aviation. The type's eventual inclusion in US Navy carrier air wings coupled with the accelerating use of automation and artificial intelligence in combat aircraft means the MQ-25 may well be the first of many such nascent unmanned systems used for roles such as strike and electronic attack.

T1 just a second from touch down at MidAmerica St Louis Airport, Illinois on September 19, 2019, at the end of the air vehicle's maiden flight.

Ongoing flight testing with T1 will evaluate the aerodynamic effects of the ARS on the air vehicle at various points of its flight envelope. Boeing/ Kevin Flynn

MQ-25 STINGRAY CHARACTERISTICS

Wingspan	75ft (22.86m)
Wingspan folded	31ft 3in (9.54m)
Length	51ft (15.54m)
Height	15ft 8in (4.78m)
Flight deck footprint	No greater than a Super Hornet

MADE IN ENGLAND: TARA

Mark Ayton details the BAE Systems' unmanned Taranis technology demonstrator, one of the most advanced air vehicles ever flown.

NIS

Taxi trials at Warton under a dramatic skyscape. This shot gives a sense of how large the main landing doors are.

The configuration of Taranis was determined by the low-observable design which aims to avoid detection by radar and infrared systems. Its fundamental features are the clean blended wing and body, which exclude radar returns due to a lack of fins and a tail plane. Similarly, the highly swept wing, swept leading and trailing edge alignment of the planform, control surfaces, access panels and doors, internal stores carriage, a low-observable system, and not least a propulsion system that incorporates novel features from intake to exhaust are all design aspects that help to minimise the vehicle's radar cross-section.

The wing, with a sharp leading edge and sweep of approximately 45°, eliminates potential large spiky radar returns which are normal to a leading edge over a very wide, 300°, critical frontal detection aspect. The greatest contributor of an aircraft's frontal radar cross-section signature, and the one capable of swamping all other returns, is that created by the intake and engine face.

Dorsal positioning of the intake on Taranis is favourable, providing some shielding from radar and IR detection. Its highly raked intake positioned well forward is conducive to achieving a long low radar cross-section installation. Radar absorbent material (RAM) treatments and/or radar blocker devices may be incorporated.

A further significant feature on Taranis is the absence of a boundary layer diverter, the latter being a problematic area for achieving minimal radar cross-section. The sharp-lipped triangular intake form, possibly a compromise between internal aerodynamic performance and low radar cross-section, and the complete intake duct have been the subject of full-scale signature reduction using the BAE Systems' Nightjar test body on the Warton range.

"The wing eliminates potential large, spiky radar returns."

Taranis is powered by a single Adour engine as used by the Hawk Advanced Jet Trainer, the most powerful version of which is the Mk951 rated at 6,500lb (28.9kN) thrust. Although not confirmed as the specific version for Taranis, the Mk951 incorporates full authority digital engine control, ideal for integration with the air vehicle's flight control system.

Given that BAE Systems reckons the Taranis is of similar size to a Hawk, an Adour engine is likely to propel the air vehicle to a maximum airspeed of Mach 0.84 (555kts/1,028km/h) similar to that of the Hawk T2.

The letterbox shape of the engine nozzle blends well with the overall configuration and offers reduced rear-aspect radar cross-section, probably with a 'bendy' duct, that primarily minimises IR returns from hot engine parts and exhaust plume: the latter by mixing external air and hot exhaust gases. A complete propulsion

Main landing gear doors open toward the aircraft's centreline rather than toward the wing tip.

This top-down view of the Taranis air vehicle shows the curved configuration of the upper fuselage surfaces, the edge treatments of the wing and control surfaces, the fuselage forward of the intake, and the narrow engine exhaust positioned on the upper surface.

rig was tested at Rolls-Royce's Bristol facility.

In side elevation, Taranis presents a somewhat tubby profile due to the high dorsal intake and deep lower body, whilst head-on, the significant depth and width of the lower fuselage is apparent. This stems from its major systems: engine, main undercarriage, airframe and mission systems and fuel tanks all of which need to be positioned close to the aircraft's centre of gravity and within its relatively short body. It's easy to see how the S-shaped ducts are readily integrated within this rotund body.

A nose boom with conventional air data sensors was fitted for early flight trials – a flight regime in which a minimal radar cross-section is of no consequence - and was not present during phases two and three of flight-testing.

"Two small air inlets on the upper surface are evident."

Two small air inlets on the upper surface are evident in the images released by BAE Systems, shown to be open on the ground and in low-speed flight, and are perhaps related to cooling or possibly just auxiliary air intakes. Clearly these would not be open in the low radar cross-section flight regime.

A truly pragmatic approach to reduce the cost of this one-off demonstrator was adopted for the Taranis undercarriage, it is an off-the-shelf system used by the JAS 39 Gripen fighter.

Aerodynamic control surfaces include upper and lower surface drag spoilers on the outer wing, which operate differentially port and starboard, to provide control yaw on this finless/rudderless configuration. Due to aerodynamic subtleties, spoilers are not fully closed flush in flight. Large-span trailing edge elevons provide pitch and roll control. Edge alignment and edge and junction shaping minimise radar cross-section penalties. On the ground and without power these surfaces

relax and give Taranis a distinctly droopy appearance. Proving this form of aerodynamic control was a prime purpose of the BAE Systems Raven demonstrator first flown in December 2003.

Flight Demonstration

Flight demonstration trials of the Taranis were flown at the Woomera Prohibited Area, a unique military test range covering nearly 47,875 square miles in the northwest of South Australia. By early 2016, BAE Systems had completed the third and final phase of flight demonstration trials.

Objectives for the flight-testing programme were demonstration of the air vehicle's low radar cross-section, the so-called low-observability capability, its ability to avoid shoot-down by either a surface-to-air or an air-to-air missile in contested airspace, autonomous operation in terms of a deep strike capability in a combat zone, and to prove the ability to scale up some of the individual technologies amalgamated into Taranis air vehicle ZZ250.

During phases two and three, air vehicle ZZ250 was used to test as many facets of the technologies as possible. Results of the flight demonstrations were used to progress Team Taranis to a point at which the maturity of the technologies amalgamated or otherwise proved they were capabilities worthy of pursuing further.

"In side elevation the Taranis presents a somewhat tubby profile."

Jointly funded by the UK government (70%) and UK industry (30%), the technology demonstrator is a UK-only programme developed by a six-party collaboration involving BAE Systems, Rolls-Royce, GE Aviation and QinetiQ, supported by the Defence Science and Technology Laboratory (DSTL) and the Defence Equipment and Support agency.

For BAE Systems, Taranis sits in an interesting place – by which the author is not referring to the hangar at Warton, its current home, but the conflict between which programme aspects can be discussed and those cannot. This information lockdown is care of the folks running the UK Ministry of Defence. According to one programme manager, air vehicle ZZ250 contains some pretty cool stuff developed by the UK industry team, much of which has to remain undercover.

Stealthy by design, engineers had to verify the air vehicle met the radar cross-section criteria set by the government. To accomplish verification, the air vehicle spent some time at Warton's radar cross-section range. Radar cross-section verification requires measurement from all aspects, which was the primary reason for supporting the air vehicle on three circular struts atop a turntable that enabled the vehicle to be spun through all aspects.

However, the Warton radar cross-section range comprises more than a turntable and a bunch of circular struts. The facility also has a hangar, but one of a different kind from the usual. Set on railway lines, the hangar is movable. When required, the test piece can be covered by moving the hangar to position overhead the turntable and moved away from the test piece during testing.

When the Taranis air vehicle was under test, each of the three circular struts was shrouded by a large cone founded on the floor as part of the range gate process. Range gates are used to select a certain target for further processing: in this case, to range gate the hangar with the test piece in the foreground.

Ground-based activities also included hardware-in-the-loop testing used to mimic flying in order to exercise fully all systems on

"Taranis is powered by a single Rolls-Royce Adour engine."

This shot shows the curved form of the fuselage and the difference in depth between its upper and lower forms. Depth of the upper surface is such to house an S-shaped air intake duct and an Adour engine.

The air vehicle's trailing edges are arranged in such a way to direct radar wave reflections in just a few angles.

The fuselage underside resembles the hull of a boat. The lower surface is gently curved and meets the upper surface at an acute angle to limit the angles of specular reflections.

Taranis is shaped to achieve specular scattering of radar waves such that they bounce off the structure: the fuselage shape and articulation is formed to minimise the returns to a radar.

Out on the Woomera range during the first flight demonstration phase when the air vehicle was fitted with antennas and a nose boom for flight sciences testing.

board and execute the mission plan.

During phase one, the air vehicle was configured with antennas and a nose boom for flight sciences testing, verifying operation of the highly automated finless air vehicle and its flight characteristics. The onboard air data system provided sufficient data to deem the air vehicle airworthy, which meant that the nose boom could be removed for the follow-on phases.

Phases two and three involved testing the air vehicle in all three signature domains: infrared (across the aft aspect); radar (from all aspects); and communications (also from all aspects) for which the air vehicle was in a low-observable configuration without antennas and the boom to further reduce the radar cross.

Specifically, reduction of the amount of communication emissions in time and volume to and from the air vehicle was one aspect of phases two and three, as was air vehicle survivability, testing the group of technologies and systems designed to prevent shoot-down across all three signature domains concurrently.

Flight Operations

Prior to each flight, the air vehicle is uploaded with the mission plan containing every objective. Taranis has three flight modes available: automatic, the primary mode used for take-off, general flying and landing, and the most common for much of the flight-testing; autonomous, used to accomplish the mission requirements; and manual, the back-up.

Engine start is a manual function, but from there on the air vehicle operates in automatic mode. The aircraft taxis to a holding point close to the runway and holds there until a take-off authorisation is received. Take-off is also an automatic function, as is transit to the area.

Once within the area, operation switches to autonomous mode. This is a neat capability. Taranis autonomously determines where to fly within the so-called search sector air space to acquire its assigned targets in accordance with the mission plan's set constraints. Surveying an area with an imaging system, collecting, storing, and relaying information back to a ground station is one example. Given the air vehicle knows its altitude, flight pattern and sensor footprint, the system could determine the number of images required to map an area fully.

Despite its autonomous capability, Taranis always operates with a two-person crew – a vehicle operator and a vehicle commander – supported by numerous technicians and flight-test engineers.

Phase two and three trials helped determine the limits of the existing technologies and what could be achieved with them. Consideration was then given to how the technologies were to be used.

Continuing with this example, once the mapping task was complete, Taranis picked up a new tasking from the mission plan: for example, an attack profile involving the simulated release of a weapon (no weapons were carried), then holding off before receiving a command to return to the target area for a simulated battle damage assessment.

The three stages outlined for the mapping task above are normally undertaken by a ISR aircraft assigned to a front line squadron with very little continuous communication. By contrast, a current generation remotely piloted aircraft requires continuous communication to achieve the task in addition to a high bandwidth for video stream downlink and a complex exploitation capability to handle the data. Continuous uplink and downlinking make that remotely piloted aircraft an emissions beacon.

"The intake's position shields it from radar and IR detection."

Taranis, on the other hand, demonstrated how it could operate in simulated contested air space with minimal communication and use of greater automation in a combat zone. This is an advantageous capability, but one that's also sensitive to all sides to which BAE Systems stressed that Taranis is not a demonstrator of a fully autonomous future weapons system.

The company says communication architecture is a key requirement for a man-in-the-loop system like Taranis.

What Next?

Now that air vehicle ZZ250 is parked up in a hangar at Warton in an airworthy anti-deterioration maintenance state, it's worth reviewing what BAE Systems will do next, not just with its light grey, wedge-shaped aircraft, but also the technologies demonstrated by Taranis.

To understand the programmatic aspects, it's best to briefly review the background of the Anglo-French FCAS programme.

BAE Systems worked on the FCAS feasibility phase back in 2016, a phase created in the Lancaster House defence accord signed in November 2010. In 2012, BAE Systems conducted a small, demonstration phase, and also received the route signposting for a two-year funded feasibility programme following an Anglo-French summit at RAF Brize Norton in 2014.

Commitment to the FCAS programme was reconfirmed in the UK government's 2015 ➲

Strategic Defence and Security Review (SDSR), with further commitment coming from the Anglo-French summit at Amiens in March 2016. Amiens confirmed the UK and France both wanted to transition to the next phase of FCAS in 2017.

Collaborative in nature, the construct of this feasibility phase included national variance of a common core solution with recognition of the possible differing operational requirements of the two nations, and an assurance that the common core could handle the individual UK and French objectives.

The £200 million, two-year FCAS feasibility phase included £120 million for the joint programme and £80 million for national technology programmes. Six defence companies were involved, two for airframes, two for systems and two for engines.

From a practical perspective, the binational programme was based on systems and components produced by each of the six defence companies as contributions to the common core.

Design and development required an adaptable programme that recognised the likelihood of two national trials each individually feeding information into the common core as well.

€2bn was committed by the two governments, with a technical review in 2020, aligned with the UK's latest defence review.

UK Combat Air

During late 2017, BAE Systems supported the government in its review of the Combat Air Strategy, and this led to the Tempest announcement at the 2018 Farnborough International Airshow. Taranis was the blueprint for how a group of companies with technologies and a vision of the future could come together to work with the UK government to mature those technologies to a point where it and industry are happy to move forward into the production phase. Taranis was significant in two ways: investment, and the technological challenge of designing and maturing critical design technology and best acquiring that capability, based on the results.

Determining how the Royal Air Force and Royal Navy will potentially train with a future air vehicle is a key point of BAE Systems' ongoing work. How will the operational use of a UAV that for 95% of the time will operate for training manifest itself when you've got a force mix of manned and unmanned?

"Flight-testing was conducted at Woomera, Southern Australia."

BAE Systems is part of a UK working group that includes the Military Aviation Authority and the Civil Aviation Authority (for administration of the civil aviation regulation component) whose first major test is the certification of the Protector UAV in UK airspace for RAF service entry - Protector will be the first CAA-qualified unmanned vehicle.

As such, Protector is core to how the UK progresses to routine UAV operations in UK airspace. This is a large programme of ongoing work, and some of the key technologies used by Taranis are evolving, such as sense and avoid and autonomous operation, which BAE Systems has to progress further and ultimately demonstrate.

It's fair to say that the level of capability demonstrated by the Taranis air vehicle can be classed as world-beating. It is equipped with some cool stuff and stands as an example of how BAE Systems and its programme teammates successfully manufactured an advanced air vehicle system in quite a short timescale and concluded with a successful flight demonstration programme.

Science Behind the Covers

Antennas fitted to the air vehicle's fuselage underside for flight sciences testing appear to be positioned within the surface area of removable panels.

Note how the curved form of the upper fuselage meets the leading edge of the engine intake at an apex.

With a pronounced wing sweep, the Taranis is subtly different in plan form to similar unmanned air vehicle demonstrators.

Taranis is shaped to achieve specular scattering of radar waves such that they bounce off the structure - the fuselage shape and articulation is formed to minimise the returns to the radar. The entire fuselage form achieves that by minimising the number of features dubbed bounce structures: the ones that reflect most of the energy of a radar wave back to source. More specifically facets, control surfaces, leading and trailing edges are arranged in such a way to direct radar wave reflections just a few angles; in engineering terms this is known as planform alignment and seeks to reduce the air vehicle's detectability at every other angle than the few mentioned above.

Radar waves occupy various frequency bands within the electromagnetic spectrum, and to date American aeronautical engineers designing stealth aircraft such as the F-117 Knighthawk, B-2 Spirit, F-22 Raptor and F-35 Lightning II have created materials with an ever greater ability to absorb electromagnetic waves. Absorption depends on two properties: one to store electrical energy (permittivity) and one to store magnetic energy (permeability). These properties are dependent on the existence of electric or magnetic dipoles at the atomic, molecular or the crystal lattice levels. Dipoles are pairs of equal and oppositely charged or magnetised poles separated by a distance, and crystal lattice is the symmetrical three-dimensional arrangement of atoms inside a crystal.

Such material is generally referred to as RAM, which tend to be composite in nature and made of a matrix material and a filler. Matrix is dielectric in nature meaning it's an electrical insulator, and therefore provides considerable permittivity and negligible permeability.

Given the Taranis is designed with stealth capability, its surfaces appear to be a low-observable coatings system. Closer inspection of edges around the air vehicle shows a visibly different band, a so-called edge treatment. This is likely to comprise an arrangement that suppresses edge waves (those emitted by surface currents when a surface edge is struck) by slowing surface current transition, and two means of absorbing electromagnetic energy: currents to suppress travelling waves (those that travel along a surface and bounce off edges in a specular manner) and incident radar waves to suppress edge diffraction.

Just what's in the edge arrangement is not clear. In cross-sectional terms, think of the edge as a triangular wedge comprising a lightweight honeycomb material impregnated with an electrical energy impeding material probably at a level of concentration that increases toward the inner base, thereby decreasing the level of impedance to the subsurface of the wedge. Edge radar-wave-generated current transition is therefore slowed down, and electromagnetic energy is absorbed. Consequently, the effect ➲

AIR VEHICLE FACTS

Taranis is an intelligent system that builds on proven systems and control technology designed, built, and tested successfully in earlier BAE Systems unmanned platforms.

It was designed by BAE System's Warton-based design office.

DSTL had a big input in the design requirements of the air vehicle and the operational environment.

Design challenges included combining advanced low observability technologies into the design, integrating secure communications on to a stealthy autonomous vehicle, and mission sensor integration.

The airframe is a combination of metal and composite materials.

of the edge treatment is a drop in the air vehicle's radar cross-section, especially abnormal angles.

Nobody outside of BAE Systems and the greater MoD agencies running Taranis knows what lies beyond the air inlet. Taranis is powered by a single Rolls-Royce Adour series turbofan engine, a successful motor used by the BAE Systems' Hawk trainer.

The inlet is positioned on the air vehicle's upper surface and triangular in forward elevation - its form is designed to minimise the radar cross-section of the inlet. Early images of Taranis supplied by BAE Systems had the inlet blackened out to prevent visual acquisition of the internal shape and form.

