Stepping down the nuclear ladder
Options for UK nuclear weapons policy

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The Cruise Missile Option for Future SSBN/SSGN or Astute SSN Submarines

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The British currently operate the *Tomahawk* Cruise Missile (Tomahawk Land Attack Missile - TLAM), manufactured by the United States, aboard the *Swiftsure*, *Trafalgar* and new *Astute* class SSNs. They also operate four *Vanguard* class SSBNs carrying *Trident D-5* ballistic missiles armed with multiple nuclear warheads. An underexplored question in the Trident renewal debate in Britain has been whether Cruise Missiles can be used as a submarine-based minimum deterrent. This article will explore current Cruise Missile performance and operations and look to future technological developments to invite a more considered debate concerning the Cruise option than has hitherto been seen.

1. The Tomahawk

There are a number of variants of the Tomahawk and they have a maximum range of between 1,250 and 2,500km from a sea-based platform and have been used in a range of conflicts for the past fifteen years (see Table 1). They are subsonic with a maximum speed of 550mph (0.98 mach) and at their maximum range means they can take between two and three hours to reach their target. Naturally, vessels carrying Cruise Missiles need to be within range of potential targets in order to conduct operations. As a result of these limitations the US Navy (and other states[1]) have looked to examine the possibility of extending the range and speed of next generation Cruise Missiles. This would both reduce the time-to-target as well as increase the operating range of the platform which decreases

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* This article is based on work conducted by the author for Lord Owen for his forthcoming book 'Nuclear Paper' to be published by Liverpool University Press.

[1] Information on Cruise Missiles from other states can be found in Andrew Feickert, Cruise Missile Proliferation, *CRS Report for Congress*, 28 July 2005. Available from http://fas.org/sgp/crs/nuke/RS21252.pdf, retrieved 27 April 2009.

potential vulnerabilities by providing greater sea-room in which to operate. This greatly decreases any risk of interdiction both of the platform and the missile.

Table 1: Current US Cruise Missiles

Range: Block II TLAM-A – 1350 nautical miles (1500 statute miles, 2500 km)
Block III TLAM-C - 900 nautical miles (1000 statute miles, 1600 km)
Block III TLAM-D - 700 nautical miles (800 statute miles, 1250 km
Block IV TLAM-E - 900 nautical miles (1000 statute miles, 1600 km)
Guidance System: Block II TLAM-A – Inertial Navigation System (INS), TErrain COntour Matching (TERCOM), Block III TLAM-C, D & Block IV TLAM-E – INS, TERCOM, Scene-Mapping Area Correlator (DSMAC), and Global Positioning System (GPS).[2]

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The Block III version, which entered service in 1993, added a capability for more precise satellite navigation than through the TERCOM guidance system alone by use of the U.S. Global Positioning System (GPS). Furthermore this improved the time of arrival on target, contained an improved warhead but, according to the U.S. Navy's Fact Sheet, reduced the range to 1,600km (1,000 statute miles). Although reduced range would have been a negative side effect, U.S. theatre commanders preferred the Block III version to the older and less accurate Block II. For example this resolved problems occurring from poor TERCOM fixes in flat or unremarkable terrain which are characteristics of major Middle Eastern littoral environments. As a consequence the Navy testified to the Senate Armed Services Committee in March 1999 that for TLAMs used in recent military operations, about 90% have been the Block III variant.[3]

2. Cruise Missile operations

[2] http://www.navy.mil/navydata/fact_display.asp?cid=2200&tid=1300&ct=2, retrieved, 21 April 2009.

[3] Ronald O'Rourke, Cruise Missile Inventories and NATO Attacks on Yugoslavia: Background Information, *Congressional Research Service*, 20 April 1999.

During the 1991 Gulf War Cruise Missiles were used extensively to attack Iraqi air defence facilities, their command, control and communications infrastructure and electrical power grid in Operation *Desert Storm*. Tomahawks and Conventional Air Launched Cruise Missiles (CALCMs) fired from submarines and surface ships were targeted against heavily defended targets deep in Iraq without putting aircraft and pilots in danger. Most were fired early on in Desert Storm. According to their own figures the United States Navy launched a total of 297 Tomahawks with 288 reaching their target demonstrating a 95% success rate.[4] As Anthony H. Cordesman of the Center for Strategic and International Studies indicates "Many of our strategic cruise missile strikes and air sorties had considerable tactical success, particularly in striking major fixed command and control facilities, bridges and major road facilities, and POL facilities".[5] They were navigated enroute by their TERCOM guidance system switching to optical DSMAC (Digital Scene Matching Area Correlator) to produce a high Circular Error Probability (CEP) in their terminal phase to target which could be as little as 3 metres.

