

The ASTUTE CLASS Submarines



HMS Astute arrives at Faslane

BARROW BUILT

THE ASTUTE CLASS ATTACK SUBMARINES

Vickers along with other great armament manufacturers in both the shipbuilding and aircraft industries have finally gone but the tradition of building and designing Royal Navy submarines still continues at Barrow in Furness. The old Vickers yard is now being run by BAE Systems.

The *Astute* Class of submarines is the planned replacement for the *Swiftsure* and *Trafalgar* Class SSNs (Sub-Surface Nuclear), and was to start entering service from the middle of this decade. Intended as a relatively low risk low-cost approach to providing a next generation nuclear submarine for the Royal Navy, the *Astute* programme has unfortunately become one of the most troubled UK defence projects since the 1980's, matched only by the Nimrod 2000 programme. Due to serious delays and problems encountered by the prime contractor BAE Systems, the first unit, HMS *Astute*, is now not expected to be delivered until November 2008 and will become fully operational in 2009 - four years later than forecast when ordered. Up to seven *Astute*'s will be procured by about 2022, and it is possible that a modified variant may also eventually replace the *Vanguard* class SSBN's. Unlike every previous class of British nuclear submarine since HMS *Dreadnought* in the early 1960's, a very significant foreign (American) content has been accepted in the design work after the failure of BAE Systems to complete the task in-house.

Nuclear powered hunter-killer submarines are at the heart of the Royal Navy force structure. They have a wide variety of roles and, although conceived towards the end of the cold war, are proving extremely adaptable to a revised employment within the new world order. The new *Astute* class will [eventually!] contribute fully to the Maritime Contribution to Joint Operations (MCJO), including covert delivery of Special Forces and close support of amphibious task groups, as well as conducting the more traditional roles of support to the nuclear deterrent and autonomous operations against maritime forces. They will be capable of deployment either as an integrated layer of defence within a task force or independently in advance of such a force.

The *Astute* project is managed by the MOD's Defence Equipment and Support (DE&S) Attack Submarine (ASM) Integrated Project Team (IPT).

Early History

In the mid 1980's it was expected that the *Trafalgar* class of "hunter killer" submarines would be succeeded by an all-new class, and in 1987 VSEL (subsequently bought by GEC-Marconi who in turn were bought by British Aerospace, now BAE Systems) was awarded a contract to carry out design work for the "W class" (SSN20), with the aim of ordering the first of class in 1990(!). With the Trident missile armed *Vanguard* Class SSBN's being given higher priority, and many other pressures on the defence budget, no orders were placed. Instead, in June 1991, approval to proceed with a programme of studies at an estimated cost of £6m (1991/92 prices) to define a Batch 2 *Trafalgar* Class Boat (now known as the *Astute* Class) was given.

In August 1991 VSEL were invited to tender for a design "based on the development, with minimum change, of the existing *Trafalgar* class". The first order was then expected in 1994 with an in-service date of 2001. This programme of studies led to the issue of an Invitation to Tender for the design and build of an initial batch of three *Astute* Class SSNs and a further approval of £2m (1992/93 prices) for contractor and Defence Research Agency support to MOD during the tendering exercise in 1994.

Invitations to tender for the first three submarines of the class were issued in July 1994, with competitive bids received in June 1995 from GEC Marconi and Vickers Shipbuilding and Engineering Limited. As a result of concerns over the overall affordability of the programme, Minister (Defence Procurement) and the Treasury approved a further £23.5m (at 1993/94 prices) for risk reduction studies to be undertaken in parallel with the formal bid phase of the project. To maintain an effective competition, contracts for the risk reduction work were awarded to both bidders.

GEC-Marconi (now BAE SYSTEMS *Astute* Class Ltd) was identified as the MOD's preferred bidder in December 1995. Following protracted negotiations, using the policy of No Acceptable Price No Contract (NAPNOC), a prime contract was placed and announced on 17 March 1997. The contract put in place the first whole boat, Prime Contract for UK nuclear powered submarines. The Prime Contract is for the design, build, and initial support of three submarines. The support task will be undertaken by the Prime Contractor for a total of eight submarine years (4.5 calendar years). The Prime Contract required an integrated Tactical Weapons System with a performance at least as good as the *Swiftsure* & *Trafalgar* (S&T) Update Final Phase. As a risk reduction measure, the former

Departmental contracts for the Final Phase of the S&T Update have since been notated into the Prime Contract for Astute.

The successful outcome of these studies led to EAC approval (the equivalent of Main Gate) in March 1997 to place a contract for the design, build and initial support of three Astute Class submarines with GEC Marconi, now BAE SYSTEMS.

The 1998 *Strategic Defence Review* decided that the SSN force level was to be reduced from the current 12 boats (itself a reduction from 15 at the start of the decade) to 10, and therefore two of the five remaining *Swiftsure* Class would not be replaced after all, but the additional two Astute units would still be ordered in about 2002 in order to replace early *Trafalgar* Class units and maintain the new force level. In August 2000 a sixth Astute was apparently provisionally added to the programme because of the ever lengthening financially driven delays to the FASM project, and the major and expensive serviceability problems being encountered with the older *Trafalgar* Class submarines - the third of which, HMS *Talent*, will be taken out of service in 2011, well before the first FASM could possibly enter service.