BAE Systems' engineers have used two longitudinal curved S-shaped ducts coated with RAM material, one to the front of the engine and one aft. Use of the S-shaped ducts prevent visual or radar wave acquisition of the front or back of the engine.

Such an arrangement helps to reduce the radar cross-section of the inlet and duct (the curved duct causes radar waves to bounce multiple times) and the RAM material absorbs significant amounts of electromagnetic energy. Edge treatment is visible on the Taranis engine inlet.

Taranis might use a composite skin with non-directional woven fibre cured into the skin to prevent electromagnetic energy from varying with angle. Stealth framer Lockheed Martin is known to have developed a method for growing cylindrical carbon molecules called carbon nanotubes (CNT) on various materials including ceramic, fibre, and metal. Fibres infused with CNT can absorb or reflect radar waves and provide pathways for the surface currents explained earlier.

BAE Systems has also paid attention to the effect of the engine exhaust on the air vehicle's radar cross-section. When radar waves enter an engine exhaust from behind, they tend to exit in the same direction; those striking the

This head-on shot shows how BAE Systems blackened the air vehicle's air intake to prevent visual acquisition of its internal form.

TARANIS PROGRAMME MILESTONES

December 17, 2003
First flight of the BAE Systems Raven used to prove novel aerodynamic flight control and autonomous operation.

December 2005
Defence Industrial Strategy programme announced by the UK government to ensure the UK has the technology to go it alone on military UAVs.

December 2006
The joint funded contract was placed in December 2006. Originally valued at £124.5m, the contract was uplifted under separate approvals to £185m and extended to accommodate an additional programme of work with a wider scope.

December 2008
Air vehicle final assembly started.

July 12, 2010
A superficially complete airframe was rolled-out to the media at Warton.

March–May 2012
Clandestine radar cross-section testing conducted on the outdoor range at Warton, mostly at night due to the sensitivity of the aircraft's design.

June 19, 2012
Taranis was placed on display during a media event at Warton. The aircraft was about to start extensive ground testing, including the first engine run and pre-flight preparation.

Early 2013
Air vehicle configured for flight sciences testing.

edges of the nozzle are diffracted in the same direction, in the same way returns from trailing wing and tail edges do. As a consequence, the aircraft's radar cross-section across the aft aspect is increased. BAE Systems' engineers designed Taranis with a narrow engine exhaust positioned on the upper surface, inset from the trailing edges, with edge treatment, while its position in azimuth is obscured by the wings that extend past the exhaust. The exhaust arrangement is colloquially referred to as the 'pillar box' which has a diverter in the very aft section that looks to be triangular in planform, suggesting the exhaust is channelled through a narrow outlet on both the left and right sides.

"The triangular-shaped inlet minimises radar cross-section."

Engineers also appear to have designed the Taranis air vehicle with broadband stealth characteristics. How? By eliminating surfaces that cause what's termed resonant behaviour, hence the lack of a tail. Resonant behaviour occurs when the air vehicle or a component of the air vehicle's dimensions are close to the radar wavelength by a magnitude between a half and ten, a behaviour that increases the radar cross-section of the air vehicle.

BAE Systems' engineers also designed the air vehicle with all of its edges in the horizontal plane and aligned with the leading edges. Furthermore, the air vehicle's profile comprises an upper and lower surface, both gently curved and joined at an acute angle, thereby limiting the angles of specular reflections. Upper and lower surface curves vary in both direction and radius to form a fuselage with sufficient depth to house the Adour engine. ●

April–May 2013
Low-speed taxi trials were undertaken at Warton.

May 18, 2013
Taranis technology demonstrator ZZ250 transported to Woomera on board RAF C-17A ZZ173 from Warton.

July 2013
High-speed taxi trials held at Woomera.

August 10, 2013
The first flight took place from the Woomera test facility at 8.09am and lasted approximately 15 minutes.

August 17, 2013
Second flight involved the retraction of the undercarriage for the first time while airborne.

October 2013
The MoD confirmed the first flight had taken place and trials were continuing.

Early 2014
Air vehicle configured for low-observability testing.

February 5, 2014
BAE Systems announced the cost of the programme to date as £185m.

Spring 2014
Start of the second flight demonstration phase.

Autumn 2015
Start of the third flight demonstration phase.

EMBARKED, UNMANNED & UNBELIEVABLE

Mark Ayton details the now-retired US Navy X-47B Unmanned Combat Air System Demonstrator.

Built in Palmdale California, flown for the first time at Edwards Air Force Base and trucked across America to Naval Air Station Patuxent River in Maryland, the X-47B Unmanned Combat Air System Demonstrator (UCAS-D) had an interesting service career. At 11.18AM EST on May 14, 2013, the 32ft 9in long X-47B BuNo 168064 made US Naval aviation history with a successful cat shot off the deck of USS *George HW Bush* (CVN-77).

Developed and built by Northrop Grumman as part of the US Navy's UCAS-D programme, the X-47B was built to demonstrate the capabilities of the tailless, low observable air vehicle in carrier operations.

Two X-47Bs were designed and built for carrier operations and served with Air Test and Evaluation Squadron 23 (VX-23) 'Salty Dogs' based at Naval Air Station Patuxent River.

Envelope Expansion at Edwards

Despite its naval roots, the X-47B started its service career in a desert environment at Edwards Air Force Base, so very different from the ocean environment of a carrier.

The test programme's objective at Edwards was to complete the Naval Air Systems Command (NAVAIR) airworthiness process to prove the X-47B air vehicle capable of safely flying in the US air space system administered by the Federal Aviation Administration.

NAVAIR managed the UCAS-D programme from its headquarters at Naval Air Station Patuxent River - referred to as Pax River throughout this feature.

The primary purpose of the Edwards-based testing was to evaluate basic operating functions during taxi, take-off and landing, basic flying qualities, and to conduct envelope expansion of the type. Parameter identification flights were flown to ensure the air vehicle's basic flight characteristics matched the computer modelling used in its development.

Because the X-47B was designed for demonstration and not fleet operations, its envelope expansion took far less time compared to an aircraft like the EA-18G Growler. All systems were fitted on the air vehicle during production and tested end-to-end in the lab: a primary difference between manned and

X-47B AV-2 moments before touchdown during the first ever series of touch and goes on the flight deck of an aircraft carrier on May 17, 2013. US Navy/ Mass Communication Specialist Timothy Walter

Build No	Bureau No	Side No	Maiden Flight
AV-1	BuNo 168063	501	February 4, 2011
AV-2	BuNo 168064	502	November 22, 2011

unmanned aircraft.

Initial envelope expansion tests validated control and subsystem design up to 15,000ft and 220kts.

Lab testing and a systems engineering process had to be completed to ensure full control functionality before AV-1 could make its maiden flight. This was primarily because the air vehicle's behaviour could not be manually compensated for during flight.

VX-23 also flew a series of test events to ensure loads on the landing gear when lowered and retracted, and those on the air vehicle itself, were within the design limits.

Just like all modern aircraft and air vehicles, the X-47B is a software driven system, so its software integration and lab testing involved thousands of hours using hardware-in-the-loop test benches, simulation testing using detailed models, and ground tests and check-outs actually on the aircraft.

Two main iterations of software were released: U4 was used for the envelope expansion flight-testing at Edwards, and U5 for carrier suitability testing undertaken at Pax River.

Modelling and Simulation

The X-47B used two modes of navigation: absolute GPS and precision GPS (PGPS). All flight-testing at Edwards was conducted using absolute navigation mode. Precision GPS mode was first used during the carrier suitability tests at Pax River. PGPS compensates for the movement of the ship allowing an air vehicle to navigate in reference to the carrier.

The X-47B operated autonomously, controlled by pre-programmed operating and contingency modes, all of which ➲

Contractors hoist the X-47B Unmanned Combat Air System demonstrator to the flight deck of the aircraft carrier USS Harry S Truman. The air vehicle arrived by barge from Naval Air Station Patuxent River, Maryland. Truman was the first modern aircraft carrier to host test operations for an unmanned aircraft. US Navy/Mass Communication Specialist Lyle Wilkie

"X-47B was built to demonstrate the capabilities of the tailless, low observable air vehicle in carrier operations."

X-47B AV-1 touches down on the flight deck of the aircraft carrier USS George HW Bush for the first time on May 21, 2013. Northrop Grumman/Alan Radecki

were extensively simulated to ensure safe functionality. During flight, the air vehicle could validate its performance against the computer modelling.

Because all systems engineering was completed before the maiden flight, the VX-23 test team was able to clear the X-47B's entire flight envelope in just 16 sorties with 14 hours of flight time, compared to 49 sorties and 100 hours which had been set aside in the plan. Results from the modelling and simulation matched the actual flight results such that the test team was able to achieve its flight envelope clearance in much less time.

When AV-2 was delivered to Edwards later in 2011 it performed a number of flights to validate that AV-1 and AV-2 behaved in exactly the same way. They did.

Flush with 86 hours of unused flight test time, the team continued with more envelope expansion work that included touch and goes and high sink rate landings.

During the envelope expansion phase the VX-23 test team used all of the air vehicle's systems, which included an end-to-end mission control station, all of the datalinks and the vehicle management system. Some systems were not used at Edwards.

First were air traffic control functionality, a TTNT datalink and PGPS relative navigation, all specific to the carrier suitability segment. TTNT and PGPS were subsequently fitted on the air vehicle and used to down link data during some of the flights made later in the flight test programme at Edwards. It was important to down link data during flights at Edwards because the PGPS was the primary means of precision navigation that was subsequently used at Pax River and during carrier embarkation. VX-23's team certified the data for use by the air vehicle at Pax River.

Second was autonomous air-refuelling equipment: the starboard wing-mounted probe, the US Air Force standard receptacle on the top of the fuselage and the vision system.

"X-47B started its career in the desert environment at Edwards."

Third, the control display unit (CDU) and its arm-mounted controller were not installed until the air vehicles arrived at Pax River. The CDU and controller were used for dynamic taxi trials that involved moving the X-47B around the Pax River ramp and network of taxiways. At Edwards, the VX-23 test team used GPS points gained from a site survey for taxiing the X-47B along the taxiways, a process known as GPS taxi.

Control Display Unit

Likened to a mission control station on the deck operator's arm, the CDU was certified through the standard airworthiness certification process as one type of controller used for the air vehicle. Additionally, the CDU required high redundancy to ensure the safety and control essential for moving an air vehicle on a flight deck. The CDU has controls for any function required on the flight deck, including throttle and brakes, push-button controls for the engine, built-in test checks, wing fold and wing unfold, tail hook lowering and retraction.

During carrier deck operations, the deck operator stood behind the flight deck director (standing in front of the air vehicle) to move the X-47B around the deck in accordance with standard hand signals. The deck operator used the CDU to send commands to the air vehicle via a wireless network, duplicating the director's hand signals. At the time of the testing, Daryl Martis, Northrop Grumman's UCAS-D test director said: "Instead of towing the aircraft out to the flight line, we can now start the X-47B at its parking spot, then use the CDU to taxi it out to the catapult for launch. Use of the CDU is the most time-efficient way to move the X-47B into the catapult or disengage it from the arresting gear after landing."

A belt pack included with the CDU held the batteries and redundant digital modems that connected in with the air vehicle.

Carrier Suitability Testing

After completion of the envelope expansion, both air vehicles were transferred to Pax River for carrier suitability testing. The station has a dedicated test facility equipped with a TC7 catapult, Mk7 arresting gear, and an air traffic control simulation facility. Pax is also home to VX-23, NAVAIR's strike aircraft test squadron, the unit tasked with conducting X-47B carrier suitability testing, the resident squadron for most of the NAVAIR experts who specialise in ship integration and carrier testing systems.

Pax River also offered ready access to test ranges and warning areas off the coast of Maryland and Virginia and FAA cover for flying X-47B to and from a carrier underway in the warning areas.

Once at Pax River, AV-1 and AV-2 were initially used for electromagnetic environmental effects or E3 testing.

In May 2012, AV-1 began E3 testing and spent many weeks in the anechoic chamber and in the E3 pad to evaluate the aircraft across the entire electromagnetic spectrum and the carrier environment. This was undertaken to ensure the air vehicle would function in those environments, with special attention given to the air vehicle's data links. Physical compatibility testing was also undertaken to ensure the air vehicle could move around on the ground and within the airspace at Pax River ➲

Sailors and personnel from the Navy Unmanned Combat Air System programme integrated test team prepare X-47B AV-2 for testing aboard the USS Harry S Truman. Northrop Grumman/Alan Radecki

and the Washington DC metropolitan area.

First Taxi...First Flight... First Cat Shot

For some of the early taxi testing the test team positioned the air vehicle close to wherever it was going to operate. A good example was roll-in testing to the arresting gear where the air vehicle rolled in and caught the gear with the hook.

The VX-23 test team then started CDU taxi testing, initially on the ramp, building-up to extensive taxi routes around the station's taxiways and runways. The air vehicle was started up on the VX-23 flight line and followed the taxiways out to the runway using GPS taxi mode, proceeded down the runway and back to the line where a deck operator took over control using the CDU and taxied the air vehicle into its parking spot.

The test team then refined the procedures used for mission planning, and those needed for integrating and operating the air vehicle into Pax River's flight operations using the station's runways and operating areas. It was the first time that NAVAIR had established and finalised procedures to operate an air vehicle as big as the X-47B - which weighs 44,000lb - from Pax River's runways, and to fly approaches and the pattern intermixed with manned aircraft.

X-47B AV-2 arrived at Pax River in June 2012 ahead of its test programme which involved catapult launches and arrested landings using the TC-7 catapult and MK-7 arresting gear test facility.

X-47B AV-2 made the type's first flight from Pax River on July 29, 2012. It lasted for 32 minutes during which time the test team accomplished everything that had been planned during the course of three flights and was a significant event in the history of the air station.

Flight one was followed by extensive preparations for the first cat launch from the TC7 catapult at Pax River.

Between July and October 2012, the test team ran thousands of simulated scenarios in the lab covering catapult launches and arrested landings before switching to U5 software. The release required for carrier operations including catapult and arrestor functionality and PGPS relative navigation.

Four main events had to be undertaken to achieve the first catapult launch:

- CDU integration because of the intensely manual process to respond to the flight deck operator's command and to taxi the X-47B into the catapult.
- A 30-minute regression flight with the U5 software.
- Integrate the landing signals officer into the flight process using the digitised control system.
- An initial low-speed catapult shot that rolled the air vehicle on to the runway to ensure the required acceleration was achieved.

"The X-47B's first cat shot took place on May 14, 2013."

After the low-speed cat shot on November 28, the test team made the very first catapult shot with AV-1 from the TC7 at Pax River the next day. This involved 12 people who conducted a standard hook-up and used standard hand signals, procedures, and safety checks as those used on a carrier flight deck.

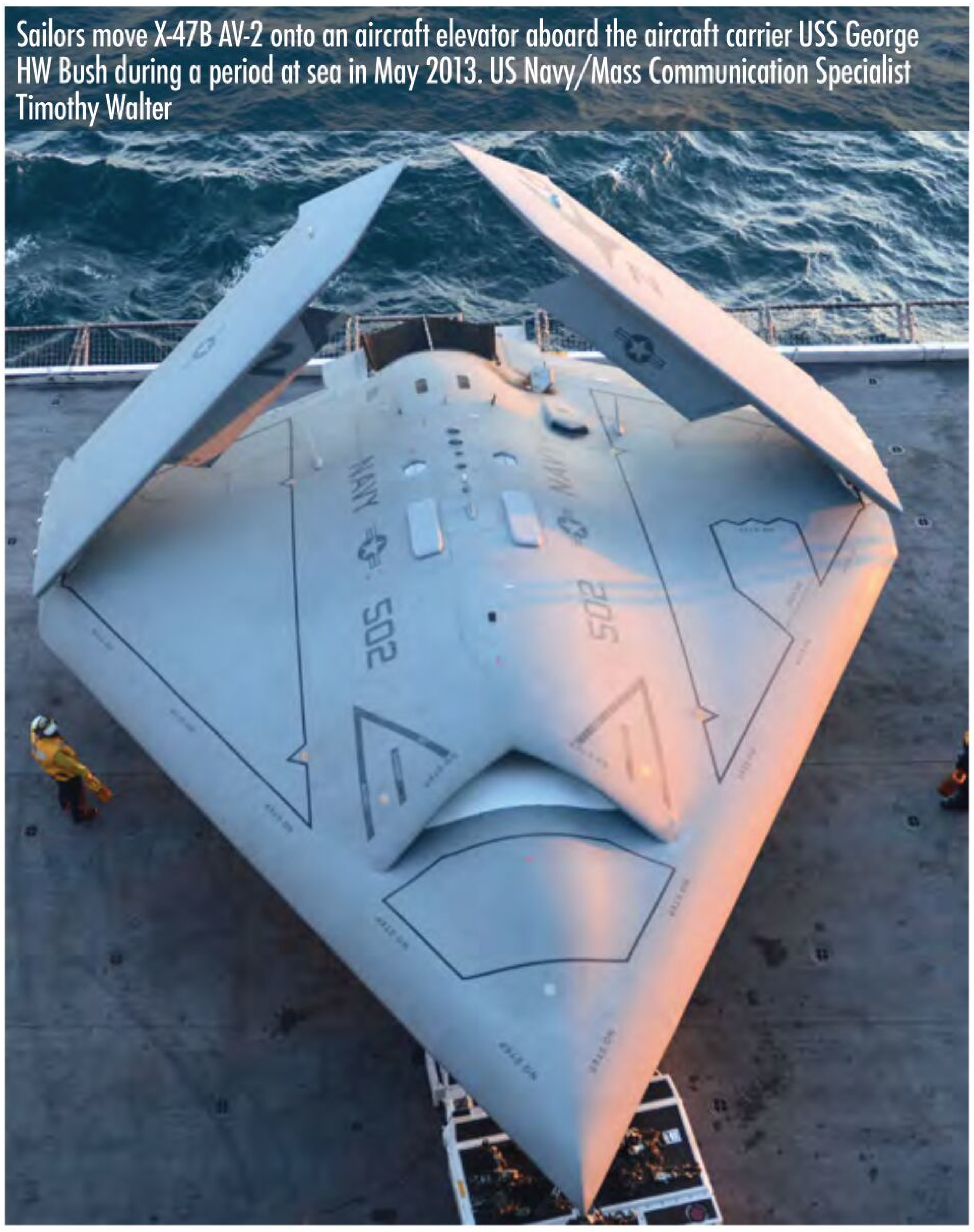
Immediately the catapult officer gave his salute, the air vehicle was autonomous and followed the mission operator's pre-programmed routine - it climbed to the

Dave Lorenz, a deck operator for Northrop Grumman, signals he has control of an X-47B as he moves the air vehicle via an arm-mounted controller on the flight deck of the aircraft carrier USS George HW Bush. US Navy/Mass Communication Specialist Timothy Walter

X-47B AV-2 makes an arrested landing on the flight deck of the aircraft carrier USS George HW Bush (CVN 77). US Navy/Mass Communication Specialist Kevin Steinberg

X-47B AV-2 on an aircraft elevator aboard the aircraft carrier Harry S Truman. Northrop Grumman/Alan Radecki

X-47B AV-2 taxies on the flight deck of the aircraft carrier USS Harry S Truman (CVN 75). US Navy/Mass Communication Specialist Kristina Young



Sailors move X-47B AV-2 onto an aircraft elevator aboard the aircraft carrier USS George HW Bush during a period at sea in May 2013. US Navy/Mass Communication Specialist Timothy Walter

pattern altitude, followed the pattern all the way around, configured itself for landing, descended, landed, and applied its brakes and came to a stop. At any point, the mission operator could command the air vehicle to perform a turn in holding or a wave off.