Cruise Missiles were also fired from the Mediterranean Sea during Desert Storm whilst it appears that attacks in 2003 were from air-launched Cruise Missiles flying from aircraft carriers stationed in the Mediterranean.[6] The generation of Cruise Missiles used in the Gulf War and in subsequent operations through to 1993 still have deficiencies when it comes to targeting. They could only be used against fixed targets with the data uploaded to the missile prior to launch. As a result targets of opportunity could not be engaged which, in the current (and future) strategic environment, are key factors for politico-military engagements.

The United States currently operates four submarines designated as SSGNs (Ship Submersible Guided [Missile] Nuclear). These were previously SSBNs (Ship Submersible Ballistic Nuclear) converted to Cruise Missile use, primarily the Tomahawk, and for the covert deployment of Special Operations Forces (SOF), following the Strategic Arms Reduction Treaties (START I and II) of 1992/3.[7] SSN's (Ship Submersible Nuclear) can also carry Cruise Missiles and SOF but their mission profile is of a more general character.

Nuclear targeting has to take into account the 'Battle Ahead'. This is advance knowledge of the operating environment and in particular what defences might degrade the attack. Elements of this have long been part of conventional strategy. The second is exclusive to a nuclear environment and is the problem of attrition. Nuclear explosions produce a range of

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[4] http://www.fas.org/man/dod-101/sys/smart/bgm-109.htm, retrieved 27 April 2009.

[5] http://www.csis.org/media/csis/pubs/dflessons21599.pdf, p. 9, retrieved 26 April 2009.

[6] http://www.sci.fi/~fta/cruise.htm, retrieved 30 April 2009 and http://www.pbs.org/newshour/updates/baghdad_03-20-03.html, retrieved 30 April 2009.

[7] START I is due for renewal or replacement by December 2009. Russia withdrew from START II in 2002, a day after the United States withdrew from the 1972 ABM Treaty.

effects including the blast and heat commonly associated with a nuclear detonation and an Electro Magnetic Pulse (EMP).

However, they are more vulnerable to the invisible portions of the energy spectrum, in particular X-rays which can be released by a defensive nuclear explosion both inside and outside the atmosphere by an anti-ballistic missile. It has been understood from the 1960s that: “Pulsed X-rays can produce such violent reactions within materials that they could turn out to be the most hazardous nuclear threat for missiles and satellites in space…[such as] a violent “boiling” within a material” exploding “from the inside, throwing off high-velocity fragments”.[8] Over 75% of a nuclear explosion comes in the form of thermal radiation with a large proportion in the form of X-rays and:

> the range at which a nuclear weapon can produce these destructive thermal effects within a missile varies according to the altitude at which it is explode. At lower altitudes the soft X-rays…are absorbed by the surrounding atmosphere…at altitudes above 90 mi. there is no longer enough atmosphere to absorb the X-rays. They spread their energy over thousands of miles…reducing the severity of the anti-missile guidance problem. [However, the] Exact range at which the X-ray effect is damaging depends on the yield of the device and how energy is partitioned.[9]

This is still a danger to Inter Continental Ballistic Missiles (ICBMs) but might potentially apply even to hypersonic Cruise Missiles which could need to enter and exit the upper atmosphere to arrive at their targets. Depending on their attack profile they could be vulnerable to a pre-emptive detonation but given their speed and range the warning time would be so short that even an advanced nuclear weapons state such as Russia would have virtually no time to respond. Less mature nuclear weapons states, or a non-nuclear weapons state, would have no defence. Their attack profile could also be adjusted to minimise the chances of interdiction by defences.

3. Hypersonic Technology

Hypersonic refers to speeds exceeding Mach 5 and are achieved by two types of jet engine. The first is the Ramjet. The Ramjet works by utilising the forward movement of the engine to help produce thrust. As speed increases the atmosphere in front of the platform (be it an aircraft or missile) is compressed whilst the air behind is of lower pressure. The high pressure is used by the Ramjet to force oxygen through its chambers where it is ignited with fuel, such as hydrocarbon, which is then passed through a nozzle to produce thrust from the exhaust. Drag is (by its nature) a limiting factor but at speeds above Mach 2-3 the ramjet is

[8] Rex Pay, ‘New Effort Aimed at X-Ray Protection’, *Technology Week*, 2 January 1967.