The Astute's will be an improved and enlarged version of the *Trafalgar* Class, and were originally intended to replace the remaining *Swiftsure* Class which were launched between 1973 and 1977 and are now approaching the end of their operational life. With the effective cancellation of the FASM project and slow progress on the MUFC project, the Astute's will now eventually replace the *Trafalgar* Class as well. The order for the first three Astute units (with an option for a further two) was placed with GEC-Marconi (now part of BAE Systems) on 17th March 1997 and the value of the contract was put at nearly £2 billion (\$3.2 billion), including a *Swiftsure* and *Trafalgar* Final Phase Integration Task and Contractor Logistic Support for the first 4.5 years from the in-service date. In January 2001 the MoD stated that the cost of each of the first three boats would be around £745m. The total programme cost of the first three units was expected (November 2001, Major Projects Report 2001) to be £2,698m. On 19 February 2003 it was announced that in the face of disastrous cost overruns that the government had agreed to increase its funding to BAE Systems by around £430m, while BAE would also contribute (or rather write-off) £250m. Under the terms of the renegotiated contract, the Design and Development phase of the programme is now separated from the Production phase. Design and Development will be completed under new Target Cost Incentive Fee (TCIF) arrangements. BAE Systems and the MoD have established new Target Costs and Fee levels for the programmes, up to the Target Cost level, cost saving will be shared by the MOD and BAE as an additional Incentive Fee for BAE. Any cost overruns above the Target Cost will be shared by the customer and the company, up to the maximum level established for the company by the agreement. Including government supplied equipment (e.g. sonars and the Tomahawk control system), the out-turn cost of the first three A's now seems set to reach £4 billion.

The Prime Contractor is BAE SYSTEMS Astute Class Limited, based at Frimley in Surrey. The boats are actually being built at the BAE Systems Marine (VSEL) shipyard in Barrow-in-Furness, England. First steel for HMS Astute was cut in October 1999 but the keel (actually the first hull section) was not formally laid down until 31 January 2001.

Fabrication of the second submarine in the class, HMS *Ambush*, started in August 2001, although progress was very slow due to the design problems being experienced with HMS *Astute*, all fabrication work on her was suspended in February 2003 (see below), although her ceremonial lay down ceremony was conducted a few months later in October - an act of purely publicity value.

On 31st January 2001 the Defence Procurement Minister, Baroness Symons, stated that "The MOD is considering plans for a second batch of up to three of these [Astute] submarines with a final decision being taken next year." A joint BAE Systems/Defence Procurement Agency team was established to deliver an Astute Second Buy (A2B) proposal by March 2002. This was intended to help inform the MOD's decision - then still planned for mid-2002 - on whether the order should be placed for two or three further submarines. It was expected to lead to the MoD's Main Gate decision soon after, with an award of contract around November of that year.

In May 2001 the FASM project was replaced by the "Maritime Underwater Future Capability" with an expected in-service date of about 2020, but perhaps as late as 2030. This made it seem likely that sufficient Astute's would eventually be ordered to complete the replacement all of the current *Trafalgar* and *Swiftsure* class SSNs, i.e., ten Astute's. Although this was not officially confirmed, *USNI Proceedings* (March 2001 edition) reported that the MoD had decided at the end of 2000 to add a third batch of three Astute's (A3B) to the programme (i.e., for a total of 9 Astute's). Official statements at the time of the 2002 SDR "New Chapter" confirmed that the projected size of the SSN force was now 9.

By mid-2002 it was clear that the Astute programme was in severe difficulties and rather than placing an order the MOD instead informed BAE Systems in November 2002 that the Second Buy

order would not be placed until it was satisfied that the all-to-evident design, engineering and management problems with the project had been overcome.

Newspaper reports in early 2003 stated that due to pressure from the Treasury, the third A2B boat had been dropped and that the order, when finally placed, would again be for two boats - thus by 2015 the SSN force was likely to consist of 5 Astute Class plus the 4 Trafalgar Class boats that have undergone the Final Phase of the S&T Mid-life Update Programme.

On 21 July 2004 it was announced in the Defence Command Paper (Cm 6269): *Delivering Security in a Changing World: Future Capabilities* that the Royal Navy's SSN force would be cut to 8 boats [from 2006], and it was presumed that in the long term these will eventually all be Astute's. However, leaks in early 2005 indicated that the MOD in fact had a requirement for only 7 Astute's, and other sources have since confirmed this same. By Autumn 2005, industry was pressing hard for the final four Astute's to be ordered in one batch, emphasising the industrial and financial advantages this would realise over ordering them in 1's and 2's.

The MOD's *Defence Industrial Strategy* published in December 2005 apparently confirmed the need for up to eight Astute's to be built, with a delivery "drumbeat" of every two years from 2010. But senior MOD officials later hinted that eight was very much a funding permitting target and Equipment Plan 2007 (EP07) apparently included on seven.

During early 2006 it became apparent that there was still a large affordability gap between what the MOD was prepared to pay for additional Astute's and what BAE considered to be a fair "ticker price" for their manufacture after having resolving many of the project's problems at its own expense and with great effort. Only one Astute (Boat Four) was ordered in 2007.

Programme Problems

HMS *Astute* was officially laid down in February 2001, although first steel was cut long before that - in October 1999. By early 2002 all major components and systems for HMS *Astute* had been delivered by sub-contractors to the Barrow yard, and material for HMS *Ambush* was also rapidly accumulating and some fabrication work began. But BAE Systems was unable to disguise from the MOD the increasingly obvious fact that it was making slower progress in the detailed design and in the build up of production than had been anticipated, and that the approved ISD of June 2005 could not now be achieved. BAE blamed the delays on "engineering complexities", although work on HMS *Astute* had also been delayed due to the diversion of skilled workers to the reactivation of the Upholder Class of SSK's for Canada.