USS Harry S Truman

While AV-1 was completing the U5 software transition at Pax River, AV-2 was loaded onto a barge and transported to Naval Base Norfolk, Virginia. On November 26, it was hoisted aboard the flight deck of the USS *Harry S Truman* for the X-47B's first phase of carrier suitability trials.

Despite this being the first time an X-47B had been on a carrier flight deck, aircraft handlers assigned to the Truman - with no X-47B specific training - were able hook the air vehicle up to the tractor, tow it, chain it down with no need for any change in their operational or safety procedures.

Furthermore, Truman's deck crew then handled the X-47B on the hangar deck and on the elevator. They hooked up the fuel hoses, undertook fuelling, ran the engines, hooked up the tractors and tow gear and moved it to different spots on the flight deck, during which the electromagnetic environment of the carrier was measured and matched to the testing done at Pax River.

One notable fact was that the EA-18G Growler had approximately 3,000 requirements to meet carrier suitability, yet 60% of those requirements were different for the X-47B.

The first phase of testing completed on December 18, 2012 but did not involve any flight operations.

TACTICAL TARGETING NETWORK TECHNOLOGY (TTNT)

TTNT is a precision location and identification network developed by the US Air Force. Two TTNT units were each fitted to the air vehicle and the ship.

Its key characteristics are:

- Internet protocol based digital network that allows users to log in to the network.
- Operates with very low latency, almost real time in terms of data flow back and forth between the ship and the air vehicle; an essential part of the tightly coupled navigation system.
- Sends digital messages containing control and navigation commands back and forth, from the ship to the air vehicle.

Carrier Segment

The X-47B carrier segment involved aviation/ship integration part of which provided distributed control of the air vehicle between different shipboard controllers:

- The mission operator in the mission control centre.
- The landing signals officer on the LSO platform.
- The air traffic controllers in the CATCC.
- The air boss in the primary flight control bridge.

"Using GPS to steer the X-47B down the flight deck was a challenge."

Digital messages from shipboard controllers were used to control the unmanned air vehicle instead of verbal instructions. In response to a digital command and control message, the X-47B software confirmed, complied, and responded with a digital 'wilco' signal.

Each type of controller used a different system to send the digital message. A mission operator used the control station, an LSO used a standard pickle switch, air traffic controllers used radar consoles and the air boss used a touch screen.

The UCAS-D concept required the X-47B to operate autonomously inside the carrier control area including checking in with the marshal controller to receive instructions just like a manned aircraft would. To achieve that, the X-47B joined the pattern at the required altitude and flew an approach at a planned time by simply reacting to a specific command.

A mission operator actually flew the air vehicle, but control was also available for the landing signals officer (LSO). His commands were digitally connected into the system to give him direct command of the air vehicle using a standard pickle switch, to either clear the X-47B to land or wave off.

At any time during the approach the LSO could hit the wave off switch to instantly send a digital message to the air vehicle, which would autonomously wave off and turn down wind for another approach. It needed positive confirmation that it was cleared to land, so if no signal was received, it waved off and flew around.

The interesting aspect about X-47B is that it was a brand new air frame with a

completely different shape and dynamics. It was an unmanned system that also included the network, the mission control element and the controllers operating the air vehicle. Yet much of the test concept for the X-47B build-up used standard NAVAIR shore-based techniques to get the air vehicle ready to go to the carrier. It was the first time that NAVAIR had tested autonomous systems during carrier suitability testing.

First Cat and Trap on the Bush

VX-23's test team undertook a second series of land-based catapult shots after the detachment aboard the USS *Harry S Truman* to complete a standard NAVAIR carrier suitability build-up process. This involved successive increases in speed and g to measure launch bar loads and to ensure the air vehicle could handle the g loads. The test team then completed some off-centre work which involved positioning the air vehicle slightly offset from the catapult and launching it to check for issues with offset loads. The test team conducted the first arrested landing with the MK-7 test facility at Pax River on May 4, 2013.

To completely clear the envelope, the team completed five cat shots with AV-1 and one standard shake, rattle, and roll test, with AV-2. Shake, rattle, and roll is a term used within the NAVAIR test community to refer to cats and traps within carrier suitability trials.

From January 2013, X-47B ground operations were performed by a deck operator using a CDU to familiarise everyone involved with its concept of operations. The air vehicles were taxied around in close quarters to other aircraft without the use of GPS coordinates or a chase vehicle. This low-risk application was

"X-47B testing at Pax River started in the anechoic chamber."

then used for the build-up to the detachment aboard USS *George HW Bush* for the historic first catapult shot of the X-47B from an aircraft carrier. Over a six-week period, the carrier was fitted with TTNT data links to feed navigation information up to the air vehicle, wiring to connect the network on the ship, and a series of test conductors.

All deck handling aboard the USS *George HW Bush* was performed by the ship's own flight deck crew with no special training other than air vehicle familiarisation and how it works. Deck operators for the historical first catapult shot were Northrop Grumman employees, and former Navy tactical jet pilots, Dave Lorenz, and Bruce McFadden.

During the morning of May 14, the test team launched AV-2 from the USS *George HW Bush*, the first catapult shot of an unmanned air vehicle from a US Navy super carrier. Planned for launch at 11.00AM EST, the X-47B was airborne at 11.18AM. It was programmed to climb and to fly a specific route. Then a mission operator with full control of the air vehicle flew it back to the ship to fly some low approaches to check the controls and gather data to check the accuracy of the PGPS relative navigation solution.

The LSO did nothing during the first approach which allowed the test team to check what happened if nobody cleared the air vehicle to land. When a clearance to land signal was not received, the air vehicle waved off, flew along the flight deck, and turned downwind for a second approach. A check of the clear to land functionality, which worked. On approach three, designed to clear the air vehicle to land, it descended to within 50 feet of the deck but was manually waved off because it encountered deck motion for the first time. Otherwise, the air vehicle was very stable flying around the carrier and even through the ship's wake.

Two days after its first cat shot aboard the USS *Bush*, VX-23 flew AV-2 back out to the ship and performed seven touch and goes in a row, another first time event.

This was significant because throughout the seven cycles, after each touch down the X-47B climbed out and joined the pattern, flew downwind, turned on to final approach, flew very stable approaches, touched down in essentially the same spot on the carrier deck, rolled down the centre line, rotated and climbed out for the next pattern and approach.

There was a very good reason for doing this for any aircraft, but specifically the X-47B. Precision landing and PGPS relative navigation are key requirements enabled by the very latest technologies and was the most important element of technology tested on the ship.

The ability to use precision relative GPS to steer the air vehicle down the centre line was a hard technical challenge, yet according to X-47 programme officials, the nose gear did not deviate from the centre line stripe during the seven touch and goes, despite the g induced at touch down.

A process known as coordinate ➲

X-47B AV-2 plugged in to the drogue of Omega's Boeing 707 tanker N707MQ (c/n 21368) over the Chesapeake Bay near to Naval Air Station Patuxent River. Northrop Grumman

transformation provided the required precision for landing the air vehicle on the deck to an accuracy measured in feet, lateral movement in inches and navigation in centimetres.

The system had to position the 62ft wide X-47B on a 100ft wide landing area while the ship was moving at up to 25 knots. The PGPS system is designed to land an air vehicle in conditions up to sea state 5, which causes significant deck motion, which according to programme officials, the system handled very well during simulation. That said, the X-47B was a demonstration programme and such limits were not in the plan, and ultimately the sea state was calm during the test period.

One notable aspect of the shipborne arrested landings was the fact that the prior land-based cat shots completed at Pax River were deliberately more severe than those undertaken on the USS *George HW Bush* to avoid any issues on the ship.

Another critical aspect of operating a UAV from a carrier is the ability for the air vehicle to conduct a 'bolter' the colloquial term used for when an aircraft misses the wires and flies off the deck for another approach. The challenge of the X-47B demonstration was to test bolter logic should the air vehicle miss the wire and roll down the flight deck.

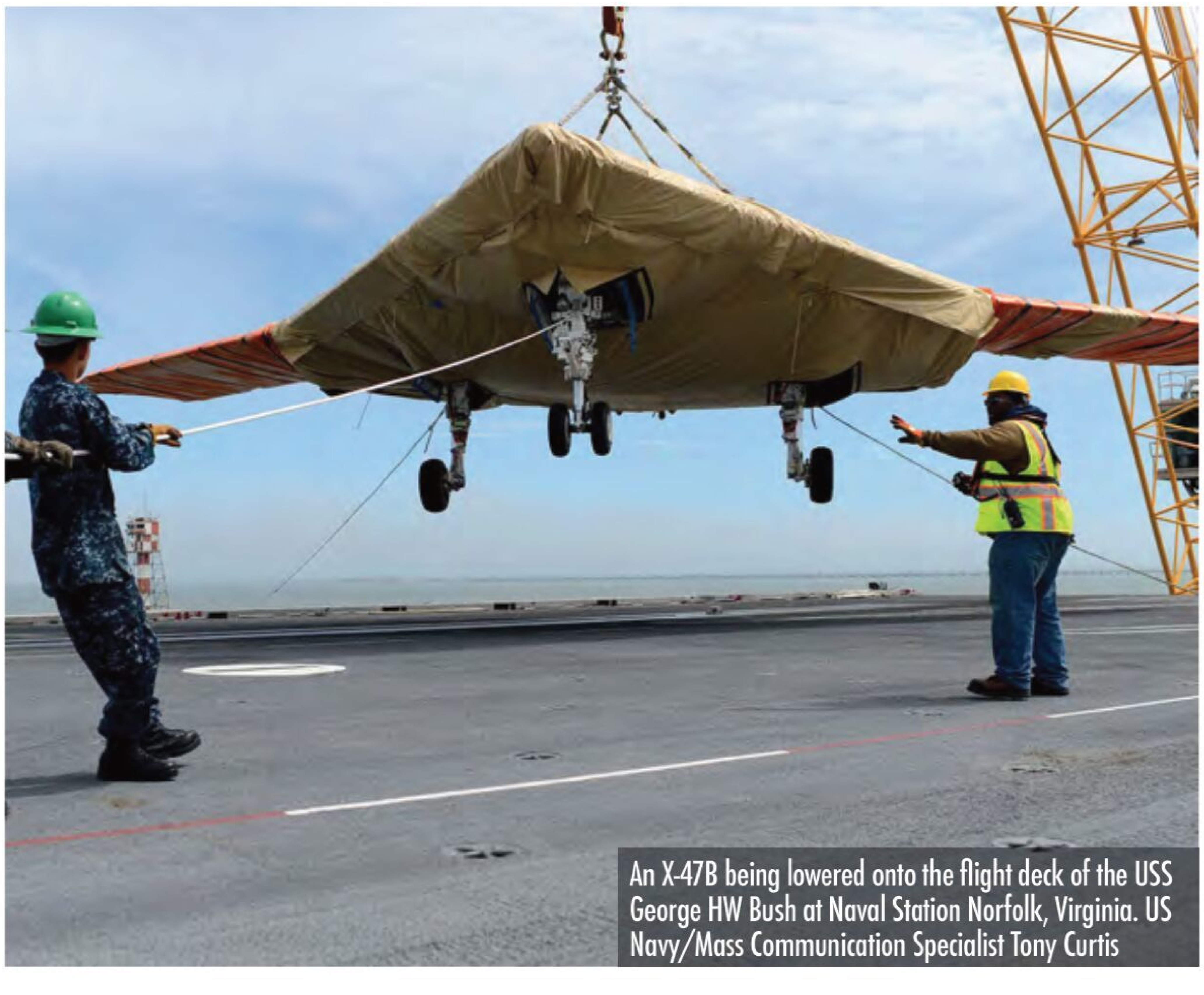
During March and April 2013, VX-23 had conducted a lot of touch and goes at Pax River to determine where the hook touchdown point was on the deck. This was followed by arrested landings involving high sink rates.

In 90 days of testing during February, March and April, VX-23 completed 48 flights with the two air vehicles (AV-1 and AV-2), performed 140 carrier approaches to the runway and 60 touch and goes.

On July 10, the test team launched AV-2 from Pax River bound for the USS *George HW Bush* where it made the first arrested landing of an unmanned air vehicle on the flight deck of a US Navy super carrier. An historic start to the third test period at sea.

This followed another build-up process which involved determination of the structural

"The last test objective for the X-47B was autonomous aerial refuelling."

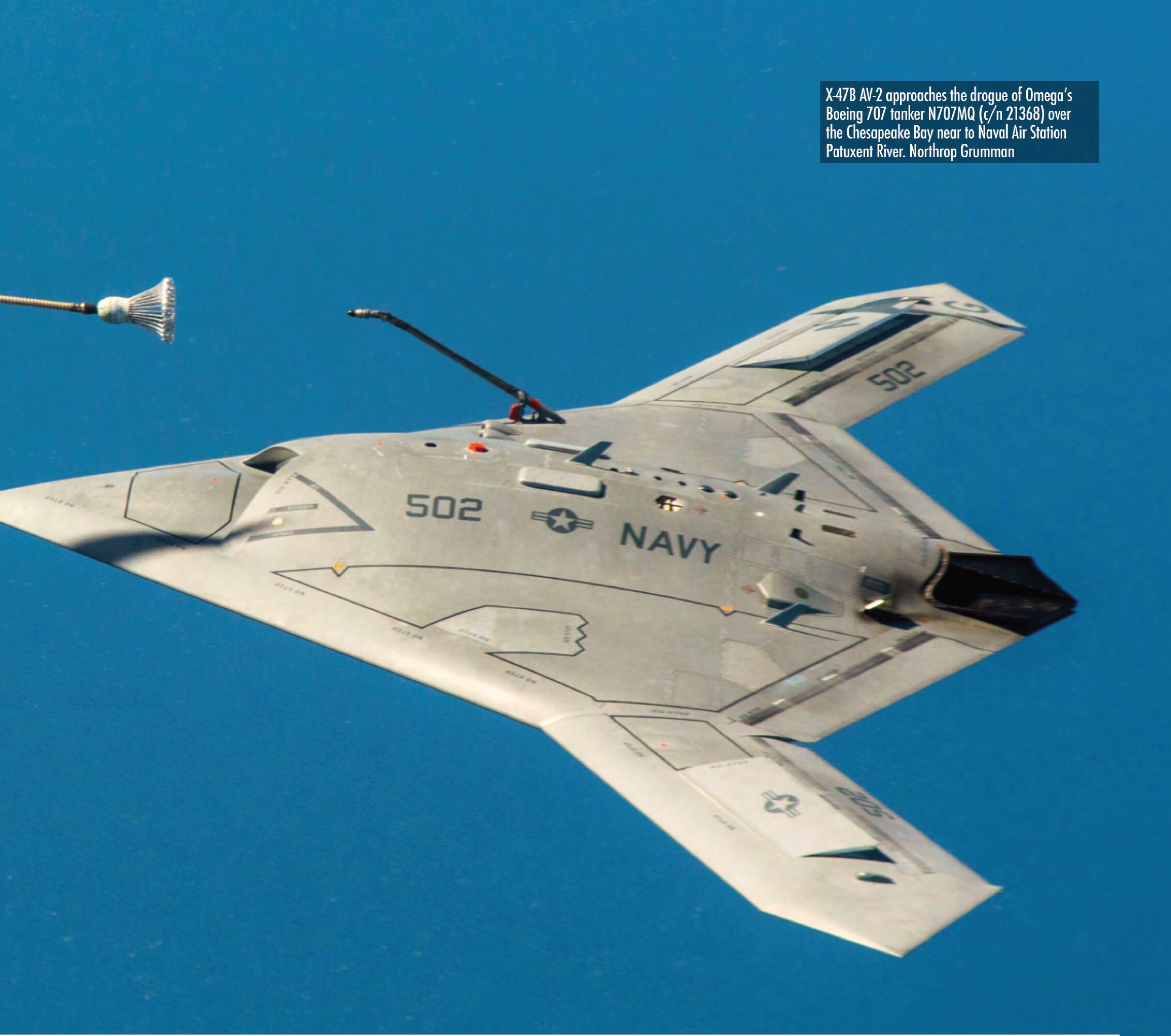


An X-47B being lowered onto the flight deck of the USS George HW Bush at Naval Station Norfolk, Virginia. US Navy/Mass Communication Specialist Tony Curtis

loads on the tail hook to complete the clearance procedure. A second landing followed, but due to a failure with a navigation sub-system a third landing was aborted on July 15 which necessitated a diversion to NASA's Wallops Island test facility.