[9] Pay, ‘New Effort Aimed at X-Ray Protection’, *Technology Week*, 2 January 1967.

self-sustaining. Ramjets can either be liquid or solid fuelled with the choice being decided by the platform requirements. The platform, and the requirements of the Ramjet, are optimised by designing them for a specific altitude and speed. However at speeds above Mach 6 current Ramjets suffer a degradation of performance as the airflow is decelerated to subsonic speeds to allow for combustion which in turn produces heating which needs to be dissipated. This sets an upper performance limit.

The second type is a Scramjet. Scramjets (Supersonic Combustion Ramjet) work in a similar way to conventional Ramjets but use supersonic combustion to fully exploit the efficiency of the combustion process. In common with conventional Ramjets they have either no moving parts or only a small number with no fast moving turbine. This reduces the internal heating problem of conventional Ramjets. The oxygen required by the engine to combust flows from the atmosphere passing through the vehicle, instead of from internal fuel supplies. This reduces weight and as a result the craft can be made smaller, lighter and faster and can be defined as an 'air breathing' engine as a result. Air breathing vehicles rely on aerodynamic forces rather than on pure rocket thrust and as a result have greater manoeuvrability

There have already been several demonstrations of scramjet technology providing a 'proof of concept'. On August 16, 2002, the University of Queensland in Australia completed the first successful flight of a scramjet vehicle. Meanwhile between March and November 2004 NASA's *Hyper-X* program produced a 12-foot long scramjet-powered research vehicle - *X-43A*[10] - flown aboard modified Pegasus rockets dropped by a *B-52* aircraft. It was launched to an altitude of over 90,000 feet, where the X-43A was released and where it flew under its own power to Mach 9.6. NASA believes this technology could be developed for speeds of up to Mach 15. As NASA's fact sheet of the Hyper-X programme states:

The eight-year, approximately $230 million NASA Hyper-X program was a high-risk, high-payoff research program. It undertook challenges never before attempted. No vehicle powered by an air-breathing engine had ever flown at hypersonic speeds before the successful March 2004 flight. In addition, the rocket boost and subsequent separation from the rocket to get to the scramjet test condition had complex elements that had to work properly for mission success. Careful analyses and design were applied to reduce risks to acceptable levels; even so, some level of residual risk was inherent to the program.

Hyper-X research began with conceptual design and wind tunnel work in 1996. Three unpiloted X-43A research aircraft were built. Each of the 12-foot-long, 5-foot-wide lifting body vehicles was designed to fly once and not be recovered. They are identical in appearance, but engineered with slight differences that simulate variable engine geometry, generally a function of Mach number. The first and second vehicles were designed to fly at Mach 7 and the third at Mach 10. At these speeds, the shape of the vehicle forebody served

[10] Detailed information on the X-43A can be found at http://www.globalsecurity.org/space/systems/x-43.htm, retrieved 22 April 2009.

the same purpose as pistons in a car, compressing the air as fuel is injected for combustion. Gaseous hydrogen fueled the X-43A.[11]

Scramjet technology has applications beyond NASA's space programmes. It has military applications in terms of aircraft development as well as next generation Cruise Missiles. One such programme is the *X-51A WaveRider*, developed by Boeing. This can fly five times faster than the Tomahawk on current specifications. If launched from the Arabian Sea it would take only twenty minutes to reach eastern Afghanistan. It is currently being designed only to carry out conventional missions and it is not known whether the vehicle can be engineered to house a nuclear warhead. However, given that the current generation of Cruise Missiles are dual-capable (of both a conventional and nuclear role) it is reasonable to suggest that it will be possible to fit a nuclear warhead inside with modifications. The customers are the U.S. Air Force Research Laboratory (AFRL) and the Defense Advanced Research Projects Agency (DARPA), with support from NASA and Pratt & Whitney Rocketdyne.

A press release by Boeing in June 2007 indicates:

> During the successful firing of the Pratt & Whitney X-1 demonstrator engine, test engineers used a Full Authority Digital Engine Controller to simulate flight conditions at Mach 5 air speed. Test of the hydrocarbon-fueled scramjet engine also demonstrated a closed-loop thermal management system that cools engine hardware and regulates fuel for the engine's combustor. The X-1 is the first of two ground test engines proposed for the program. The successful completion of the CDR and X-1 ground demonstration indicates that the X-51A program is on track to proceed with its first flight tests in 2009. "The CDR and engine test are key validation points for the X-51A program," said George Muellner, president of Boeing Advanced Systems. "The X-51A is a remarkable system that will answer many questions necessary for the development of future hypersonic propulsion vehicles that can be used for delivering payloads to space as well as for atmospheric flight applications." "These successes are critical for the development of the X-51A," said Charlie Brink, U.S. Air Force Research Laboratory X-51A program manager. "It also marks the first time that a scramjet engine was tested in its simulated 'full flight' propulsion configuration -- the Boeing-designed full vehicle fore-body inlet and nozzle."[12]