The biggest headache came with the computer-aided design tools. The system chosen was CADD5, made by the American software company PTC. Although it was a proven piece of software, it was overwhelmed by the size and complexity of *Astute*. According to BAES's head of the submarine business, Murray Easton: "This was the first submarine designed in a three-dimensional computer model, and there wasn't a system capable of doing it. This has caused us a big delay. We have collaborated with PTC and customised the system extensively, but it is still not capable of doing what we want it to." John Hudson, Engineering Director, said the problems were made worse by a welter of work landing at the same time. As well as winning *Astute*, BAE Systems was awarded contracts for two large amphibious assault ships and a fleet of auxiliary oilers [the Wave Class]. All this happened within 18 months, and at the same time we were changing procurement methods and introducing new computer design technology. The system (the computer design tools) would go to sleep for long periods, or take five minutes to update every time you did anything. That's obviously time-consuming, but it also leads to a loss of concentration on the part of the designer."

On 9 July 2002, Mr Lewis Moonie, Armed Forces Minister, announced in answer to a Parliamentary Question that the first of class, HMS *Astute*, had been due to enter service in June 2005, but "is not now expected to enter service before late 2006, although this date has yet to be agreed with the contractor". It was still hoped at this point that *Astute* would be launched in 2004, be accepted from the contractor (safe operation and start of operational work-up) in June 2005 and be in-service (operationally available) by late 2006, after concluding about 18 months of trials and work-up.

Work now focused on BAE Systems establishing a robust revised programme for *Astute* to which the MOD could agree. But the problems came to a head in late 2002 when the frantic negotiations between BAE and the MoD on *Astute* and *Nimrod*, another problem contract, broke down. In the face of increasingly public statements of dissatisfaction from the MOD over its performance on the *Astute* and *Nimrod* contracts, on 11 December 2002 BAE Systems had no choice but to tell the market about the problems — which had become something of an open secret in the shipbuilding industry in the preceding months. It admitted that "additional issues" had arisen with the *Astute* [and the *Nimrod* MRA.4] contract and that it had "become apparent that there are substantial

schedule and cost implications. The company and the MoD are continuing to discuss the extent to which these two contracts can be modified to the mutual benefit of the MoD and BAE Systems." It also said that BAE Systems' Underwater Systems division was awaiting the award of various contracts; in the meantime, the firm said it was not able to find enough work to keep its staff busy.

As BAE Systems share price collapsed, the MOD and BAE Systems had to choose between renegotiate or cancel. The contract was renegotiated. BAE and the MoD will now share the risk and reward, and Easton, who had quit BAE in October 2002 after only five months as boss of its naval shipyards, was brought back into the fold. Industry insiders said the MoD told BAE that Easton had to come back — a suggestion that the company declined to comment on. Easton himself described his period away from the company as "my little break". His first priority was to "stabilise" the Astute schedule, something he now thinks has been achieved. "We have had a complete design review, with input from American experts, and we are on track for a November 2008 delivery," he said. The Americans in question were from General Dynamics, the company that has built most of the US Navy's nuclear submarines. Some reports have suggested that General Dynamics has been brought in by the MoD in a project-management role, but Easton said it is mainly providing extra resources for the computer design task. General Dynamics has 11 staff at Barrow, with others trained on the computer design system working from America. Easton has also launched an efficiency drive — 20% will be cut from the company's costs in the next 15 months.

In an article published in the *Sunday Times* newspaper in November 2003, managers at Barrow were quoted as saying the Astute Project's problems went all the way back to the initial contract in March 1997:

"We had a contract that frankly was not working," said Murray Easton, MD of BAE Systems' Submarine division. GEC-Marconi, then the Barrow yard's owner, promised to build the submarines for a fixed price. "It was one of a series of what the MoD called napnoc deals — no agreed price, no contract," said Malcolm Christie, Astute Project Director. Barrow was desperate for work. There had been "a significant gap" between the last Trident construction contract and the award of the Astute deal, said Easton, which not only spurred GEC's determination to win the work, but also depleted the ranks of experienced staff. The biggest headache came with the computer-aided design tools. The system chosen was CADD5, made by the American software company PTC. Although it was a proven piece of software, it was overwhelmed by the size and complexity of Astute. "This was the first submarine designed in a three-dimensional computer model, and there wasn't a system capable of doing it. This has caused us a big delay. We have collaborated with PTC and customised the system extensively, but it is still not capable of doing what we want it to," said Easton. John Hudson, engineering director, said the problems were made worse by a welter of work landing at the same time. As well as winning Astute, BAE Systems was awarded contracts for two large amphibious assault ships and a fleet of auxiliary oilers. "All this happened within 18 months, and at the same time we were changing procurement methods and introducing new computer design technology. The system (the computer design tools) would go to sleep for long periods, or take five minutes to update every time you did anything. That's obviously time-consuming, but it also leads to a loss of concentration on the part of the designer," said Hudson.

On 19 February 2003 the MOD and BAE Systems announced that they had reached agreement on the restructuring of the Astute contract. As part of this agreement, all construction has been halted while design issues are resolved, and the first submarine will not enter service until at least 2008 (three years later than planned). The cost of the Astute submarine programme - already running at over £2.5bn - is also to rise by almost £700m.

A BAE Systems press release dated 19 February 2003 stated:

In December 2002, the company announced that additional issues had arisen in relation to these programmes and that it had become apparent that there were substantial schedule and cost implications.

Under the terms of today's agreement, the current contracts for design, development, production and support on each of the two programmes will be revised. These revisions will separate the Design and Development phase of each programme from the Production phase. Design and Development will be completed under new Target Cost Incentive Fee (TCIF) arrangements. Both programmes will be placed on a firm footing for the delivery of the Astute and Nimrod capabilities into service.