During the July embarkation on board the USS *George HW Bush*, AV-2 completed three catapult launches, the two arrested landings and 16 precision approaches. The approaches included five wave-off functions and nine touch-and-go landings.

Both X-47B Unmanned Combat Air Vehicle demonstrators were due to retire following sea trials aboard the USS *George HW Bush* in the summer of 2013. But by late summer, additional funding was awarded to the X-47B programme which allowed PMA-268, Naval Air Systems Command's programme management authority for unmanned carrier aviation, to extend the X-47B demonstration. Consequently, the test team was able to accomplish more objectives in support of the US Navy's then nascent Unmanned Carrier-Launched Airborne Surveillance and Strike (UCLASS) programme. The X-47 programme undertook its 100th



X-47B AV-2 approaches the drogue of Omega's Boeing 707 tanker N707MQ (c/n 21368) over the Chesapeake Bay near to Naval Air Station Patuxent River. Northrop Grumman

flight on September 18, 2013.

In November, PMA-268 embarked an X-47B on board the USS *Theodore Roosevelt* (CVN 71) for the fourth sea trial to test the interfaces between the air vehicle and deck personnel during launch, recovery, and flight operations around the ship.

On April 10, 2014, the test team completed the X-47B's first night-time flight from Pax River, followed in August by the final sea trial, once again on board the Roosevelt. This fifth and final trial tested launch, recovery and holding within the carrier's pattern shared with manned aircraft, and successfully did so without causing disruption to carrier operations.

Notably, on August 17, the X-47B launched and landed on board the Roosevelt with an F/A-18 Hornet. Another history making event. It was the first time an unmanned air vehicle had undertaken flight operations with a manned aircraft aboard an aircraft carrier.

On August 24, the air vehicle conducted five catapult launches, four arrested landings, and nine touch-and-go landings. In doing so, the X-47B successfully met the 90-second interval between launches and recoveries with F/A-18 Hornet jets.

"The X-47B's first night flight took place on April 10, 2014."

The August test period involved eight catapult launches, 30 touch-and-goes, seven arrested landings, night-time taxi, and deck handling operations on the flight deck.

Cooperative Flight Deck Ops

During the final 10-day period aboard the Roosevelt, the X-47B test team introduced cooperative manned and unmanned flight deck operations for the first time.

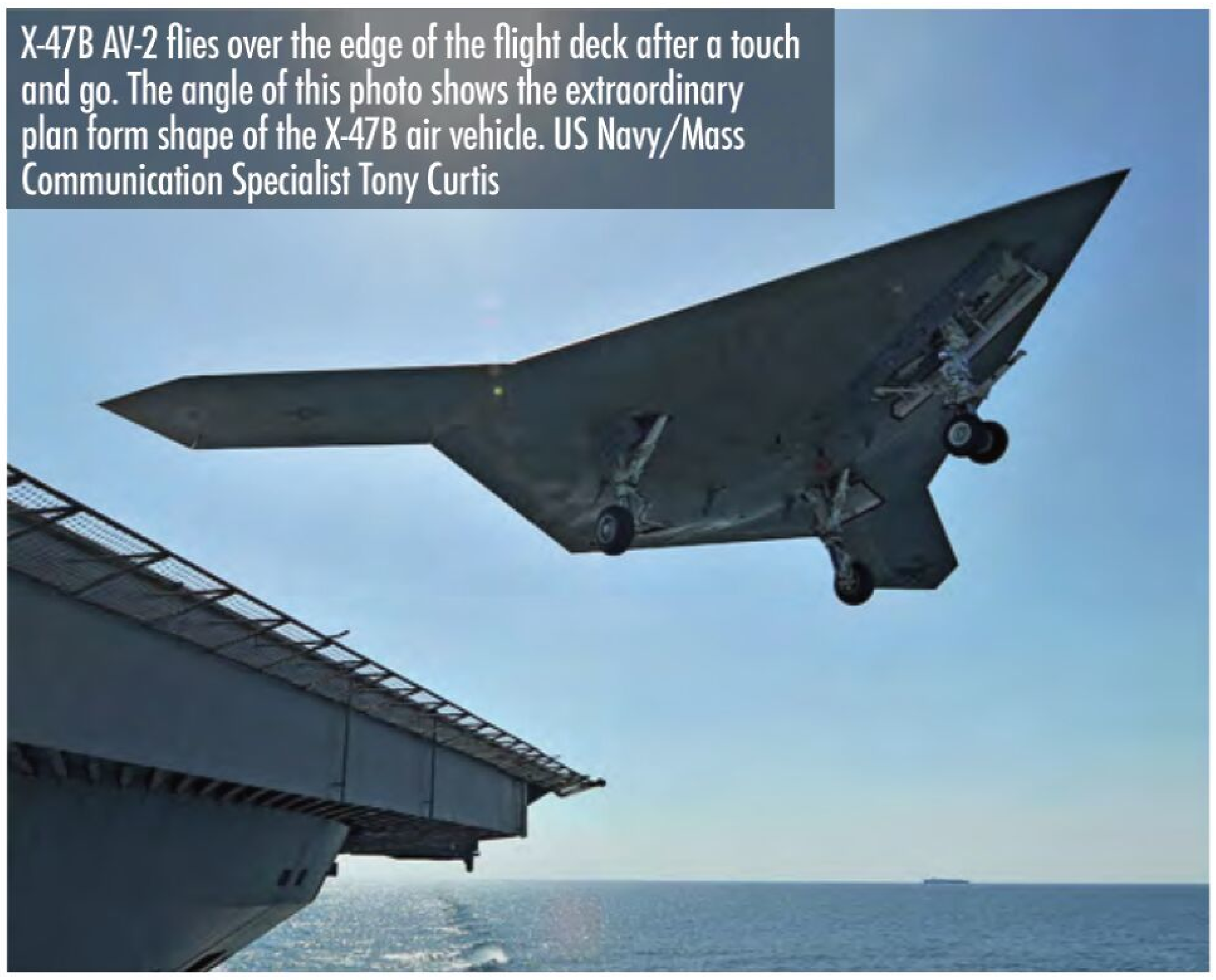
Prior to embarkation on the Roosevelt, AV-2 underwent modification for the detachment. This included installation of a new actuator which enabled auto-retraction of the tail hook after landing. During previous carrier embarkations, the hook was manually lifted. The air vehicle also had a mechanised wing-fold capability introduced into its U5 software which enabled the wings to be automatically folded after landing.

To integrate an unmanned air vehicle into the carrier flight deck environment, the operator needed to be able to clear the landing area quickly and efficiently. This included raising the hook and folding the wings to clear space, so that another aircraft can recover or jets ready to launch can take their catapult shots.

Captain Beau Duarte, PMA-268's programme manager at the time said: "With the two enhancements fitted, we were able to fly an X-47 in the carrier's landing pattern with an F/A-18 Hornet. Our primary goal was to demonstrate a comparable landing interval between the X-47 and an F/A-18 behind it and show that the X-47 could clear the landing area on a timeframe commensurate with manned aircraft. From a demonstration perspective, it showed we could integrate with an existing standard procedure on the flight deck without the need to change training and procedures."

During the 10-day mini cruise off the ➲

An X-47B is loaded onto the flight deck of the aircraft carrier USS George HW Bush on May 6, 2013 at Naval Station Norfolk, Virginia. The carrier was the first to catapult-launch an unmanned aircraft from its flight deck. US Navy/Mass Communication Specialist Kevin Steinberg



X-47B AV-2 flies over the edge of the flight deck after a touch and go. The angle of this photo shows the extraordinary plan form shape of the X-47B air vehicle. US Navy/Mass Communication Specialist Tony Curtis

X-47B AV-2 flies near the aircraft carrier USS George H.W. Bush during an at sea test period in May 2013. US Navy/Erik Hildebrandt

Virginia shore, the X-47B and an F/A-18 also performed multiple catapults and traps to a typical landing interval for the first time.

By the autumn of 2014, PMA-268 and the test team had successfully demonstrated digitisation of carrier flight operations with the X-47B. The team had launched, landed, held, performed an immediate landing, and when required, diverted the air vehicle as commanded.

Captain Duarte said: "Without someone in the cockpit you need to be able to send signals to the aircraft for a whole range of typical carrier procedures. We devised a set of messages and digitised them. They are the backbone for introducing future unmanned systems as operational weapon systems. We also demonstrated very precise landing navigation performance by picking the same spot on the deck and hitting it within inches, over and over again. To be able to land precisely on a moving ship was a big accomplishment."

The test team also successfully demonstrated a safe way to taxi the air vehicle around the carrier deck during day and night-time flight operations.

"The test team achieved four five-minute probe engagements."

Aerial Refuelling

After completion of the third at sea period, the last big outstanding objective for the X-47B was autonomous aerial refuelling. In this instance, the term autonomous was used to denote that no one was flying the air vehicle remotely by stick and throttle. The flight management computer navigated the air vehicle to perform aerial refuelling.

Discussing the aerial refuelling segment Captain Duarte said: "It was an initial programme goal dating back to 2009. We had developed software and completed surrogate trials with a Learjet but had not had the opportunity or resources to conduct aerial refuelling with the air vehicle itself. In September 2014, sufficient funds remained to complete an autonomous aerial refuelling flight-test programme and the team decided we could do it."

The decision required further software development, a tanker and modifications to the Boeing 707 tanker aircraft provided by Omega Aerial Refueling Services.

X-47B BuNo 168064/502 (c/n AV-2) was built with the plumbing required for both types of aerial refuelling: the US Air Force type flying boom and the hose and drogue system used by the US Navy. The two methods are fundamentally different involving either Navy aircraft flying into the refuelling basket or drogue or an air force jet flying in formation with the tanker so the boom operator can manoeuvre the boom into the receiver aircraft's receptacle.

"Because the basket is moving, you need a way, other than GPS, to get into the basket because its position is changing rapidly. Any pilot will tell you, it's a high game task to fly manually into a basket to start out with," said Captain Duarte.

AV-2 was fitted with an air refuelling probe and an infrared camera system capable of providing precise navigation updates used to

PRECISION RELATIVE GPS

Precision relative GPS works by having three EGIs (embedded GPS/INS) systems on the air vehicle and three on the ship.

Data about the ship's speed and motion was sent to the air vehicle via the TTNT data link. The air vehicle performed relative navigation calculations to determine its precise position in space relative to the ship.

The air vehicle flew a precise GPS line relative to the ship, used a specific point on the flight deck as a datum, and flew a specific glide slope all the way down to touch down.

PGPS relative navigation mode used the TTNT data link to send command and control data from the air vehicle down to the ship. PGPS was crucial to convert the air vehicle's position on space into the same relative reference frame of the moving ship.

VX-23 performed the very first PGPS on March 2, 2013 using EGI systems located at Pax River. This was the first time all of the systems had been linked up in a relative sense. The air vehicle did not know it was going to a static runway, so by using a standard PGPS relative navigation solution the air vehicle flew the pattern relative to the navigation solution which it took to be at the ship.

PGPS was used to conduct all of the precision touch and goes at Pax River. The only difference between the shore-based landing test and the carrier equivalent was that the EGIs were positioned on the runway at Pax River and not moving through space (water) on a carrier.

position and get the air vehicle into the moving basket.

The two cameras were fitted side by side, one for back up if the other did not work. An additional computer was also installed to blend the image fed from the cameras and the differential GPS.

Explaining the control, Captain Duarte said: "On the carrier we used differential GPS so we could tell the difference between the air vehicle and the deck to an accuracy within 10mm and to close the navigational loop. The same concept was used for the tanker. A GPS and a link were installed on board to provide the [geospatial] difference between the two aircraft. We calculated the difference and commanded the navigational system to position the air vehicle in trail [behind the tanker] and to hold a very close position until we were ready to tank."

Omega's Boeing 707 tanker was fitted with a data link, a navigational system, and a control station to enable the operator on the tanker to abort or disconnect either when refuelling was complete or for safety. This allowed the operator to push a button to disconnect rather than relaying a command on the radio to the X-47 operator located at Pax River.

"We used the differential GPS to rendezvous with the tanker and then a trail position behind it. We usually started about a mile behind. Using a 1,000ft step down, we closed to a quarter mile. The operator on board the tanker cleared the X-47B in to about 20ft and, at that point, we started to blend the camera's imagery with the differential GPS data. Once the basket was within the field of view and stabilised, we switched to what we call drogue relative. At that point, the aircraft was navigating primarily off the basket and commanding the signals received to place the coordinates of the probe into the sweet spot of the basket to effect air refuelling," said Captain Duarte.

Flight tests started in early March 2015 and demonstrated that the X-47B could rendezvous, hold station, and get close to the tanker safely. In a series of flights conducted in April, X-47B AV-2 engaged the basket and finally transferred fuel.

The original objective of the X-47 demonstration was to keep the air refuelling probe in the basket for five minutes, transfer fuel, and to do so repeatedly with at least three engagements; the test team achieved four engagements. A successful demonstration of autonomous aerial refuelling with an unmanned air vehicle.

Eight years after Naval Air Systems Command awarded Northrop Grumman a contract to build air vehicles for the Unmanned Combat Air System Demonstrators, the history-making programme was closed after the aerial refuelling sorties completed the demonstration's original objectives. Closing the demonstration coincided with the end of the additional funding awarded in 2013.

The X-47B conducted operations aboard three different aircraft carriers: USS *Harry S Truman* (December 2012), USS *George HW Bush* (May and July 2013) and USS *Theodore Roosevelt* (November 2013 and August 2014), and aerial refuelling trials. Lessons learned from all events throughout the demonstration were subsequently used in the performance specification and concept of operation, initially for UCLASS programme, but ultimately the CBARS programme. The latter won by Boeing's MQ-25 Stingray.

Summing up the demonstration Captain Duarte said: "The X-47B done wonderful work and allowed us the ability to transfer a lot of technical and operational information into the next phase with a coordinated set of requirements."

Today both X-47B air vehicles are stored at the Northrop Grumman facility at Air Force Plant 42 near Palmdale, California. ●

X-47B AV-2 launches from the aircraft carrier USS George HW Bush (CVN 77) on May 14, 2013. US Navy/Mass Communication Specialist Tony Curtis

CALIFORNIAN AND ATTRITABLE

Mark Ayton spoke with Kratos' unmanned division president, Steve Fendley about the company's XQ-58A unmanned air vehicle.

XQ-58A Valkyrie 58-001 in level flight during the type's maiden flight from Yuma Proving Ground on March 5, 2019. This image has been altered to mask the white coating applied to the edges of two panels under the fuselage. US Air Force

Kratos Defense and Security Solutions is perhaps a less well-known defence company, but its name has been around since September 2007. Its unmanned systems division based in San Diego, California is promoted as "a leading provider of high performance unmanned aerial drone and target systems for threat representative target missions to exercise weapon, radar, and other systems; and tactical aerial drone systems for strike/ISR and force multiplication missions." Quite a promotional line, but one that's fully justified given its experience for producing target aircraft. Its president is Steve Fendley, a career systems engineer who spoke with the author about the company's XQ-58A Valkyrie experimental stealthy unmanned combat aerial vehicle.

Genesis of the Valkyrie started in 2015 when consideration was given to developing a tactical unmanned system conceptually based on the company's first non-target tactical system, the Mako tactical unmanned aerial system.

According to Steve Fendley, Kratos engineers recognised the ability of the Mako to replicate a threat as a target aircraft, and the type's design as a starting point from which to develop a tactical system.

The concept offered commercial advantage based on Mako's low-cost base and its cost extrapolation for a tactical system. Describing the ideology, Steve Fendley said: "We started an internal research and development [IRAD] programme with the objective of developing a tactical unmanned aerial system designed to carry sensor and weapon payloads, with substantially more endurance and range than the Mako system, and characteristics that enable the aircraft to survive in contested environments."

"Kratos is currently building a dozen XQ-58A Valkyrie aircraft."

Nine months after Kratos started its IRAD effort, the Air Force Research Laboratory launched its Low-Cost Attritable Aircraft Technology or LCAAT programme, one designed to break the escalating cost trajectory of tactically relevant aircraft and determine requirements for the US Air Force Low-Cost Attritable Strike Demonstrator or LCASD programme. Following an Air Force competition, Kratos won with its design.

"Genesis of the Kratos XQ-58A Valkyrie started in 2015."

Based on its self-funded IRAD programme, Kratos was well into the conceptual design stage of its aircraft when the request for proposals was issued by the Air Force Research Laboratory. Kratos had to tweak its IRAD-based design to meet the LCASD requirements. Starting from a clean sheet design, Kratos had an air vehicle ready for first flight in 30 months.

Steve Fendley was quick to point out that its IRAD design was not derived in its own vacuum, but included considerable input from multiple Air Force agencies, groups and commands, the navy, and the army about their respective crucial requirements for a survivable larger scale tactical system. Survivability was the key requirement from all services, which Kratos provided by designing an air vehicle capable of Mach 0.8, in excess of 6G to avert a threat missile, and a configuration that makes it difficult to detect on radar. When designed in an appropriate way the three characteristics listed increases the air vehicles survivability.

Operational Objectives

As Kratos discussed its preliminary IRAD design with the various armed services, company engineers were repeatedly asked to provide a runway independent system, one with expeditionary take-off and landing capability. That meant no runway, no prepared surface, no paved road, or no dirt road. This was the number one requirement.