There are associated problems with hypersonic cruise should it be considered as a viable nuclear option for the UK. The X-51 is being designed with a requirement for the need for Prompt Global Strike – the ability through real-time intelligence to be able to hit anywhere

[11] http://www.nasa.gov/centers/dryden/news/FactSheets/FS-040-DFRC.html, retrieved 21 April 2009.
[12] http://www.boeing.com/news/releases/2007/q2/070601a_nr.html, retrieved 22 April 2009.

on the globe. It is estimated it might take ten years to develop the WaveRider into a deployable system.[13] In the mutated security environment after September 11 2001, and the increasing requirement to strike hard and sure against fleeting terrorist targets, the need for a range of options beyond the current range of systems is clear. However, should Britain seek to examine this particular option as a nuclear delivery system then fitting a nuclear warhead on board entails a series of political and strategic problems.

Firstly would the United States be prepared to sanction the sale of such an advanced system or allow Britain to participate in the development programme? Secondly, as with proposals for a conventionally armed Trident, it is explicitly designed to carry a conventional payload and a potential adversary would not know whether it was one of Britain's nuclear armed versions or one from the United States with a conventional warhead. Depending on the flight path and target this could send the wrong signals to a state; this would be especially dangerous if that state was nuclear armed or had a nuclear security guarantee.

There is however evidence that Britain and the United States are already looking in the direction of a joint Cruise Missile development programme. In May 2002 Janes, the respected defence and security company, reported that:

> The USA, joined it hopes shortly by the UK, plans to begin a research and development programme to look at a new land-attack supersonic cruise missile that could help strike time-critical targets and ones buried underground. The programme, an advanced concept technology demonstration being sponsored by the US Defense Threat Reduction Agency and the US Navy, will explore development of a cruise missile capable of carrying a 200 lb (90.7kg) payload at least 400nm and preferably 600nm. The missile would have a speed of M3.5 with a goal of M4.5 and a circular error of probability accuracy of 3m.[14]

Given that this report dates from 2002 it is possible, perhaps likely, that this research and development programme has evolved into the hypersonic programme described above. Again Janes provides a valuable insight:

> NASA, the armed services and DARPA are working together as never before. NASA's alignment with the USAF and National Reconnaissance Office on space research is being replicated in air-vehicle programs, particularly when they have military and commercial applications. The latest batch of NASA Revolutionary Concepts (Revcon) programs include one project which meshes closely with a

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[13] http://www.popularmechanics.com/technology/military_law/4203874.html?page=3, retrieved 19 April 2009.

[14] http://www.janes.com/defence/air_forces/news/jdw/jdw020507_1_n.shtml, retrieved 20 April 2009.

> DARPA effort, and another which is based on an operational vehicle concept devised by the USAF Research Laboratory.[15]

In February 2007 Janes also reported that:

> Lockheed Martin Missiles and Fire Control has broken cover on studies for a next generation very long range cruise missile for the USAF and US Navy. Lockheed Martin's concept is known as Cruise Missile Extended Range (Cruise Missile XR) and gives an indication where the thinking of US rivals - Raytheon and Boeing - may also be headed. The weapon will be a 5,000 lb (2,268 kg) class missile (incorporating a 2,000 lb warhead) with a range in excess of 1,000 n miles (1,852 km). It will be fully datalinked and capable of 'seekerless precision' (potentially combining enhanced GPS navigation with networked third-party targeting data). The warhead (ideally a multi-mode unit) will be effective against hardened buried targets with the potential to fit precision-guided submunitions if ever required.
>
> What the US is seeking is a new cruise missile system with more or less the same reach as today's Tomahawk weapons, but with much increased accuracy and a significantly larger payload. The Cruise Missile XR has been designed for carriage by tactical fighters, large bombers or even submarines. Other similar designs will emerge from the shadows sooner or later as the US considers its long-range strike options for the 2015-2020 timeframe.[16]

Additional information from the journal *Aviation Week* from March 2009 makes this potential more explicit:

> Unlike NASA's pioneering X-43A Hyper-X, which flew on gaseous hydrogen for a 10-sec. flight at Mach 9.6 in 2004, the X-51A is aimed at proving the longer-endurance, weapon-like capability of a hydrocarbon-fueled scramjet. Carrying around 270 lb. (45 gal.) of JP7 fuel, the 168-in.-long cruiser is expected to fly for approximately 300 sec. at full power until the fuel runs out. Optimized for a missile application, a modular version of the existing X-51A would travel around "600 mi.