BAE SYSTEMS and the MoD have established new Target Costs and Fee levels for both programmes, and have high levels of confidence of delivering the programmes within these new target levels. Up to the Target Cost level, cost saving will be shared by the customer and company as an additional Incentive Fee for the company. Any cost overruns above the Target Cost will be shared by the customer and the company, up to the maximum level established for the company by the

agreement. These new arrangements will place a significant economic incentive on the company to perform. The company has reviewed its project management of these programmes, consistent with today's best practice, and is taking actions based on lessons learned.

Pricing of the Production phase of each programme will be concluded following achievement of sufficient risk mitigation from the Design and Development phase to enable production costs to be established with confidence.

The difficulties in the Astute programme stemmed principally from moving the design of the submarine to a fully electronic CAD (Computer Aided Design) design basis - a process that neither party understood would be as difficult as it has turned out to be.

Production work on the Astute Programme will only be resumed after design maturity has been established. Design and Development, which includes the build of the First of Class, HMS Astute, will be completed under new TCIF arrangements.

Pricing for the production of HMS Ambush and HMS Artful will be established once adequate design maturity has been achieved and progress has been made on the First of Class. In order to maintain progress on the programme, General Dynamics Electric Boat Division (GD) will provide design assistance to reinforce the project team. This will enable the Astute project team to take advantage of lessons GD learned in computer-aided design on major US submarine programmes.

An official government statement was simultaneously made by Defence Procurement Minister Lord Bach:

The original contract was based on a single source supplier, namely GEC-Marconi (which subsequently merged with British Aerospace to form BAE Systems) as the only UK provider of this unique defence capability. We sought to establish a fair price given the economic conditions and agreed joint assumptions on an open book basis at the time of contract signature in March 1997 on how the project would be delivered. These related, in part, to the benefits to be derived from the first comprehensive application of computer aided design (CAD) techniques to UK submarines.

This will deliver significant advantages in the future, but its benefits have proved more difficult to realise on a programme of this complexity than either we or the company had assumed. We now know that the introduction of CAD requires more time and effort than either of us had originally anticipated.

As a result, the Government has agreed to increase its funding by around £430M, subject to final negotiations, as against an increased contribution by the company of £250M which it has announced will be included as a provision in its preliminary results for 2002. These increases reflect the Government's acceptance of a share of the responsibility along with BAE Systems for the under estimate of the required effort and the consequent design delays. They also cover costs incurred through restructuring and other revisions to the project and will result in the first of class coming into service by 2008. In the light of what we now know about the costs and benefits of CAD, we are confident that the new deal represents a good deal for the taxpayer and will provide outstanding new generation attack submarines for the Royal Navy.

Road to Recovery

On 24 November 2004 the First Sea Lord Admiral Sir Alan West said of Astute "I think it is firmly back on track now, I think they have really gripped it, and some of the things like the welding practices there and the levels - almost no re-weld required at all - and the quality of that sort of thing; they have started to master the computer-assisted design, which was a much bigger issue than anyone thought it would be, and I am very impressed that they are getting to grips with it".

The plan for future Astute buys will now be re-addressed in the light of the BAE's revised programme for the first buy of Astute, and the Main Gate submission for the "Astute Subsequent Procurement" (as A2B has been renamed) is expected in early 2006.

In April 2003 a leak of the contents of the MOD's "Equipment Plan 2003" indicated that the SSN fleet was to be reduced to just 7 boats, compared to current 12 and the SDR mandated 10 SSN's. This report was confirmed by government sources, although emphasising that no final decision has been made. In July 2004 the government stated that the SSN force would be reduced to 8 boats by December 2007, and it is suspected that in the long term these will be solely Astute Class boats. However, reports in early 2005 indicated that only 7 Astute's are planned, appearing to confirm EP03.

EP07, approved March 2007 apparently included a total of 7 Astute's - this number was finally officially confirmed in mid-2008, with the UK press already doubting that even seven would ever be ordered.

Admiral Sir Alan West said on 24 November 2004 "When I have got the Astute's, then, with eight, I will be able to do all the things that we need to do. The Defence Planning Guide, requires

actually six SSNs, five or six (operational), depending on the circumstances, available for use. The current fleet has eight of these old ageing ones. Can I actually provide that? When I have got the Astutes, then, with eight, I will be able to do all the things that I need to do, they are newer, they have got a different core, all of these sorts of benefits. I am convinced we need to keep them, I believe we need to keep building the Astutes, once I have got those my worry about the ageing fleet and my worry about having availability will go". (Source: House of Commons Defence select Committee, 24 Nov. 2004)

According to *Defence News* (a leading and well-informed news source) an early order for a fourth Astute is now expected in order to sustain the industrial base. BAE Submarines supply chain coordination manager William Jones told *Wavelength*, a BAE SYSTEMS house magazine published in August 2004 that "Due to the timing of Boat 4 it is possible that some suppliers will have gone out of business, or have lost critical capacity or capability, before we are able to place orders for equipment" The BAE magazine said that the MOD had sought special approval from the U.K. Treasury for advance procurement of major items from a small number of key suppliers, including Rolls-Royce Marine, which makes nuclear power plants, and Weir Strachan & Henshaw, which builds weapon discharge and handling systems. More work was expected to go to other suppliers later this year, it said. A Ministry of Defence (MoD) spokesman confirmed that the government so far has spent about 70 million pounds on long-lead items for Astute Boat 4. A spokesman for Rolls-Royce Marine declined to give any details of their contract, saying any discussions with the MoD were private, but the firm spokesman did say, "We don't see the business as fragile, although clearly there has been a slowdown in order flow from the MoD. This is a business we are in for the long term. Everybody understands the capacity situation: If we don't have work, we have to adapt our resources accordingly."