Second, was the ability to preposition or deploy the system in a dispersed manner, avoiding a concentration of multiple systems at one base where they may be susceptible to air strikes. Air vehicles would launch from multiple locations, rendezvous if required, and fly the mission as tasked. An enemy is then presented with multiple tracks making it difficult to prevent the Air Force from completing the intended mission.

Third, was the ability to operate as a loyal wingman: Valkyries flying with and in support of fifth-generation F-22s or F-35s or legacy fighters. Operating as a loyal wingman, a Valkyrie can function as an offboard sensor system or an offboard weapon system or a combination of the two.

Fendley painted a scenario: "Imagine an F-35 flying with four Valkyries that are part of your team. The F-35 is configured with a full weapons loadout but has additional offboard weapons and sensors carried by the Valkyries. As a consequence, the F-35 pilot has a ➲

An artist's impression of two XQ-58A Valkyries. Kratos Unmanned Aerial Systems

XQ-58A Valkyrie 58-002 launches at the US Army's Yuma Proving Ground, Arizona, on December 9, 2020. The flight successfully demonstrated the ability of new communications data to exchange information with an F-22 Raptor and F-35 Lightning II. US Air Force/ Sgt Joshua King

substantially increased level of battle space awareness and an equally substantial greater weapons load at their disposal."

High-level control of the Valkyrie is provided by either the F-35's pilot or a ground-based operator. Fendley explained: "Imagine the F-35 is flying and let's say that the F-35 pilot hits an icon on his tablet control to select and command one Valkyrie to fly in formation, forward projected by one mile. Without any further communication, the Valkyrie flies as commanded, in front by one mile thanks to a single high-level command. If the F-35 pilot wants to re-task Valkyrie to survey an area, they either drag an icon shown on the table representing the Valkyrie to the required area, or they can make the command using the sensor portion of the F-35's cockpit display that's slaved to the unmanned aircraft. All enabled by high-level control of the Valkyrie's functionality with no need for working through multiple steps and keying information."

Because all Valkyries in the group would be linked to the secure network, all assets on the network would have access to the information gathered by the unmanned system, and with permission, could take control. The intention is to make operating with loyal wingman a low workload task for a pilot but to have the unmanned systems available for him to task.

Operating from dispersed locations, the Valkyrie's flight from launch to rendezvous is all pre-programmed, a capability already tested during test flights.

A manned chase plane flies to a rendezvous point. The Valkyrie, pre-programmed before launch, takes off, flies to the rendezvous area, and enters a loiter pattern until the manned aircraft arrives or vice versa, allowing the mission sequence to begin.

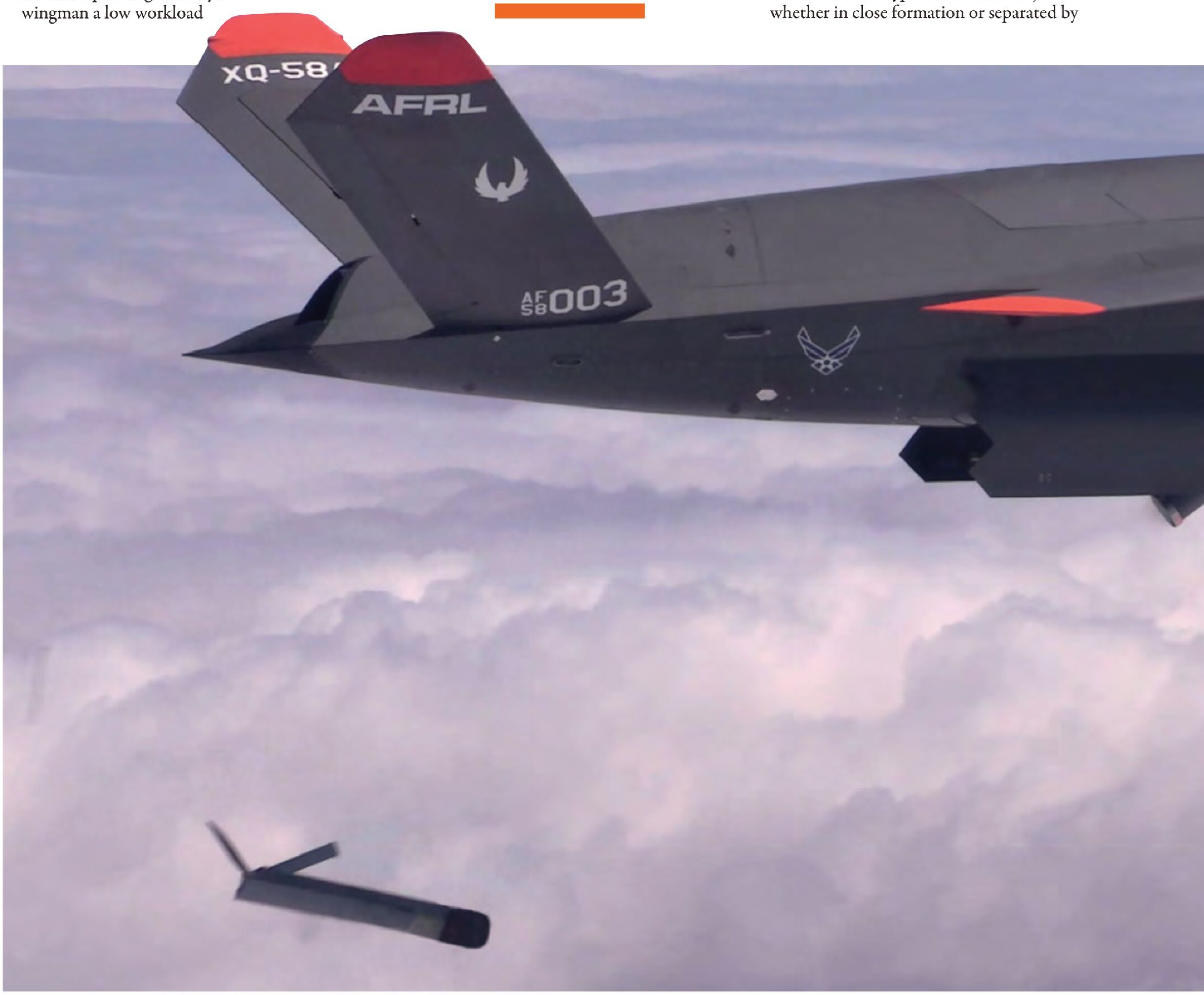
Steve Fendley reckons it's really effective because it's such a low additional workload on the pilot but such a substantial increase in capability.

Fourth, is the ability to fly Valkyries in a group. DARPA uses the term 'volley-quantity' to denote 20 loyal wingmen or a 'swarm' to denote a group of more than 20 aircraft. From one to a volley-quantity to a swarm, the Valkyrie is intended to operate in any of those tactical groups. All groups comprising multiple air vehicles have a distributed capability. So, if one aircraft is shot down or disabled, overall capacity is not lost because of the distributed capability. Nothing in the mission is dependent on any one aircraft by itself, it is the mass of aircraft that counts. Whether it's two or 20 or a swarm, the mass determines the ability to conduct the mission. Realistically this is a capability not available to manned systems because no nation is prepared to send up multiple aircraft and be prepared to lose some of the pilots.

Fifth, is the ability to operate in a group with other types of unmanned air vehicles, which is the core requirement of the Air Force Research Laboratory's Skyborg Programme.

Skyborg is aimed at developing a standard autonomy set that's interoperable between different types of unmanned aircraft. One ground station interface would receive information from different types of unmanned aircraft and be able to command each one. This allows different types to work in conjunction whether in close formation or separated by

"LCAAT is designed to break the escalating cost of tactical aircraft."



hundreds of miles in a battlespace.

Discussing some of Valkyrie's characteristics, Fendley said: "To meet the requirements of the Skyborg programme we need to be able to send a high-level command that's common between different aircraft rather than a full set of Valkyrie unique commands, otherwise integration of different UAVs into the mission space would be an insurmountable challenge."

"The 3,000 nautical mile unrefuelled range enables Valkyrie to be used for a variety of missions within a manned-unmanned teaming concept, with the ability to loiter while manned jets complete necessary aerial refuelling, or by joining them before and after their aerial refuelling cycles."

The US Air Force has set $2m to $20m as its per unit cost range to define an attritable unmanned aircraft. Valkyrie sits within the low end of that range. In the future, Air Force commanders could launch a mission from a range close to 3,000nm split between the transit and strike phases intent on sacrificing Valkyrie aircraft to accomplish their objective.

XQ-58A Flight Test Programme

The first XQ-58A aircraft made the type's first flight in March of 2019. Kratos built three air vehicles, 58-001, 58-002 and 58-003. All are flying or have been flown for the six publicised experimental flights detailed by Kratos and the Air Force Research Laboratory to date. All six of those flights were conducted over the Yuma proving grounds in Arizona, a hot, arid location with an environment that's suitable for stress testing the systems.

Steve Fendley offered some insight of flying an XQ-58A Valkyrie: "Even in the basic control mode, you do not fly the aircraft like you would fly a manned aeroplane. The autopilot is always in the loop, so you command the aircraft's attitudes but do not use hand-on control for the minute-to-minute flying. The autopilot ensures you don't stall the aircraft and have sufficient airspeed and energy to complete a roll before letting you engage. Most control inputs are made by clicking a mouse, but there is a control stick. During recent test flights, less than five minutes of the approximately 90-minute mission, has seen the operator control the aircraft using the stick."

Fendley said Kratos has six current contracts all related to the integration of mission systems, the advancement of autonomy, and in some cases focused solely on the unmanned mission, and the loyal wingman mission. He said: "Among the contracts there are similar thrusts such as missionizing the system, determining ➲

XQ-58A VALKYRIE CHARACTERISTICS

Length: 29ft
Wingspan: 27ft
Empty weight: 2,500lb
Max launch weight: 6,000lb
Cruise speed: Mach 0.72
Operational altitude: 50 to 45,000ft
Range: 3,000nm
Engine: One Williams FJ33 turbofan rated at 1,850lb with high reliability and better endurance characteristics

- Rail launch, parachute recovery
- Internal bomb bay with 600lb payload capacity
- Single mid-wing pylon per wing each with a 600lb payload capacity
- Internal and external mission system or weapon payload carriage
- Flight controls are commanded by a low-level autopilot mission system
- An outer loop control interfaces with the network-based command and control systems to enable the high-level commands to go back and forward
- All-carbon composite aircraft

"The US Air Force has set a cost range between $2m and $20m to define an attritable unmanned aircraft."

XQ-58A Valkyrie 58-003 releasing an ALTIUS-600 small, unmanned aircraft system during the type's sixth flight on March 26, 2021. US Air Force

the operational uses, developing the associated tactics, and evaluating different sensor and weapon systems that can be part of the aircraft."

The US Department of Defense is seeking a programme of record for an attritable aircraft, of a class like the Valkyrie, in the 2022-2023 timeframe, the Skyborg programme is part of the requirement.

Commenting, Steve Fendley said: "Skyborg started in December and will require a lot of flights this year. It's very focused on autonomy and enabling the entrant's different aircraft with different missions to operate on the system. It's not a fly-off programme but intended to try to optimise the autonomy regardless of the aircraft mission type. Skyborg is a key part of the evolution."

Production

Kratos is currently building 12 more Valkyrie aircraft. Some will be assigned to Skyborg, others will be deployed on other programmes.

Asked if the XQ-58A might require changes to improve, or advance the current experimental demonstrator baseline design, Steve Fendley said: "We have toyed with that. Before the LCASD programme emerged, we had intended to develop and build just a low-cost, proof of concept aircraft. Once we had the LCASD contract, which effectively funded the demonstration flights and the build of one aircraft, but not the design and development itself, we were more confident in the ultimate application of the system and therefore produced the three aircraft that have been in operation. They are advanced prototypes and production representative aircraft. The other 12 are considered low-rate initial product aircraft and do not include major design or capability changes. We designed the system to be configurable, both internally and externally. For example, the existing aircraft can be fitted with different wings without modifying the aircraft, but we do not expect any wholesale changes to the design."

All three original prototypes were built at the Kratos facility in Sacramento, California, but production has now switched to a new production centre in Oklahoma City, Oklahoma opened in November 2018.

"During flight 3, the XQ-58A met all 56 baseline test points."

Autonomous Control System

On May 5, 2021, US Air Force test units completed a series of flights with the Skyborg autonomy core system (ACS) loaded on a Kratos UTAP-22 Mako tactical unmanned vehicle at Tyndall Air Force Base, Florida. Conclusion of the flights completed the first phase of what's known as the Autonomous Attritable Aircraft Experimentation (AAAx) campaign.

The aim of the Skyborg programme is to integrate full-mission autonomy with low-cost, attritable, unmanned air vehicles to enable manned-unmanned teaming. Skyborg will provide the foundation on which the Air Force can build an airborne autonomous best of breed system

XQ-58A Valkyrie 58-001 in a right turn over the Yuma Proving Ground during the type's maiden flight on March 5, 2019. Note the white coating applied to the edges of two panels under the fuselage. US Air Force/88th Air Base Wing


The Skyborg autonomy core system launches aboard a Kratos UTAP-22 tactical unmanned vehicle at Tyndall Air Force Base, Florida on April 29, 2021. US Air Force

XQ-58A FLIGHT TEST CHRONOLOGY

Date	Duration	Objectives
Maiden flight March 5, 2019	76 minutes	Basic control objectives and autonomy evaluation; runway independent launch, runway independent recovery.
Flight 2 June 11, 2019	71 minutes	An expansion of flight 1.
Flight 3 October 10, 2019 After flight three, Steve Fendley said: "Based on the flights performed to date and the resulting data generated, we do not need to revise any of the airborne control systems, which is amazing for any newly developed system, but especially so for an unmanned system."	90 minutes	Executed a perfect launch and met all 56 baseline test points, and two additional test points. The recovery parachute system worked flawlessly, and the aircraft descended nominally under the canopy system. In final descent, the prototype cushion system did not employ correctly resulting in the aircraft sustaining damage upon touchdown. Aircraft was deemed fully repairable.
Flight 4 January 23, 2020	Over 60 minutes	Successfully completed all 43 baseline test objectives, plus 6 additional tests. The aircraft deployed its parachutes and landed normally, validating the design changes incorporated in the airbag system following flight three.
Flight 5 December 9, 2020		The aircraft successfully flew as the communications link between and in formation with an F-22 and a F-35A during an Advanced Battle Management System demonstration.
Flight 6 March 26, 2021 After flight six, Fendley said: "In addition to this first SUAS separation demonstration, the XQ-58A flew higher and faster than previous flights."		The aircraft successfully operated its bomb bay doors and the internal weapons release system, launched an ALTIUS-600 small, unmanned aircraft system, and further increased the aircraft's aerodynamic envelope.

This shot of XQ-58A 58-001 during the type's second flight on June 11, 2019 shows the form of the fuselage chine, the empennage, vertical stabiliser configuration and the engine exhaust. Air Force Research Laboratory/Holly Jordan

of systems that adapts, orients, and decides at machine speed for a wide variety of increasingly complex mission sets.

During the flights, the ACS demonstrated basic aviation capabilities and responded to navigational commands, reacted to geo-fences, adhered to aircraft flight envelopes, and demonstrated coordinated manoeuvring. This included navigating in shared airspace with up to four manned fighter aircraft, including F-16s and F-15Es assigned to the 40th Flight Test Squadron based at Eglin Air Force Base, Florida.

Ground-based aircraft controllers provided commands to the ACS during the flights. In the future, the plan is for direct manned-unmanned teaming via commands sent from a manned F-16 aircraft to the ACS onboard the unmanned aircraft. Commands could task the ACS 'brain' to find and track targets by flying the unmanned aircraft to an area of interest and report enemy contact locations to the manned fighter.

Major Nathan McCaskey, a test pilot assigned to the 40th Flight Test Squadron and the AAAx lead pilot said: "This test is a significant step toward teaming manned and unmanned aircraft in combat in the not-too-distant future. Unmanned aircraft using the autonomy system developed for this experiment could go to locations where manned fighters can't go, providing sensor information back to manned teammates, increasing the power projection capability of the Air Force."

During the test programme, flying an F-16, McCaskey made history by flying closer to an unmanned aircraft under autonomous control than at any other time in the history of the Department of Defense.

The test period was the first time an active autonomy capability had been demonstrated on an Air Force test range and was the first step to integrating autonomous attritable aircraft into an operational environment. Follow on events will demonstrate direct manned-unmanned teaming between manned aircraft and multiple ACS-controlled unmanned aircraft. ●

During the XQ-58A's fifth flight on December 9, 2020, XQ-58A 58-002 successfully flew in formation with an F-22 Raptor and an F-35A Lightning. Both of the fifth-generation fighters used were assigned to the 412th Test Wing based at Edwards Air Force Base, California. US Air Force

K-MAX IN AFGHANISTAN

Mark Ayton spoke with Steve Athanas, general manager of Swanson Aviation Group about operations using unmanned Kaman K-MAX helicopters in Afghanistan.

A Kaman K1200 K-MAX unmanned helicopter hovers over a landing zone at Camp Dwyer while awaiting a load to deliver to a forward operating base. Both K-MAX aircraft were assigned to Marine Unmanned Aerial Vehicle Squadron 2 (VMU-2) during their deployment to Afghanistan. US Marine Corps/Sgt Michele Hunt

Kaman's K1200 K-MAX is an unusual looking helicopter equipped with 48 foot intermeshing rotors and a Honeywell T53 turboshaft engine. The power plant is rated at 1,350shp and there's a single pilot in control. Imagine such an unusually configured manned helicopter re-configured as an unmanned system used to lift supplies and cargo in a combat zone. That's exactly what happened in Afghanistan in 2011 following a US Marine Corps joint urgent operation need issued two years earlier.

Improvised explosive devices (IED), a brutal and cowardly type of weapon used by insurgents in Afghanistan and Iraq, were killing many coalition troops in both nations. Road convoys were vulnerable to IED attacks such that troops faced the greatest chance of being killed when travelling in a convoy. The US Department of Defense sought to replace some of the road convoy re-supply effort with night-time rotary wing airlift.