[15] http://www.janes.com/defence/air_forces/news/idr/idr000704_1_n.shtml, retrieved 21 April 2009.
[16] http://www.janes.com/defence/air_forces/news/jalw/jalw070219_1_n.shtml, retrieved 20 April 2009.

in 10 min.--well in excess of any conventional cruise missile," says Charles Brink, AFRL X-51A program manager.[17]

AFRL, U.S. Air Combat Command and Pacific Command are also evaluating long-range strike weapon options through a project codenamed *Trespass/Trespals*. The former is aimed explicitly at air-strike weapons with the latter focused on a broader combination of air, land and sea-strike operations. Phase I of these studies, including other hypersonic projects like the U.S. Navy's *HyFly* and *RATTLRS* (revolutionary approach to time-critical long-range strike), are expected to be completed by the late summer of 2009. However a decision on whether to pursue a scramjet-based joint concept technology demonstrator is likely be deferred until late 2010.[18]

Moreover a March 2009 report in *Flight International* stated that the USAF has set a deadline of 27 October 2009 for the first flight test of the WaveRider "but there is already talk of expanding the rigidly controlled hypersonic test programme".[19] There are already plans to increase the flight trials from four to six partly to allow for a margin of error but also to possibly explore the use of the X-51A's GPS antenna for a demonstration of waypoint guidance in the terminal phase. This appears to have firm military implications but there are well-known risks in expanding the operational requirements of leading-edge technologies such as the WaveRider. Furthermore at the moment the use of GPS is limited to speeds below Mach 10 when plasma formation around the platform makes communications difficult.[20] Follow-on flight tests are scheduled for 15 January 2010, mid-February and again in mid-March. There are also plans to fund an X-51B prototype.

5. Conclusion

More generally, and relevant to any UK decision, on future Cruise Missiles in a submarine platform is borne out by a Congressional Research Service Report from April 2008 which stated:

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17 http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/SCRAM033109.xml, retrieved 22 April 2009.

18 *Ibid.*

19 http://www.flightglobal.com/articles/2009/03/26/324373/afrl-mulls-adding-scope-to-x-51a-waverider-hypersonic.html, retrieved 22 April 2009.

20 http://www.aviationweek.com/aw/generic/story_channel.jsp?channel=defense&id=news/SCRAM033109.xml, retrieved 22 April 2009.

Navy and industry officials, Members of Congress, and other observers are concerned that unless a major submarine-design project is begun soon, the submarine design and engineering base will begin to atrophy through the departure of experienced personnel. Rebuilding an atrophied submarine design and engineering base, Navy and industry officials believe, could be time-consuming, adding time and cost to the task of the next submarine-design effort, whenever it might begin. Concern about this possibility among some Navy and industry officials was strengthened by the UK's difficulties a few years ago in designing its new Astute class SSN. The UK submarine design and engineering base atrophied for lack of work, and the subsequent Astute-class design effort experienced considerable delays and cost overruns. Submarine designers and engineers from GD/EB were assigned to the Astute-class project to help the UK overcome these problems.[21]

If the United States can convert SSBNs (Ship Submersible Ballistic Nuclear) to Cruise Missile operations then the United Kingdom, with a new build of submarines for deterrent purposes, would find it easier to design from scratch a suitable platform or modify the Astute class. This could also have an added benefit to the United States for their next generation SSGNs with the potential for a significant trade of design information, estimates of service life and experience of operational service.

However, as technologies advance they become more complicated and more can go wrong impeding performance. Moreover advanced systems are based on the integration of multiple technologies. State-of-the-art technologies in particular, with very limited testing or operating experience, mean there is increased risk that something can and will go wrong. It also frequently leads to delays and cost over runs. One example of this is the US Joint Strike Fighter (JSF) programme in which Britain is a partner nation.[22]

[21] Ronald O'Rourke, 'Navy Attack Submarine Procurement', *Congressional Research Service*, 8 April 2008. This is available from http://assets.opencrs.com/rpts/RL32418_20080408.pdf.

[22] http://www.defenseindustrydaily.com/f-35-jsf-hit-by-serious-design-problems-04311/, retrieved 27 April 2009.