Another factor that emerged in June 2004 is the possibility that the Maritime Underwater Future Capability (MUFC) studies currently being undertaken might result in a new multi-role nuclear submarine with an ISD as early as 2020 (rather than previous estimates of 2030) in order to allow it to replace the Vanguard Class SSBN's. MUFC would probably be improved Astute type design, but with 16 VLS tubes for cruise missiles or 4 more versatile Trident missile tubes. The revised ISD for MUFC would allow it to replace the last of the updated Trafalgar's.

Work on the third boat, HMS *Artful* was due to commence in 2003, and the First Sea Lord, Admiral Sir Alan West finally performed the delayed keel-laying ceremony on 11 March 2005. On 29 June 2005, Murray Easton, Managing Director of BAE Systems' Submarines Division said during a briefing for BAE staff that Astute project was likely to make a modest profit in 2005. Mr Easton said: "We are not banging the drum and we are not shouting from the roof tops, but the word is getting out that this project is back on the right track. A project that was demonstrably out of control is now in control. But we are only half way there. People have long memories. Astute is very sensitive so we need to be careful. Miss a target and it's 'here we go again'. So we have to avoid complacency."

Astute was "the most complex engineering challenge in the UK, comparable to the United State's space programme," Mr Easton said, involving 7,000 design drawings and 23,000 pipes. Since October 2003, BAE's submarine yard in Barrow-in-Furness, Cumbria, has cut absenteeism among its 3,000 staff by two thirds to 3pc and halved sickness rates to 2.1pc of the workforce. Reportable accidents resulting in staff being off work for more than three days were down 75pc in 2004 and 45pc in 2005. Mr Easton attributed the success to using "lean manufacturing" tips from the car industry. Overheads are down by 27pc over the past two years and staff are meeting and beating stretching deadlines, incentivised by a bonus scheme which could net them £5,000 each in total if they hit all deadlines by 2008. Mr Easton has brought forward the completion date of HMS *Astute* to August 2008 to allow for any slippage when trials start at the end of the year without incurring penalties (this margin may be required due to the emergence of reactor commissioning problems)

Current Situation

HMS *Astute's* naming ceremony was performed on 8 June 2007 and she was floated a few days later. She is expected to be completed and handed over by BAE Systems to the Royal Navy in August 2008. After completing 12 months of extensive test, communication and weapons trials, checks and training. It's hoped that she will be potentially available to the Fleet for limited operations by November 2008 (technically entering service) before these trials complete, but she won't be fully operational until late 2009.

An investment decision on the "Astute Subsequent Procurement" had been expected to be made in Q1 2006 but was delayed. On 21 May 2007, the MOD finally announced an approximately £200 million order for the start of the construction of the fourth Astute-class nuclear powered attack

submarine, which it named as HMS *Audacious*. The contract runs to March 2008 and covers initial build work on the submarine. The MOD aims to contract for the whole boat by late 2008, and detailed terms and conditions will be agreed over the intervening period. The final contract placed will cover all aspects of the construction and completion of the submarine. It comes on top of orders for long-lead items that have already been placed with industry both to prepare the way for the construction of *Audacious* and to support the industrial infrastructure.

BAE said that that about 35% by value of HMS *Audacious* had previously been contracted for under long lead contracts (presumably this had now increased to about 50%). BAE also said that HMS *Audacious* would be delivered in accordance with 22 month "drum beat" for the class - which would imply early 2014. The Barrow yard had already completed preparations to cut first steel in the hull.

In November 2007, the NAO's annual *Major Projects Report 2007* revealed that the Ministry of Defence had agreed to BAE ordering "long lead items" including gear boxes and reactor components for three more submarines, making a total of seven in all. However, in early December 2007 there were press reports speculating that these three boats could be cancelled and that the Astute Class would be limited to just four boats - improbable but an indication of just how much strain the defence budget is under.

Cost

Development costs and production of the first three boats has been budgeted at 3.5 billion pounds (\$6.5 billion). It had been anticipated that an order for a further three Astute class submarines would be placed in late 2002 at an estimated cost is £1.7bn, but this order has now been delayed indefinitely and their cost will be re-assessed. However, some long lead time items for the fourth Astute had been ordered by mid-2004 to help sustain the industrial base.

The pricing of Astute boats resulted in a number of questions for Sir Peter Spencer, Defence Procurement Agency chief, when he appeared 10 October 2006 before the parliamentary Defence Committee. Despite the two boats being under construction, the MoD and BAE have yet to agree on a final price. That stems from a complicated renegotiation of the Astute contract in the wake of the design problems. Lack of a firm price was raising concerns, Spencer said. "At the moment, we have unlimited financial liability for boats 2 and 3 because we have not managed to agree the prices. We know there have been problems in terms of rework and in terms of fragility of the supply chain. I am extremely keen to bring this to a conclusion, ideally before the end of this financial year," he told the committee.

In October and November 2006, it also became public that significant efforts are being made to reduce the cost of the Astute Class. Rear Adm. Andrew Mathews, the MoD's director general nuclear, is said to have told BAE Systems and its suppliers that he wants cut the slash acquisition costs of the fourth boat in the program by 30 percent. By the sixth sub, he wants the reduction to amount to 45 percent.