Lockheed Martin proposed the concept of using an unmanned K-MAX helicopter to meet the requirement and a couple of demonstrations were conducted. This was undertaken in partnership with Kaman, the manufacturer of K-MAX. More interest was shown by the DoD, and more money was spent on the programme culminating in a fly-off between the K-1200 K-MAX unmanned variant and Boeing's A160 Hummingbird unmanned helicopter. There were some essential differences between the two types: The K-MAX retained its cockpit and provided an optionally manned solution which held some advantages, whereas the Hummingbird was smaller and only unmanned. Payload capacities were also considerably different; 4,500lb for the unmanned K-MAX and just 750lb for the Hummingbird.

"The original mission was a hub and spoke operation."

Selection and Afghanistan

Steve Athanas, general manager of commercial K-MAX operator Swanson Aviation Group spent seven years working for US companies in Afghanistan. His last three-plus years were spent operating K-MAX. Explaining the genesis of the fly-off, Steve said he arrived at Marine Corps Air Station Yuma, Arizona in the spring of 2011 where he and a Kaman team conducted K-MAX flight testing. He said: "In August, we were supposed to conduct a quick reaction assessment and a fly-off between the K-MAX and the Boeing Hummingbird. Its aim was to determine which type would deploy. Under US law there has to be a competition in place to qualify the selected weapon system for programme of record status. That's the process which formally incorporates a weapon system into the inventory of the United States military.

The terrible tsunami had hit Japan before we went to Yuma, and for a short time consideration was given by the DoD to

deploy K-MAX to Japan for the purpose of taking photos of the nuclear reactor pointing straight down. The gamma rays were too intense for humans to get anywhere close.

"Boeing didn't show up because its A160 Hummingbird was suffering problems. So, we conducted the fly-off requirements with the K-MAX as planned and met our task to lift 20,000lb of cargo over five night-time periods. The Marine Corps was satisfied with the performance and results such that by November my team and I were at Camp Dwyer in Afghanistan's Helmand province with two K-MAX aircraft and all the supplies. Eight Marines from a Marine Corps Unmanned Aerial Vehicle Squadron been trained to operate the KMAX with us.

"Our mission was originally a hub and spoke operation in which we used K-MAX to lift supplies from Camp Dwyer to the two designated FOBs [forward operating bases] and return empty, with the requirement to deliver 6,000lb of supplies each night. Due to the security situation at the FOBs, the marines deployed to both locations from where they grabbed control of the aircraft from us about mid-way. We grabbed back control of the aircraft on its return to Dwyer where we landed, refuelled and prepared it for the next sortie."

During the first six weeks of K-MAX operations, many marines were sceptical of the aircraft and its ops, muttering that it would never work and was crazy. Very little tasking was given to the K-MAX team. Faced with the situation, the marine officer-in-charge decided to lift dummy loads to the FOB as a means of demonstrating the K-MAX capability.

Steve Athanas explained: "We lifted 4,000lb of ready-to-eat meals to the FOB, placed the load on the ground to demonstrate the ability to deliver such a load, never let go of the load, but instead lifted it back to the FOB. We did that for six weeks and built up data as proof of the concept. Marine Corps logisticians eventually decided to start tasking us with lift sorties. We conducted up to six sorties a night and lifted up to 30,000lb of supplies, much more than the intended 6,000lb.

This was proof enough of both the machine, the utility and benefit that K-MAX gave to marines based in Helmand. What happened next makes the story more interesting. After four months deployed, the war strategy changed such that FOBs began to close down and only required re-supply of water and food.

Picking-up the story, Athanas said: "Originally, we were supposed to be in Afghanistan for six months and return home. As a matter of fact, many people in the military thought we would lose both K-MAX aircraft before the six months was up, either to enemy action or aircraft malfunction. To the contrary, we were knocking it out the park. The marine officer-in-charge and I devised a way to retrograde material from the FOBs back to the main base. This was difficult because when we hook up to a load on the ground to lift, we can see the load and the aircraft. The load is on the ground, the aircraft is already attached to the load. We bring it to a hover, manipulate control over the load with small control stick inputs, then we bring it up. Very simple. Conducting the retrograde lift missions, we had to hook to a load at different location up to 50 miles away. All we had to use as a guide was the laptop and help from anybody that could provide commentary over the phone about what the aircraft was doing."

The Marine Corps' first two Kaman K1200 K-MAX helicopters arrived at Marine Corps Air Station Yuma, Arizona on May 7, 2016. US Marine Corps/Pfc George Melandez

"K-MAX flew six sorties and lifted 30,000lb of supplies per night."

During the quick reaction assessment at Yuma, the K-MAX team had asked marine observers if they would be willing to put a helicopter support team underneath the hovering, unmanned helicopter to hook the load. Based on the perceived danger, the marine observers said they would never allow that. However, the K-MAX team eventually convinced the observers that an unmanned K-MAX hovers better than a piloted helicopter would, concluding that the concept was rock solid. The K-MAX team proved the concept with a Marine Corps helicopter support team at Yuma. This paved the way for the concept to be used in Helmand to safely hover the K-MAX over a load, hooking it and lifting it back to the main base. Once this demonstrated its utility and benefit, the Marine Corps tasked the K-MAX team to service all FOBs located in range of the aircraft from Camp Dwyer.

According to Steve Athanas, K-MAX operators learned how to go to any FOB that was within range of the aircraft without any local operators despite a six second lag between input and response. He said: "Imagine flying a helicopter where you input a command and have to wait six seconds to see a response. Sometimes it wouldn't even work. Overcoming that challenge tremendously expanded our utility to the Marine Corps and that's why we stayed 33 months instead of the original six. Once we moved our operation from Camp Dwyer to Camp Bastion, we flew our longest ever mission to the Kajaki Dam, two-and-a-half-hours there and back. We installed an auxiliary fuel tank under the transmission and needed every drop of fuel for that mission.

"From time to time we delivered ammo and water to a grid to re-supply a long range

A marine in a helicopter support team walks away from a container after attaching it to a Kaman K1200 K-MAX at Camp Dwyer, Afghanistan. US Marine Corps/Sgt Michele Hunt

The CQ-24 K-MAX unmanned helicopter is a revolutionary cargo resupply capability that helped to save lives and support troops in Afghanistan. US Marine Corps/Sgt Michele Hunt

The CQ-24 K-MAX unmanned helicopter's expedience made it a preferred method for delivering small loads to forward operating bases in southern Helmand Province, Afghanistan. While a convoy could take five hours to reach a remote forward operating base, the CQ-24 took 10 minutes. US Marine Corps/Sgt Michele Hunt

"The CQ-24 K-MAX retained its cockpit and provided an optionally manned solution."

patrol in pursuit of the Taliban. K-MAX was often the only type of helicopter able to re-supply them due to adverse weather or night-time operations. Many of the marines in Helmand didn't know where we came from or who we were. But one night we were getting ready for a mission and a staff sergeant showed up at our command post. He was practically in tears because we had retrograded materials from his FOB. If we hadn't have done that, he and his fellow marines would have been forced to transport the materials by road convoy. In that event, the staff sergeant knew some marines would have been killed given the tough situation in the area. He was so appreciative."

The K-MAX team flew its final Afghan mission in May 2014 and returned the aircraft to Lockheed Martin's Owego facility in New York. A ceremony was held at Owego during which Marine Corps leaders spoke of how successful the KMAX deployment in Afghanistan had been. Both aircraft were subsequently flown by pilots to Yuma for storage.

New Lease of Life

Despite its combat success, there was no funding available to continue the development of a large, unmanned logistics programme. Both K-MAX aircraft remained in storage for a number of years before new Marine Corps leadership reversed the decision. In 2019, NAVAIR's Multi-Mission Tactical unmanned programme office based at Naval Air Station Patuxent River, Maryland received funding for developmental work using the two K-MAX aircraft as test platforms. The funding allowed both aircraft to be returned to flight status and for the development of technologies for beyond line of sight satellite communication, W-band radar, and autonomous terminal area collision avoidance.

In early 2020, the K-MAX programme received more funding via a congressional add, for maturing the air vehicle's autonomy with beyond line of sight satellite communication technologies. The systems are due to be integrated on one of the K-MAX aircraft in preparation for a demonstration to the US Marine Corps in late 2021.

Whether KMAX becomes a programme of record remains to be seen. Commenting on the

"The longest Afghan mission lasted two-and-a-half hours."

perception military personnel have about the K-MAX, Steve Athanas said that some people look at the K-MAX as an old school system that they don't want to go forward with, saying: "Heaven forbid we get into another war, but if we do, then the US military will want the unmanned K-MAX back and will probably buy several more."

When the K-MAX team first arrived at Camp Dwyer, the marine officer-in-charge presented Steve Athanas with an exercise. The marine asked Steve to assume he had eight KMAX aircraft assigned to his squadron and was flying four aircraft each night. The marine officer wanted to know how many people the K-MAX contractor team would need to run that operation? After some thought, Steve told him 37 people. He was amazed. When asked, the marine officer said the Marine Corps would employ 180 troops. Steve considered the reasons why the marines would need that many people and tried to impress upon the officer that in reality he would not need that many.

Steve recalled an occasion at Bastion where he had a four-man team comprising another operator, a mechanic, and a marine mission commander. He said: "A crew at Dwyer sent an aircraft to Bastion in the early night-time period. We refuelled the aircraft and hooked up a payload and then used it all night to re-supply the FOBs around Bastion. At the end of the night, we sent it back to Dwyer where the main maintenance facility was. We operated a K-MAX during night-time missions from Bastion with a four-man team for three months. This was conclusive proof that the K-MAX team could operate reliably and safely with fewer people than originally planned by the company.

During his years spent working in Afghanistan, Steve Athanas was asked to take the job as the deputy for the unmanned

A K-MAX unmanned helicopter lifts a load from Camp Bastion, Afghanistan. US Marine Corps

A night-time lift by a K-MAX helicopter during operations in Afghanistan. US Marine Corps

K-MAX programme in the United States, eventually becoming the lead member until December 2012. He subsequently joined Swanson Group Aviation, which was a subcontractor to the Lockheed Martin-Kaman partnership. Originally Swanson provided maintenance services for the K-MAX, but eventually supplied the majority of K-MAX operators and logistic support for the Afghanistan operations.

The 33-month K-MAX stint in Afghanistan throws up some interesting operational facts about the helicopter. The aircraft was completely unarmed, and the team did not know if either of the aircraft had been shot at but know for sure that neither had ever been hit. Despite having two aircraft in country, the K-MAX team never flew them simultaneously and lifted 4.5 million pounds of cargo during the 33 months. Based on the number of tons lifted, official Marine Corps analysis determined the two KMAX aircraft saved the lives of at least 48 marines who otherwise would have been killed in insurgent attacks on ground convoys.

Reflecting on his experience of operating the K-MAX in Afghanistan, Steve said: "Even if it was the apex of my professional career, I can live with that, because it was a wonderful experience to save those lives. We were at the forefront of aviation history. It was the first wartime use of UAV cargo resupply in history. The unmanned K-MAX competed for the 2013 Collier Trophy, but we were beaten by the Mars Rover. I don't feel any shame in that. That's pretty awesome."

Both of the Marine Corps' Kaman K1200 K-MAX helicopters at Marine Corps Air Station Yuma, Arizona. US Marine Corps/Pfc George Melandez

BOUND FOR LINCOLNSHIRE

Mark Ayton details the General Atomics MQ-9B SkyGuardian which has been dubbed the Protector RG1 by the Royal Air Force.

GA-ASI company-owned MQ-9B SkyGuardian N190TC close to the UK coastline toward the end of its historic transatlantic flight to RAF Fairford, England in July 2018. GA-ASI

If things go to plan, the RAF's 31 Squadron will be reactivated at RAF Waddington, Lincolnshire in 2024 and take the task of being the first drone squadron equipped with the Protector RG1. Designed and built by General Atomics Aeronautical Systems (GA-ASI) it will be the first drone capable of autonomous operation in non-segregated airspace, specifically to meet UK the RAF's requirements. The MQ-9B SkyGuardian is the latest and most advanced version of the original MQ-9A Reaper. Despite not being operated by any branch of the US armed services, GA-ASI is able to use an official US military designation because some of its customers are foreign military sale customers who buy the system through contracts placed by the US Air Force. In keeping with RAF tradition, the all-new MQ-9B was christened the Protector.

Genesis of the Protector

To meet its replacement requirement for the MQ-9A Reaper, the RAF had to procure a new unmanned aerial vehicle that fully conformed to all certification procedures managed by the UK's Military Airworthiness Authority (MAA). The MAA was established in accordance with the recommendations listed in the independent review by Charles Haddon-Cave QC surrounding the loss of RAF Nimrod MR2 XV230 in Afghanistan on September 2, 2006.

"DRR tracks multiple targets while scanning for others."

In order to meet the MAA's stringent certification requirements and bid to secure a contract to supply the RAF with a new unmanned aerial system, General Atomics' leadership decided to develop the MQ-9B SkyGuardian that conformed to both UK Def Stan 00-970, the design and airworthiness requirements for military registered aircraft and NATO STANAG 4671 UAV system airworthiness requirements.

To meet UK requirements, GA-ASI engineers re-designed and re-developed many of the MQ-9A's major components. Additionally, the company opted to use new materials including Cycom 5320-1, a highly toughened carbon fibre-reinforced epoxy prepreg material. Cycom is a material that's not only bonded, as per the Reaper, but also fastened. GA-ASI uses a new robotic manufacturing system that places fasteners into the components during production.

Some of the Protectors features are:

- An airframe that is promoted as 'damage tolerant' and features a bulkhead forward of the engine to prevent fire spreading through the fuselage.
- A nose configuration designed to house a Due Regard Radar (DRR) which is part of a Detect and Avoid (DAA) system, an essential ➲

MQ-9B SkyGuardian N190TC is used by GA-ASI and the Protector integrated test and evaluation team for systems testing. Royal Air Force/7664 Squadron

device for an unmanned air vehicle to meet the see and avoid requirements for operation in non-segregated airspace.

- A 79ft wingspan to increase endurance and performance and provide better take-off parameters. The leading edge of the wing, engine intake and the pitot tube all house de-icing systems. Each wing is configured with four hardpoints, as opposed to the Reaper's three.
- Details of mission systems remain scarce. One senior RAF officer said the air vehicle will carry varying payloads of intelligence gathering systems. A description that no doubt refers in part to GA-ASI's APY-8 Lynx IIe Block 20A synthetic aperture radars with ground moving target indicator modes and Raytheon's DAS-4 Multi-Spectral Targeting System. This combines four high-definition electro-optical and infrared cameras covering five spectral bands, a three-colour diode pump laser designator and rangefinder, laser spot search and track capability, automated sensor and laser bore sight alignment, three-mode target tracker, all housed in the single turret ball located under the forward fuselage. Built with a digital architecture, the DAS-4 provides long-range surveillance, target acquisition, tracking, range finding and laser designation capability. The cameras have multiple fields of view, electronic zoom, multimode video tracking and capacity to incorporate future enhancements. The MTS system is operated by a sensor operator from a console housed in the Protector's advanced ground control system.

Given that 12 UK defence companies are involved with the Protector programme it's likely that as-yet unspecified intelligence gathering systems might be integrated into the air vehicle, most likely carried externally on the underwing hardpoints.

"On August 14, 2020 the USAF awarded a contract for Belgian MQ-9s."

- A lightning protection system comprises layers of mesh placed into the composite material and use of hardened avionics.
- Updated mission system software.

Detect and Avoid System

GA-ASI has been working on the development of a Detect and Avoid (DAA) algorithm, in cooperation with Information Systems Delft, and a complete DAA system since 2011. According to the company, collaboration with several industry partners including Honeywell, Aviation Communication & Surveillance Systems, BAE Systems, and multiple flights using NASA's Ikhana air vehicle were instrumental in achieving an industry-wide solution.

In 2017, Minimum Operational Performance Standards were adopted by the Federal Aviation Authority into two Technical Standard Orders (TSOs) as the certification basis for DAA and Air-to-Air Radar systems.

GA-ASI developed a prototype system called Baseline DAA, which in 2016 was installed on MQ-9 air vehicles operated by US Customs and Border Protection and has flown thousands of operating hours.

The baseline DAA programme provided insight and experience to begin designing and building the first-ever certified DAA system in 2018, which should receive authorised TSOs in 2024. The certified DAA system incorporates a traffic collision avoidance system dubbed TCAS II, certified hardware and software.

The company has also participated in the development of standards for the Airborne Collision Avoidance System-Xu (ACAS-Xu), that were scheduled for release late last year. ACAS Xu is deemed to be key to international harmonization of DAA standards.

Additionally, GA-ASI has developed a Due Regard Radar (DRR) comprising two air-cooled, active electronically scanned array (AESA) panel antennas and an electronics assembly that detects and tracks all types of aircraft, including microlights, across the same field-of-view as pilot flying a manned aircraft.

Algorithms combine three source feeds - radar, TCAS and ADS-B (see below) - to provide comprehensive details about a contact which are displayed on the operator's screen. Dubbed the probe, the system's screen shows the zone to avoid, to remain well clear of other aircraft, which turns red if the air vehicle is flying a course that could conflict with another aircraft, allowing the pilot full authority for avoiding action. The system is capable of automatic collision avoidance manoeuvres following TCAS resolution advisories, but for radar-only contacts, the pilot decides where to fly based on the avoidance zones.

The DRR set is designed to track multiple targets while simultaneously scanning for new aircraft thanks to the AESA radar. DRR is a key component of GA-ASI's DAA architecture for the Protector. Flight tests of a pre-production standard DRR were completed onboard NASA's MQ-9 Ikhana air vehicle.