According to an article in BAE's internal newspaper *Wavelength* in November 2006, the company and its suppliers already have substantially exceeded the targets set by the MoD. "Measures identified exceed the challenge by 25 percent for boat 4 and 10 percent from boat 5 onwards". The internal newspaper says that BAE and others have a "design for cost reduction contract" with the MoD covering the whole of boat four. The company reckons an industry team including Thales, QinetiQ and others will have cut the cost of the fourth boat by 55 percent when compared with the build-to-print system to be used on the third boat of the class. BMT is also believed to have been brought in by the MOD to bring some radical thinking to the redesign effort.

Cost reduction efforts include more than 60 cost-saving measures for the redesigned combat system. Among the changes are using commercially available processing rather than custom-made systems, and the adoption of common cabinets and multifunction consoles across the entire combat system.

One of the most significant innovations in the new combat system has been the use of commercial, off-the-shelf (COTS) systems, said Gavin Ireland, a researcher at the Royal United Services Institute. "The extensive use of COTS on a submarine is a severe challenge, given the harsh operating environment and strict safety standards involved, and given the need to educate suppliers in how to engineer-in survivability without adding excessive cost," he said. "Therefore, the COTS success being achieved in the combat system is of great significance, and is likely to lead the way for greater input of this sort of technology for Boat 4 and beyond. BAE examined other options for reducing the combat capability of the boat to improve affordability, but the cost savings were insufficient to justify compromising the capability of a boat that is required to be even more flexible

than its predecessors. Importantly, there is no capability reduction between the combat systems of boats 3 and 4, even with a substantial cost saving."

One of the aims of the combat system changes, according to *Wavelength*, is to link into MoD initiatives toward a common combat system with open architecture for the submarine fleet. Capt. Paul Jagger, the MoD project leader for combat systems, was quoted saying that applying the initiative across Astute, the existing nuclear submarine flotilla and future boats has the potential to save "tens of millions of pounds."

Ireland also said the MoD is facing significant financial challenges for its future nuclear-powered submarines, not only in terms of driving down the costs of individual hulls, particularly the fourth boat, but also in developing a more affordable acquisition architecture for future programs. He warned, though, that the reduction target will be difficult to achieve if the fourth boat is ordered as an individual vessel, rather than part of a second batch. "The real cost of boat 4 and beyond largely depends on how the MoD structures the procurement of further Astute-class submarines," he said.

Ministry of Defence officials revealed on 27 February 2007 that government negotiators and BAE Submarine Solutions had agreed on a deal on the price of the second and third Astute's, but that it still required endorsement by the hierarchy of the two sides. The formal order for the fourth boat was then expected to follow rapidly order. BAE Submarine Solutions reported that had completed preparations for manufacture of Boat 4 on 8 February 2007, and had begun procuring combat system equipment in the shape of a towed array handling system.

BAE Systems confirmed on 21 May 2007 that the first three Astute's were expected to cost £3.65 billion.

During 2007 the MOD and BAE Systems (Submarine Solutions) finally agreed a Target Cost Incentive Fee for Boat One, and a Target Cost Incentive Fee with Maximum Prices for Boats Two and Three, the current forecast cost for the three boats was £3,798 million, compared with £2,578 million when ordered, the cost growth is despite economies - including capability reductions taken in Equipment Plan 2007 (EP07), approved March 2007.

The MoD has said the approval to build Boat 4 was sought on the basis of meeting a construction drumbeat that required a new submarine order every 22 months in order to ensure vital skills and capabilities were not lost to BAE and its supply chain. However, it is frequently emphasised that the MOD's ability to maintain the necessary stream of orders in face of its budgetary problems is dependent on BAE and key subcontractors meeting the cost targets being set by Rear Adm. Andrew Mathews.

Basing

The Astute Class SSN's will all be based at Faslane on the Clyde.

The implications of the Astute project delays for the SSN flotilla are currently being studied by DNRP involving CinC Fleet and WSA with input from the ASM IPT. The ASM IPT continues to work closely with the WSA to ensure that the predicted in service dates are consistent with the programme for the jetty project at HMNB Clyde - construction work for which finally began in 2004.

Training

A 30-year contract, worth about £300 million, to train crewmen for the Royal Navy's latest Astute class attack submarines was originally awarded by the Ministry of Defence in September 2001 to the UK-based FAST consortium. The FAST consortium is composed of AMS (a joint venture company owned by BAE Systems and Finmeccanica Spa of Italy), CAE Inc of Canada and Flagship (a joint venture company owned by BAE Systems, Vosper Thornycroft and Johnson Controls of the US).

AMS will provide the Command Team Trainer, Weapons Handling and Launch Trainer, Optronics trainer, other related training devices, and trainer maintenance support. CAE will provide the Manoeuvring Room Trainer, Submarine Control Trainer, Platform Management System Trainer, other related training devices, and trainer maintenance support. Flagship Training Limited will provide the building, facility management service, and the instructors.

The Astute Class Training Service (ACTS) contract is heavily dependent on accurate Astute design information being supplied from BAE Systems, and thus has been badly affected by the problems and delays experienced by the programme. In light of the slippage to the submarine build contract, a submission for re-approval of ACTS via a Review Note is expected in early 2003. Should further Astute class boats be ordered, the ACTS contract could be extended to run for 40 years.

Design

In origination, the design and performance of the Astute Class closely relates to that of the earlier Trafalgar Batch 1, but updated tactical weapon systems and the enlarged hull required to accommodate the newer Rolls Royce Pressurised Water Reactor 2 (PWR2) which was originally developed for the Vanguard Class submarines.