According to GA-ASI, the DAA system must detect and avoid cooperative (aircraft ➲

This top down shot of MQ-9B SkyGuardian N190TC shows the radome housing its satellite link atop the mid-fuselage. GA-ASI

"On April 23, 2021, the US State Department approved a possible FMS of 12 MQ-9Bs to Australia."

equipped with a transponder) and non-cooperative (aircraft not equipped with a transponder) aircraft. Detection and tracking of cooperative aircraft is performed by two devices: the TCAS (traffic collision avoidance system) and the automatic dependent surveillance-broadcast (ADS-B) receiver. By tracking non-cooperative aircraft, DRR provides a collision avoidance capability for the air vehicle and allows the remote pilot to separate the air vehicle from other air traffic in cooperation with air traffic control.

Protector Specific Features

Given that Protector will replace the MQ-9 Reaper in RAF service, it will be employed in a number of military roles including ISR and strike, and probably maritime surveillance, electronic warfare, and electronic attack.

To meet its strike tasking, the RAF plans to arm Protector with the Brimstone air-to-ground missile and the Paveway IV precision-guided munition. Both are UK-produced weapons.

Protector has to be equipped with an X-band SATCOM system to link with the MoD's SKYNET satellites. The X-band satellite link will enable Protector to take off and land under the control of an aircrew based at RAF Waddington rather than by a launch and recovery crew deployed to a forward operating base. This capability increases the RAF's operational flexibility and reduces the number of personnel deployed to a forward operating base. The X-band satellite link is a completely different system to the one used by Reaper.

Protector's ground control stations will be customised to facilitate a third aircrew member who serves as a mission intelligence coordinator.

Additionally, the type will be able to undertake civil missions, most notably search and rescue.

UK Airspace Integration

While the MAA will ensure that Protector complies with design and airworthiness requirements, work is ongoing with the UK's Civil Aviation Authority (CAA) to gain compliance certification for Protector's operation in non-segregated UK airspace. In July, GA-ASI plans to deploy a company-owned SkyGuardian air vehicle to RAF Waddington to conduct a series of flights to demonstrate the air vehicle's ability to safely fly through UK non-segregated airspace. The RAF is providing its expertise and understanding of UK airspace in support of the trial. CAA certification will allow the SkyGuardian to take-off from Waddington, climb to 10,000 feet and route through non-segregated airspace to operating areas from where the trial team will demonstrate the aircraft's capabilities. The aircraft will be deployed to the UK configured with maritime surveillance sensors and is expected to participate in the multi-domain Exercise Joint Warrior in late September while operating from RAF Lossiemouth in Moray.

CAE's Predator B mission trainer at the GA-ASI Flight Test and Training Centre at the Grand Sky Unmanned Aircraft System Business Park near Grand Forks, North Dakota. CAE

"Belgian MQ-9Bs will be based at Florennes Air Base."

GA-ASI company-owned Protector touches down on the runway at Creech Air Force Base, Nevada. Royal Air Force/7664 Squadron

Protector First Flight

First flight of a Protector RG1 air vehicle took place on September 25, 2020 from GA-ASI's flight operations facility at El Mirage, California. The air vehicle was marked with its FAA registration, N990DA (c/n GA-6-1496) and listed as a model UBC97000-10. This is the fourth MQ-9B SkyGuardian built but the first example destined to be owned by the United Kingdom Ministry of Defence. Dubbed UK1, the first aircraft will be formally delivered this summer. The aircraft, and UK2, will remain in the US to support system testing as part of an integrated test and evaluation team comprising UK MoD, US Air Force and GA-ASI personnel. The first operational aircraft, likely to be UK3, will be delivered in 2023 followed by service entry in 2024.

Air vehicle UK1 made its first flight on September 25, 2020, followed by UK2 in May 2021 when UK3 was still on the production line.

The first three UBC97000-1 model SkyGuardians N190TC (c/n YBC1), N191FP (c/n YBC2) and c/n YBC3, which remains unidentified, are company-owned, and support all developmental flight testing and certification support.

In July 2018, MQ-9B N190TC flew a non-stop transatlantic flight to RAF Fairford, England for the Royal International Air Tattoo. It was the first transatlantic crossing flown by a medium altitude long endurance class unmanned air vehicle.

Two more MQ-9 UHK97000-15 models also support flight testing, N341HK (c/n FC341) and N361HK (c/n FC361), which appear to be variant models.

Aircrew Training

RAF personnel selected to fly and operate the Reaper now spend six weeks at the GA-ASI Flight Test and Training Centre at the Grand Sky Unmanned Aircraft System Business Park near Grand Forks, North Dakota. During the course, personnel undergo ground school and learn basic aircraft operations. Further

training is undertaken with the US Air Force at Holloman Air Force Base, New Mexico. Students then join 39 Squadron at Creech Air Force Base, Nevada to undergo combat ready work-up training. The Creech element includes UK-specific aspects of operating the Reaper including rules of engagement and UK safety procedures, previously taught by 54 Squadron's Reaper Training Flight. Post-course, personnel then fly operational sorties.

GA-ASI will use the Grand Forks facility to provide the RAF with Protector training for its initial cadre of aircrews leading up to the type's initial operating capability declaration. Decisions about follow-on training have yet to be taken, the RAF might opt for a complete in-house course or one that's shared with GA-ASI.

Belgian SkyGuardians

On March 25, 2019, the US State Department approved a possible foreign military sale to Belgium of MQ-9B SkyGuardians and related equipment for an estimated cost of $600m.

The Belgian government requested to purchase four MQ-9B air vehicles, two certifiable ground control stations, five DAS-4 Multi-Spectral Targeting Systems (four installed, one spare), 15 embedded GPS/INS navigation systems (12 installed, three spares), five APY-8 Lynx synthetic aperture radars (four installed, one spare), and five Detect and Avoid Systems (four installed, one spare).

Also included are an initial spares package and readiness spares package to support a five-year period of performance; spare and repair parts; support and test equipment; publications and technical documentation; personnel training and training equipment; and other related elements of logistical and programme support.

According to the US Defense Security Cooperation Agency (DSCA), the sale will enhance the intelligence, surveillance, and reconnaissance capability of the Belgian military. The DSCA reported that Belgium intends to use the air vehicles and services to provide for the defence of its deployed troops, regional security, domestic security, and interoperability with the US/NATO partners.

The MQ-9B system will enable the Belgian Air Component to conduct persistent and wide area ISR, including target acquisition, target designation, provide precision coordinates for GPS-guided munitions, battle damage assessment, signal intelligence, communication, and data relays.

According to a written statement by former Minister of Defense Philippe Goffin to Belgian politician Steven Creyelman, GA-ASI will submit all details of the MQ-9B's certification in accordance with NATO STANAG 4671 to the UK Military Airworthiness Authority (MAA) in July 2021 so the UK organisation can support Belgium in achieving a national Military Type Certificate for the MQ-9B for use by the Belgian Air Component. According to the official Belgian Air Component schedule, they will complete the certification process in 2023 enabling the MQ-9B to operate in Belgian airspace.

"The DAA incorporates a traffic avoidance collision system."

Belgian MQ-9Bs will be assigned to 80 UAV Squadron based at Florennes Air Base. They will serve as a replacement for the already retired RQ-5 B-Hunter reconnaissance unmanned air vehicles which, according to the DSCA proved to be insufficient to support sustained and persistent ISR operations. A new maintenance hangar and workshops are planned to house the new drones at Florennes.

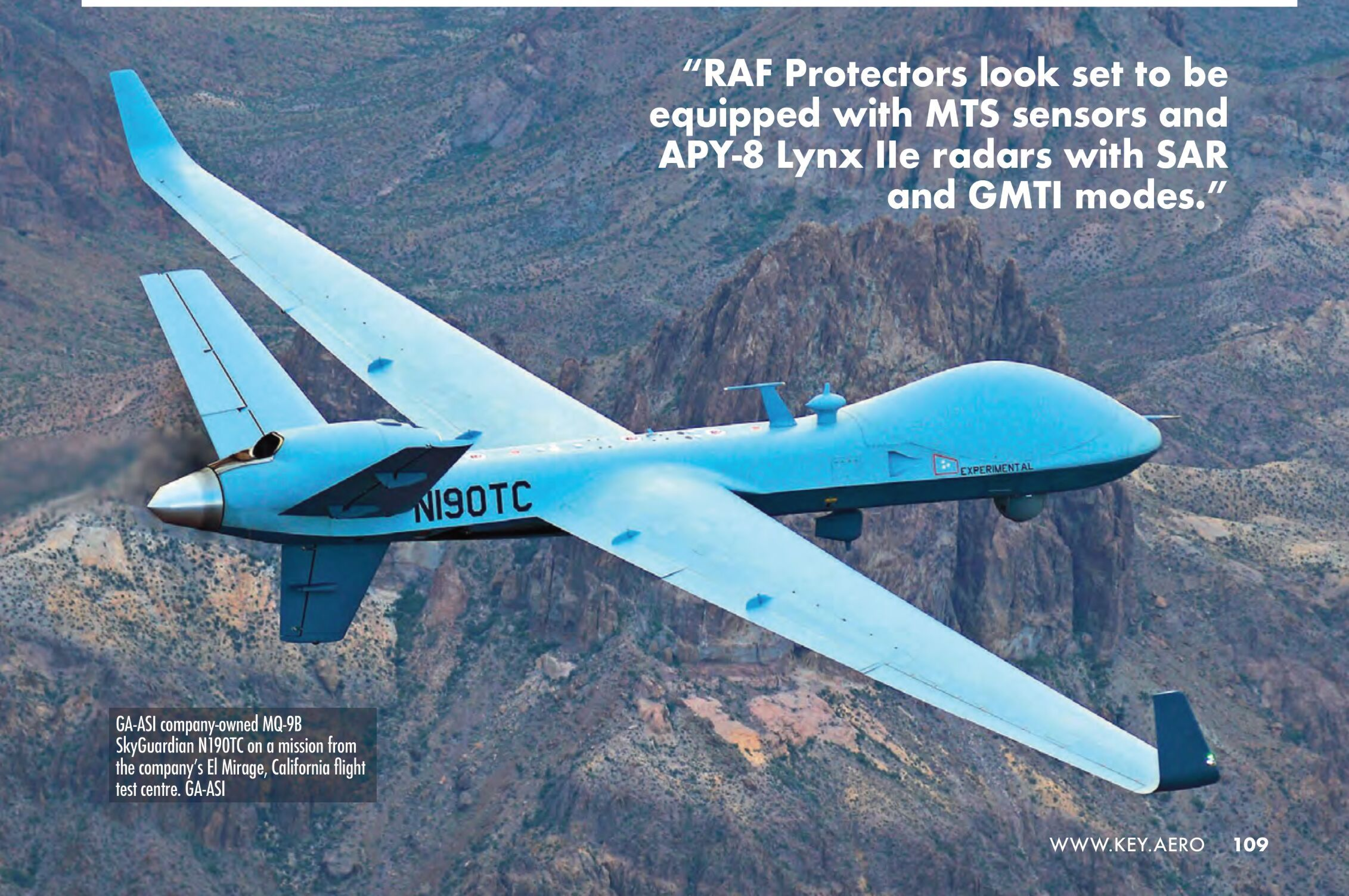
On August 14, 2020, the US Air Force awarded General Atomics a $188.8m contract under the foreign military sale programme to supply the Belgium Air Component with the requested systems. The first system is expected to be delivered in 2023.

Four days after the contract award, the Belgian Air Component and the Royal Air Force agreed and signed what was called a bilateral statement of intent to explore collaboration in training, maintenance, logistic support, interoperability, and capability enhancement for the MQ-9B.

Australia MQ-9Bs

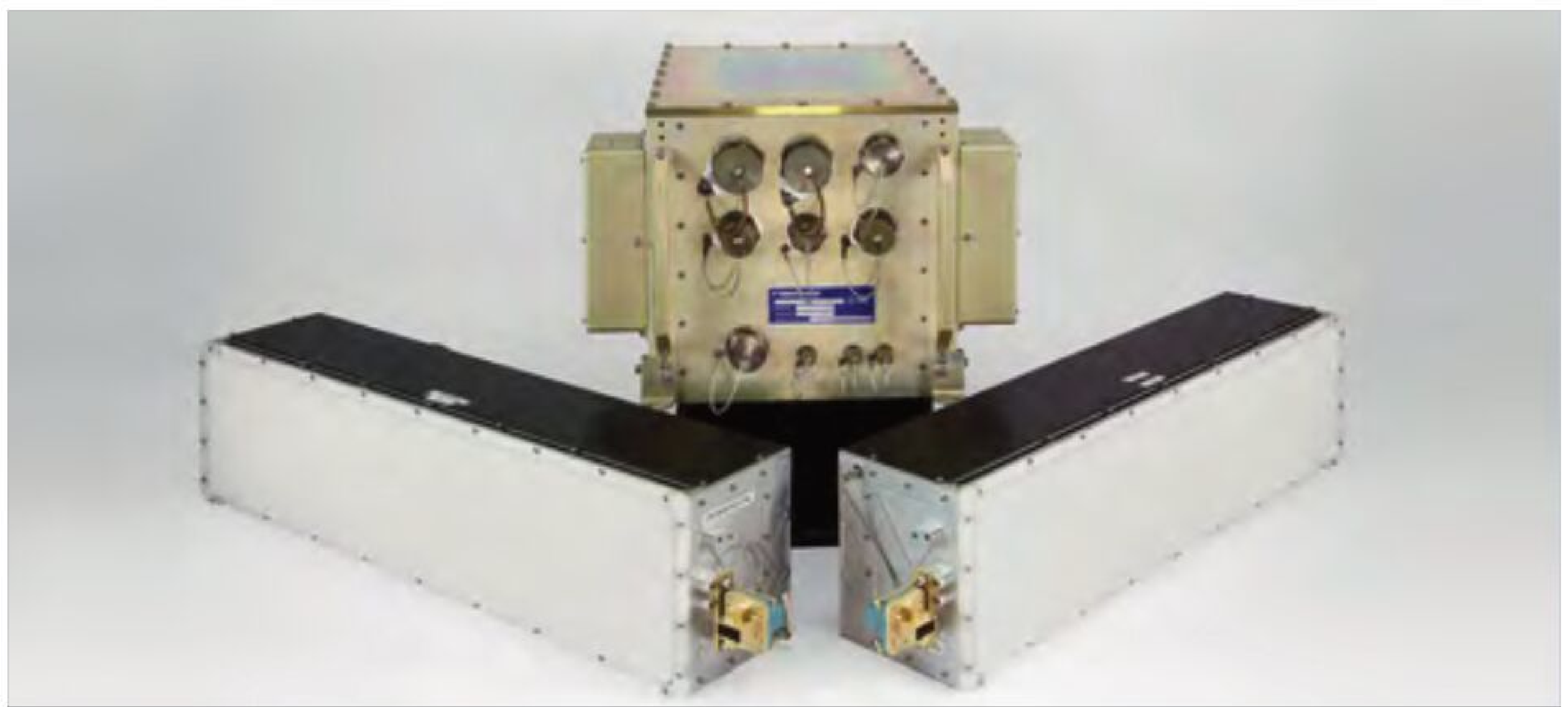
On April 23, 2021, the US State Department approved a possible foreign military sale to the Government of Australia for MQ-9B unmanned air vehicles and related equipment for an estimated cost of $1.651bn.

The Australian government requested to buy up to 12 weapons-ready MQ-9B air vehicles, 15 Raytheon Multi-Spectral Targeting Systems-D sensors, 16 Lynx APY-8 synthetic aperture ➲



GA-ASI company-owned MQ-9B SkyGuardian N190TC on a mission from the company's El Mirage, California flight test centre. GA-ASI

MQ-9B SkyGuardian N190TC at Creech Air Force Base. Royal Air Force/7664 Squadron



This shot shows both of the air-cooled, active electronically scanned array panel antennas and the electronics assembly of the GA-ASI-developed Due Regard Radar. These are essential components for the RAF Protector to enable operation in non-segregated airspace. GA-ASI

radars with ground moving target indicator capability, 15 L3Harris RIO communication intelligence systems, 36 embedded GPS/INS navigation systems with anti-spoofing modules, and various tail kits and air foils for munitions already in Australia's arsenal.

Also included are Honeywell TPE331 aircraft engines, certifiable ground control stations, mobile satellite communication ground data terminals, Leonardo SAGE 750 electronic surveillance measures System, automatic information systems, ARC-210 radios, DPX-7 IFF transponders, General Dynamics satellite communication antennas, Leonardo/Selex SeaSpray 7500 maritime radars, and KOR-24A small tactical terminal Link 16 datalinks. There are also various weapon components, and other related elements of logistical and programme support.

Royal Air Force Protectors

On November 16, 2016, the US State Department approved a possible foreign military sale to the United Kingdom for Certifiable Predator B unmanned air vehicles, equipment, training, and support. The estimated cost was $1.0bn.

The United Kingdom requested a possible sale of up to 26 Certifiable Predator B unmanned air vehicles (16 with an option for an additional ten), 12 advanced ground control stations (eight with an option for an additional four), four new launch and recovery element ground control stations, four upgrades to the existing Block 15 launch and recovery element ground control stations (two with an option for an additional two), 25 Multi-spectral Targeting Systems (12 plus two spares, with an option for an additional ten plus one spare), 25 APY-8 Lynx IIe Block 20A synthetic aperture radars with ground moving target indicator modes (12 plus two spares, with an option for an additional ten plus one spare), and 86 embedded GPS/INS guidance units (three per aircraft) (48 plus five spares, with an option for an additional 30 plus three spares).

The sale also included communications equipment, identification friend or foe equipment, weapons installation kits, Honeywell TPE331-10YGD engines, unique and common spares package, support equipment, US Air Force technical orders, country specific technical orders, contractor logistics support for two years with an option for a third year, contractor provided aircraft components, spares, and accessories. It also incorporates personnel training and other related elements of logistical and programme support.