In practice, the Astute Class is entering new waters by adopting the fully modular construction technique which it is hoped will significantly reduce cost and build time. The decision to use the modular technique to build the Astute's involved not a little controversy within BAE Systems Marine (and between the engineers of its formally independent and competing constituents GEC Marconi, VSEL, British Aerospace, etc.), and a calculated amount of risk. The standard method of submarine building in the UK is to assemble the components inside the pressure hull after it is completed. Electronic equipment is fed in through the hatches and sometimes shoehorned into whatever space is available, making the final fit-out time-consuming. Traditionally the attitude has been: 'We've got a huge amount of welding to do on this, so let's get on with it.' Using these techniques, it would take about 12 million staff hours to actually build three submarines of the size of the Astute Class, so the production phase is the obvious main target for reducing costs. Building the boat in sections has been proven by submarine builders in Sweden and Germany as the best way to reduce production labour costs. As late as May 2001 BAE engineers were publicly claiming that by adopting modular construction techniques, they could cut Astute design time by 25% and production time by 30% compared to previous submarine projects. BAE also said that it hoped to build the Astute's in an average of 6 years compared with the 8 years of the smaller Trafalgar Class. Unfortunately, these expectations soon proved to be badly mistaken.

The Astute's hull will be built in ring-like sections, rafts of components will be assembled simultaneously and installed before the sections are welded together at the latest possible stage. When the hull modules are welded together, the restricted access to the interior will multiply the time it takes to carry out further work by many times. The Astute design is actually broken down into nine hull sections and 11 main modules of equipment, including the reactor section, a 400-tonne command and control unit and more than 30 mini-modules.

MoD cost estimates are usually calculated in direct proportion to weight - hence the drive towards smaller vessels. It was hoped that the modular construction technique, with concurrent construction and fitting out of multiple modules saves time (and thus money) would allow BAE to build a larger hull for less than it cost to build the smaller Trafalgar class. The cost savings anticipated by the modular approach led to a decision to make Astute hull as big as possible - 10.7m in diameter, determined by the space needed to accommodate the new PWR2 reactor - to reduce the risks of the new technique. The larger hull also in turn created space for 50% more weaponry. The previous plan had been for the hull to bulge around the reactor, but this would have been more complicated and costly than extending the whole sub's diameter and simplifying construction.

Rolls-Royce is supplying the PWR2 nuclear propulsion units for all the Astute boats. It has already delivered the first reactor pressure vessel to BAE Systems. As with earlier designs, the plant has a 25-year lifespan. However, the Astute's will be fitted with a new long-life core (known as core H), which will power the boat for its full-service term, eliminating the need for expensive and time-consuming refuelling.

The latest computer-aided design (CAD) methods are being employed in the design and construction of the Astute's. These supposedly allow full concurrent engineering and enable the work of designers in several companies and sites to be fully integrated, with regard to the performance and layout of all the individual elements of the submarine in a reduced overall design time. Reduction in both build and support costs was a key objective of the design work. Unfortunately, the adopted CADD5 system proved to be total disaster - despite BAE's expected input of significant expertise in this area given its advanced aerospace industry background - and this has been largely blamed for the enormous cost over-runs and multi-year delays that the Astute project has suffered. During 2001 and 2002 shipyard workers found that the designs they were working to simply did not make sense, and equipment wouldn't fit together as it was supposed to, thus unassembled materials and equipment rapidly accumulated at Barrow, and delays lengthened as the designers tried to resolve the rapidly multiplying issues. BAE's project management team also proved simply not up to the job of managing of a project as large and complex as Astute.

In March 2003 it was announced that the American company - General Dynamics Electric Boat Division - would provide design assistance, and also help reinforce BAE's own Astute Project Team. Under an agreement finalised in April 2003, up to 10 designers and engineers will be assigned to BAE SYSTEMS' Barrow-In-Furness shipyard for a period of approximately two years. Additionally, a number of American engineers and designers from EB will be familiarized on BAE Systems'

computer-aided design system and produce initial output drawings to support critical construction needs. When they return to Groton USA, these employees will assist in familiarizing the main body of EB designers with BAE SYSTEMS' design system and methods. EB will provide the resources required by BAE SYSTEMS to complete timely, high-quality drawing outputs to support the production program of the Astute-class submarines. On 23 October 2003 General Dynamics Electric Boat announced that it had received a \$23 million contract modification to the contract initially announced in March 2003, which brings the total value of the work to \$52.7 million. Under the contract, Electric Boat will provide the resources required to complete timely, high-quality drawing outputs to support the production program of the Astute-class submarines. Ninety percent of the work will be performed in Groton, USA; the remainder will be done in Barrow-in-Furness, Cumbria, UK. By April 2004, EB had 13 staff at Barrow, and another 50 working on the Astute project at Groton, the two teams networked via a secure high-speed link.

On 3 September 2004 it was announced (by the US DOD, not the MOD or BAE Systems) that Electric Boat Corp had been awarded a \$144,848,826 cost-plus-fixed-fee modification to the previously awarded contract for Design Agent, Planning Yard and engineering and technical support for a foreign submarine program. The contract provides services for the Astute-Class Submarine in the area of design support. The contract will provide for U.S. submarine design and production expertise; assisting with the development of computer aided design (CAD) tools and their use in submarine design and production processes; producing Astute-Class production drawings; and assisting/exchanging of expertise on submarine construction techniques. Work will be performed in Groton, Conn. (90 percent) and Barrow-in-Furness, Cumbria U.K. (10 percent), and is expected to be completed by January 2007.

The failure of BAE to be able to successfully complete the design of the Astute's in-house, and its now all too public reliance on an American company to help complete the design, is a major failure. Indeed, in May 2004 it seemed that BAE Systems was about to sell its Barrow facility to General Dynamics, but this was stopped when the MOD indicated that it would oppose the sale on national security grounds - the commercial logic of the deal for GD was based on it being able to transfer as much work as possible to its underutilised Electric Boat facilities in the USA and reducing Barrow to a minimal "metal bashing" facility for only the final assembly of RN boats. The loss of a UK national capability to design and upgrade submarines is not [yet] considered acceptable by the MOD, given that the UK's nuclear deterrent is still reliant on this.

Assuming that all the problems are eventually overcome, the final design will include the following significant improvements over the current Trafalgar Class submarines:

The latest, fully integrated submarine combat system; significantly (50%) increased weapons load - including Spearfish, Sub-Harpoon and Tomahawk land attack missile; two COM 10 "optronics" periscopes with electronic displays to avoid hull penetrating masts; external actuation for all control surfaces to reduce hull penetrations and simplify aft end construction; a digital control and information system for the submarine, to minimise costly cabling; extensive detailed improvements to avoid outdated equipment's, improve operability and save cost; reduced radiated noise.

During the redesign process, submerged displacement increased by 600 tonnes, from 7,200 to 7,800 tonnes.

Weapon Systems

Astute's combat system is an uplift of technology originally developed for the Final Phase update of the Swiftsure- and Trafalgar-class SSN tactical weapon system (TWS). Its principal components are: the Astute Combat Management System, which ports existing Submarine Command System (SMCS) functionality onto a more open computing and display infrastructure; the Sonar 2076 integrated sonar suite (comprising bow, intercept, flank and towed arrays); the Outfit UAP (4) electronic support measures equipment; and the FDDI-based TWS Highway. The Astute Class will have six 21-inch torpedo tubes and a capacity for a total of 38 torpedoes, missiles, mines and other weapons and systems. Contrary to some reports, a Vertical Launch System (VLS) will not be fitted.



The Astute's will be equipped with the Tomahawk Block III cruise missile from Hughes Missiles Systems (became part of Raytheon Systems Company in December 1997). The UK is also looking at developing a torpedo tube launched version of the successor to Tomahawk Block III in USN service, the Tactical Tomahawk ("TacTom"). This can

currently only be fired from VLS tubes however a joint US/UK feasibility study established the integrity of an encapsulated version of Tactical Tomahawk suitable for torpedo tube launch, and early testing has been promising.

It is currently planned that the Astute Class will also have the capability to fire the Sub-Harpoon anti-surface warfare (ASuW) weapon developed by McDonnell Douglas Missile Systems Company (now part of Boeing). Sub-Harpoon is an anti-ship sea-skimming missile with maximum velocity in excess of 0.8 mach and range in excess of 70 miles. However, the existing Sub-Harpoon inventory is due to be withdrawn by the end of 2003 on the grounds that it is ill-suited to littoral operations and subject to restrictive rules of engagement. It is still being considered whether RN submarines should retain a capability to fire the new Harpoon Block 2 missile which has increased capability.



The Astute's will also carry Spearfish heavyweight torpedoes, originally manufactured by Marconi - now part of BAE Systems. Procured against Staff Requirement (Sea) 7525, Spearfish replaced the Mk 24 Mod 2 Tigerfish torpedo. Spearfish is powered by a Sundstrand 21TP01 gas turbine (using HAP-Otto fuel) driving a shrouded pump jet propulsor. The Spearfish torpedo is an advanced wire-guided with an active/passive homing head and a directed energy warhead. Its admitted range is 65km at 60 knots and it costs over £2 million each! A progressive programme of through-life technology insertion and capability enhancement is being developed under the Advanced Spearfish initiative.

Spearfish packs a major punch in the ASuW role, but it is optimised against large targets and is an expensive weapon to expend against the small surface threats likely to be encountered in the littoral.

Given the costly "heavy weight" and frequently overkill limitations of Spearfish and Sub-Harpoon, there is growing interest from both FOSM staff and Director Equipment Capability (Under Water Battlespace) - DEC(UWB) - within the Ministry of Defence (MoD) in a shorter-range fibre optic-guided regional conflict weapon, such as the Triton submarine-launched weapon being developed by EADS LFK.

According to FOSM, such a regional conflict missile could offer universal application to influence the land battle ashore, provide precision ASuW against fast-attack craft and offer a self-protection capability against maritime patrol aircraft and anti-submarine helicopters.

In parallel, plans are being formulated to introduce TTWCS as part of a rolling programme of technology refresh planned for the RN Tomahawk during its lifecycle. UK mission planning facilities would also be the subject of a concomitant upgrade.

A wire guided Uninhabited Underwater Vehicle (UUV) will be carried for use in visual and sonar intelligence roles, and for remote SATCOM. Approximately 15 nm of wire.

Finally, as part of very early studies in to the possible replacements of the Trident missile armed Vanguard class submarines in the nuclear deterrent role, consideration has been given to a dual role Astute variant. BAE has considered a hull plug accommodating a silo of 16 Mk36 vertically launched cruise missiles (with nuclear or conventional warheads) forward, or 4 Trident D5 SLBM tubes incorporated in to an extended sail. It appears that Prime Minister Blair authorised further studies in to a replacement of the UK's nuclear deterrent around May 2005, although no new system is needed until 2024 the lead times are very long.

Names

The names of the first 3 units will be HMS ASTUTE, HMS AMBUSH and HMS ARTFUL.