"Defence Secretary Ben Wallace signed for three MQ-9Bs in July 2020."

The quantities listed by the DSCA were based on a Protector fleet of 20 plus air vehicles as set out in the UK government's 2015 strategic defence and security review. At the time, the Protector system was forecast to enter RAF service in 2018, a date that slipped to 2021, and more recently 2024.

Protector: Accountant's Assessment

There were more problems with the UK Protector programme as reported by the MoD's accounting officer, Sir Stephen Lovegrove in his November 5, 2019 letter to Meg Hillier MP, chair of the Programme Accounting Office. Lovegrove stated: "The Protector programme was approved by the Investment Approvals Committee [IAC] in June 2016, leading to contract award with industry and the US Air Force. To manage a wider affordability challenge, the department [the Ministry of Defence] decided to delay the programme by two years. As a direct consequence, the Protector programme milestones approved by the IAC in Jun 2016 were no longer achievable. This also led to increased costs of £187 million."

On value for money Lovegrove stated: "Against the authorised budget level of £812.6 million approved at the 2016 main gate, Protector programme costs have increased by £325.6 million. This figure includes: the costs associated with the delay (£186.8 million); the cost of changing the primary sensor to avoid future obsolescence (£64.6 million); additional programme costs identified in advance of the programme delay (£23.4 million) and foreign exchange and accounting adjustments (£50.8 million).

"In terms of determining value for money, a comparison was made: developing a new remotely piloted aircraft system (RPAS) capability (either collaboratively or nationally); procuring the current Reaper Block 5 (as used by the US Air Force and others); and procuring Protector. This concluded that procuring Protector represented best value for money, as its higher performance meant that the operational task could be delivered by procuring fewer air vehicles. The two-year delay and resultant cost increase have not undermined this value for money case. The main gate business case confirmed that the Protector programme was deliverable within budget; it remains affordable despite the cost growth."

On deliverability, the MoD's accounting officer stated: "At this early stage of the programme delivery, the senior representative officer's confidence is set at amber. The procurement strategy is a single-source procurement through a hybrid government-to-government foreign military sales case with the US Department of Defense [DoD] and through an agreed direct commercial sale arrangement with GA-ASI. Positive behaviours demonstrated by the US DoD and GA-ASI throughout give significant confidence in their future support and ability to deliver. The most significant risk to the Protector programme is the RAF's ability to generate and sustain the volume of trained personnel necessary to assure initial operating capability in November 2023. The Protector workforce builds on the current Reaper force; training and retaining sufficient crews has historically proved challenging and is being closely monitored."

In conclusion, Lovegrove said: "The cost growth and time delay to the programme imposed in July 2017 were outside of programme tolerances but were the result of the need to ensure the affordability of the overall defence programme. At all times, the programme has been properly governed and assured in accordance with HM Treasury rules. The accounting officer is satisfied that where programme tolerance has been exceeded it has been for valid reasons."

On July 15, 2020, UK Defence Secretary Ben Wallace signed a £65m contract for the RAF's first three Protector aircraft and one ground control station. Wallace announced the deal online during the virtual 2020 Air and Space Power Conference. The deal includes an option to buy 13 more aircraft and four more ground control stations. The UK MoD has yet to announce confirmation for the option but given its requirement and commitment to the Protector programme to date, there's little doubt of a follow-on commitment.

On the occasion of the announcement, a MoD spokesperson refuted that the split buy was due to the MoD's over-stretched budget and confirmed the department was evaluating the procurement of more drones above the 16-aircraft Protector requirement. Effectively increasing the future fleet to the DSCA's original listing of 26 aircraft. ●

The console layout of GA-ASI's certifiable ground control station in the company's simulator facility. GA-ASI


Credit GA-ASI

A BRITISH LOYAL

The Mosquito unmanned air vehicle is set to be the UK's first loyal-wingman aircraft. **Mark Ayton** examines the type.

The UK government continues to fund large projects designed to design, demonstrate, and ultimately produce future weapon systems for the nation's defence. The technology demonstrator programme named Taranis succeeded in flight testing a stylish looking air vehicle from the Royal Australian Air Force Woomera range complex in South Australia. The flight tests undertaken reportedly proved functionality of the air vehicle's primary sensors and systems. Today, the air vehicle remains in storage at Warton, Lancashire staring at an as yet unknown future. At the 2018 Farnborough International Airshow the world discovered the first snippets of detail about Team Tempest, a group of industry partners working with the RAF's Rapid Capabilities Office to develop the technologies required for a new generation combat aircraft. In late January, the world discovered similar first snippets of details about Team Mosquito, another group of industry partners, also working with the RAF's RCO to develop and build a full-scale, unmanned air vehicle in support of the RAF's Lightweight Affordable Novel Combat Aircraft concept. If you're confused by that gracious title, you're not alone. It's an unmanned air vehicle for the loyal-wingman role (what the RCO terms uncrewed adjunct), a capability that first emerged in Australia with the Boeing Loyal Wingman.

Like all government programme announcements, there are plenty of glorious claims about development, delivering and staying within budget. Like all government programmes little is ever said about how the assembled teams will achieve their tasks.

Mosquito Project Phases

According to the RAF RCO, Project Mosquito is a technology demonstration for the LANCA concept. It originated from studies undertaken by the Defence Science and Technology Laboratory (DSTL) in 2015 that sought to understand innovative technologies and concepts that might offer radical reductions in cost and development time. Subsequently, LANCA entered the RAF RCO's tasking as part of the Future Combat Air System Technology Initiative dubbed FCAS TI. LANCA aims to explore the utility and feasibility of unmanned capability adjuncts to existing and future fast jet aircraft, specifically those that offer substantial reductions in traditional cost and development times. The RAF RCO launched a competition to seek a technology demonstrator for what is known as Project Mosquito run by Team Mosquito. At its core, the winning team has to generate evidence to inform on a potential future LANCA requirement.

This image shows a Mosquito unmanned air vehicle parked under a typical Rubb aircraft hangar showing the landing gears, landing gear doors and a sense of the aircraft's size - if the proportionality of this image is intended to be accurate. Spirit AeroSystems

In 2019 the RCO awarded three contracts to teams led by Blue Bear Systems Research Ltd, Boeing Defence UK Ltd, and Callen-Lenz for a 12-month Phase 1. Preliminary system designs for a technology demonstrator vehicle were produced by each team with an assessment undertaken of the key risk areas and cost-capability trade-offs for operational concepts. Phase 1 included exploration of novel design, development, prototyping, manufacture, and support, in an attempt to achieve rapid development and evolution of a loyal wingman unmanned air vehicle but as cost effectively as possible.

Down-select and a Phase 2 contract was

An artist's impression of a Mosquito unmanned air vehicle showing the digital paint scheme, a chine between the upper and lower fuselage surfaces, an air inlet positioned atop the fuselage, canted vertical stabilisers and downward-cranked wing tips. Spirit AeroSystems

WINGMAN

awarded in November 2020. The three-year Phase 2 will complete design, manufacture and integration of the demonstrator system and conduct a limited flight test demonstration programme. This implies the Mosquito is a proof-of-concept programme.

Mosquito is a UK national project under FCAS TI. The group of companies in Team Mosquito all work with other companies across the global aerospace supply chain. The intent of this is to best deliver the project aims and harness 'best of breed' with the objective of contributing to the prosperity of the UK. The RCO maintains that it is following all relevant activities of allies and international partners who are also developing new generation aircraft. In its close ties with the United States Department of Defense, the RCO seeks to keep Mosquito's capabilities interoperable and effective.

Team Players

Team Mosquito is led by Spirit AeroSystems Belfast, teamed with Northrop-Grumman (UK) and unmanned specialist Intrepid Minds. The selection of Spirit is seen by some as an unusual

"Delivering the Mosquito sales pitch will require high-performance."

choice given its Belfast plant's specialisation in manufacturing composite aerostructures and not the design and manufacture of aircraft as is the case for the Mosquito. The company states it [the entire company] is one of the world's largest tier-one manufacturers and suppliers of aerostructures, which applies research and emerging technologies in designing, fabricating, assembling, and integrating components and structures for premier commercial and defence aerospace programmes. The author asked the RCO how the company had justified its position to lead a team whose objective is to design and build a jet-powered unmanned air vehicle? In response, the RCO said: "Our overall assessment against the Mosquito's goals to deliver maximum UK learning and demonstrate UK combat air through design, build, manufacture and flight test, determined Spirit's proposal as offering the best value for money, in accordance with the pre-defined evaluation criteria."

As a team player, Northrop Grumman is reportedly providing its advanced mission management and airborne communication node technologies to enable seamless human-machine collaboration and cooperative mission management across distributed manned and unmanned assets. When asked what those technologies enable the Mosquito air vehicle to do, the RCO referred to a December 21, 2020 Northrop Grumman press release about the first flight of an RQ-4 Global Hawk with a modernised ground control station featuring open architecture design, a new suite of operating software and new console displays.

One claim made by Team Mosquito is that the project will deliver dramatic cost reduction and development timelines. These pledges are made at the outset of most modern weapon system programmes and are certainly not unique to UK defence. When asked to provide ➲

This image depicts a Mosquito unmanned air vehicle flying in formation with a UK F-35B in the loyal-wingman role. Spirit AeroSystems

examples of how such pledges will be realised the RCO replied: "The project specifically looks to understand the value of technologies and methodologies across the system life-cycle. Ones that can offer substantial reductions in traditional cost (by a factor of ten) and development timelines (by a factor of five) in comparison to modern manned combat aircraft such as Typhoon."

Details of specific project applications of such technologies are limited for commercial sensitivities but might include:

- Use of model-based and synthetic design and engineering environments.
- Robotic manufacture and assembly, novel materials, and structures.
- Modular open-systems architectures and modern software development practices.
- New methods for safe certification.
- Different operational deployment and support concepts.

In addition to Spirit AeroSystems, Northrop Grumman (UK) and Intrepid Minds, Team Mosquito reportedly comprises other innovative partners from across the UK, but the RCO was not prepared to provide names or examples of the types of engineering and aerospace disciplines involved.

Air Vehicle and Its Systems

Based on the artist impressions released of the future Mosquito air vehicle, it's clearly an aircraft designed with low-observable characteristics and may well be fielded as an attritable system: one that trades reliability and maintenance for being low-cost, reusable and eventually expendable. The US Air Force defines an attritable unmanned aircraft as one with a per unit cost between $2m and $20m.

Inclusion of low observable technologies into the design dictates that Team Mosquito will have to integrate secure communications on to the stealthy jet. During flight test, based on the air vehicle's configuration shown in the artist impressions, Team Mosquito will have to demonstrate the air vehicle's low radar cross-section, its ability to avoid shoot-down by either a surface-to-air or an air-to-air missile in contested airspace, and autonomous operation in a combat zone, which lies at the heart of Mosquito's eventual loyal-wingman role.

"The Mosquito programme is a UK national project under FCAS T1."

The RCO confirmrd that the artist impressions released provide good representation of the nascent Mosquito technology demonstrator air vehicle's eventual design.

Mosquito is a software driven system, so software integration and lab testing using hardware-in-the-loop test benches, and simulation testing using detailed models will be a big part of Phase 2.

Given its limited flight-test programme, it's likely that expansion of the air vehicle's flight envelope will be relatively limited but will have to include validation of its flight controls and subsystems. Unlikely to be flight-tested in UK airspace, the Mosquito tech demonstrator might be test-flown at the Royal Australian Air Force Woomera range complex in South Australia, as was the Taranis.

Mosquito's sales pitch refers to its eventual operational capability to shoot down adversary fighter aircraft. This places a high-performance requirement on the air vehicle's design, configuration, powerplant and performance. Traditionally, unmanned air vehicles have not been designed to fly at high airspeeds and with high-manoeuvrability. Meeting the air-to-air capability will require co-operative targeting, engagement and missile launch authorisation provided by a manned fighter or its own radar and missile launch logic. Carriage of air-to-air missiles is not a standard requirement for unmanned air vehicles, but the US Air Force recently demonstrated carriage of an AIM-9X Sidewinder on an MQ-9A Reaper.

Similarly, meeting the Mosquito's eventual front line objective to fly with Typhoon and F-35 fighters implies that its engine will need high subsonic airspeed performance capability. Based on the perceived size of the Mosquito air vehicle, it's probable that a single engine, originally developed for a business jet, might power the aircraft. No details were given about the type of engine to be used, or the manufacturer.

Another claim made by Team Mosquito refers to the air vehicle as a revolutionary capability. This seems slightly ambiguous given that Australia and the United States are already flying their first loyal-wingman air vehicles. Australia is operating an air vehicle built by Boeing and referred to as the Loyal Wingman, while the United States has already completed a series of test flights with its rail-launched XQ-58A Valkyrie. The RCO provided no response to the question asked by the author.

Official government information states that Project Mosquito is using game-changing research and development, but the RCO was not prepared to provide any examples.

An ability to fly as a loyal wingman with and in support of Typhoons and F-35s means a Mosquito air vehicle will function as an offboard sensor system or an offboard weapon system or a combination of the two. Such capability will require high-level control from one of two known sources: either a pilot in a manned fighter or a ground-based operator. In the future, autonomic operation controlled by AI is likely.

A group of Mosquitos will be linked to a secure network. This will enable all weapon systems on the network to have access to the information gathered by the Mosquitos, and with the required permission authorised, any aircraft on the network could in theory take control of and fly at least one Mosquito.

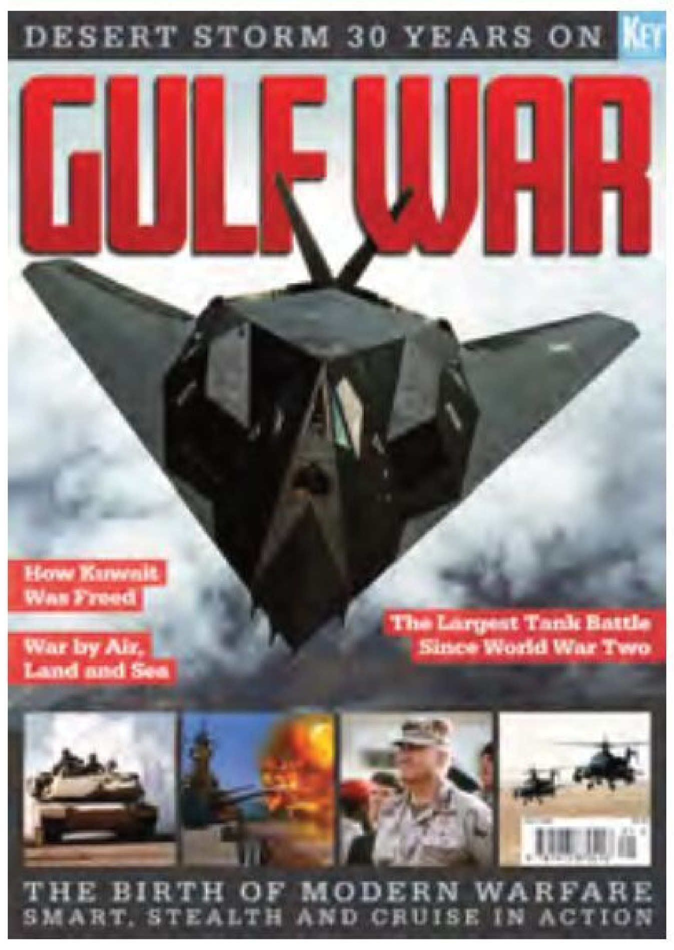
The RAF occasionally refers to swarming drones as an operational concept. Based on US doctrine, the term swarm refers to 20 or more drones. If the RAF is considering use of swarm-sized drone formations, the nascent Mosquito may eventually be designed to operate in such-sized tactical groups. This would provide commanders with a distributed capability, such that if one aircraft is shot down or disabled, overall capacity is not lost because the group's mass determines the ability to conduct the mission.

AVIATION SPECIALS

ESSENTIAL READING FROM KEY PUBLISHING

SUPER CARRIERS
Aircraft Carriers of 21st Century

£8.99 inc **FREE** P&P*



THE GULF WAR
30th anniversary special looking backat the operations that still echo in global politics today.

£8.99 inc **FREE** P&P*

SPACE
60 years of Human Space Flight

£9.99 inc **FREE** P&P*

C-130 HERCULES
This much-anticipated special publication covers many of the military versions.

£8.99 inc **FREE** P&P*

SPY PLANES
Conducting Covert, Clandestine Reconnaissance

£8.99 inc **FREE** P&P*

AFOTW PACIFIC ASIA
Air power analysis and profiles from the Pacific Asia region.

£8.99 inc **FREE** P&P*

B-52 STRATOFORTRESS
Commemorating almost 70 years of America's first truly strategic bomber.

£8.99 inc **FREE** P&P*

RAF AIR CAMPAIGNS
The main air campaigns of the RAF over the past 30 years.

£8.99 inc **FREE** P&P*

AVIATION SPECIALS

ESSENTIAL reading from the teams behind your **FAVOURITE** magazines

HOW TO ORDER

VISIT shop.keypublishing.com/specials

OR

PHONE
UK: 01780 480404
ROW: (+44)1780 480404

*Prices correct at time of going to press. Free 2nd class P&P on all UK & BFPO orders. Overseas charges apply. Postage charges vary depending on total order value.

FREE Aviation Specials App

Simply download to purchase digital versions of your favourite specials in one handy place! Once you have the app, you will be able to download new, out of print or archive specials for less than the cover price!

IN APP ISSUES from £6.99

205/21


WAR THUNDER
New? GET YOUR FREE BONUS
Experience the Battle of Britain yourself in War Thunder!
PLAY NOW FOR FREE
WARTHUNDER.COM/FLY
Windows
STEAM
Mac
oculus
VIVE
PS4
XBOX ONE
PS5
XBOX SERIES X|S
Gaijin entertainment
© 2009—2018 by Gaijin Entertainment. All rights reserved.
12
www.pegi.info