Annex A

Estimating the Acquisition Cost of the Alliance Ground Surveillance (AGS) System

NATO RTO Systems Analysis and Studies Task Group-076*

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1.0 INTRODUCTION

1.1 Historical Background

The concept for an all-weather military surveillance capability for NATO followed from Operation Desert Storm in Kuwait and Iraq, where in 1991 the U.S. successfully deployed the then developmental Joint Surveillance Target Attack Radar System (JSTARS). Unaffected by day/night or adverse weather conditions, JSTARS proved formidable in detecting and tracking enemy movements over vast terrain, while simultaneously disseminating near real-time data to U.S. and coalition forces.

In 1994, following a detailed operational assessment of NATO's military requirements, NATO formalized Alliance Ground Surveillance (AGS) as a Military Operational Requirement (MORS), and in 1995 the North Atlantic Council (NAC) formally validated the requirement for a NATO-owned and operated wide-area air-to-ground surveillance capability, known as the Alliance Ground Surveillance (AGS) system [1].

After years of exploring options for AGS that repeatedly saw the NATO nations unable to reach agreement towards a viable procurement programme; in September 2009, 15 of the 28 member nations[1] signed a Program Memorandum of Understanding (PMoU) to fund the developmental phase of a programme, overseen by the NATO Alliance Ground Surveillance Management Agency (NAGSMA) located in Brussels, Belgium.

1.2 AGS Core Overview

Figure 1 depicts the general principle of operation for the AGS wide-area ground surveillance system. The AGS core consists of a fully integrated system with an air segment, a ground segment and a support segment.

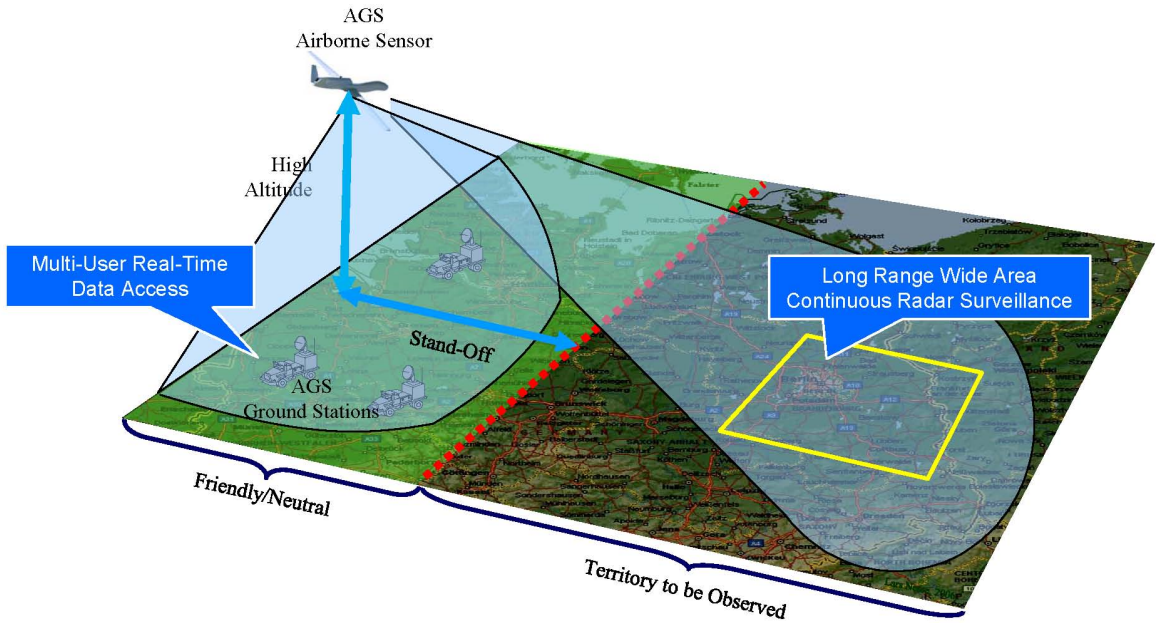

Figure 1: Principle of operation of the AGS core wide-area ground surveillance system

[1] In June 2010, Denmark formally withdrew from the program as part of a move to cut $500 million from planned defence spending between 2010-2014 [2]. The 14 remaining nations are: Bulgaria, Canada, the Czech Republic, Estonia, Germany, Italy, Latvia, Lithuania, Luxembourg, Norway, Romania, Slovakia, Slovenia, and the United States.

The air segment will be based on the Northrop Grumman RQ-4B Global Hawk Block 40[2] high-altitude[3], long endurance, unmanned aerial vehicle (UAV), equipped with advanced multi-platform radar technology insertion program (MP-RTIP) for wide-area surveillance. MP-RTIP uses active electronically scanned array radar to provide a near-real-time horizontally integrated view of the battlespace, capable of detecting and tracking moving objects throughout the observed territory and beyond line-of-sight, as well as providing radar imagery of target locations [3, 4]. Figure 2 depicts the main components of the system.

The ground segment will provide a direct interface between the AGS core system and a number of fixed and deployable Command, Control, Intelligence, Surveillance and Reconnaissance (C2ISR) systems for ISR data exploitation and external dissemination to multiple deployed and non-deployed operational users.

The deployable components consist of four shelter-based Transportable General Ground Stations (TGGS), 11 vehicle-based Mobile General Ground Stations (MGGS), and five Command & Control Units (UCE) that are each self-contained elements with communications and complete environmental control for a crew of two. Also included are 15 Mobile General Communications Stations (MGCS), which serve as the mobile communication component for the MGGS. In that sense, each deployable ground station must be fully functional with low probability of being inoperative, be able to support NATO operations on a continuous basis, and being able to provide a fully integrated capability to each user without having to rely on external infrastructure [1].

The non-deployable component provides a centralized ISR service for high-performance processing at a Main Operating Base (MOB), currently located at Sigonella Air Base, Italy. This Main Operating Station (MOS) will be operate continuously in support of missions, training and maintenance; and will maintain the same data link connectivity with the AGS air platform as the deployable ground stations albeit through a satellite communication (SATCOM) link since the MOS will most certainly be beyond line-of-sight range from the operational theatre [1].

The support elements will support users from operative to tactical levels, and consist of UAV flight trainers, operator trainers and remote work stations. Also included are Peculiar Support Equipment (PSE) which will consist of a set of specialized tools for maintenance and repair of the MGGS and the MGCC in the field [5].

Figure 2: Elements of the NATO AGS system

[2]Variants of Global Hawk aircraft are described by reference to 'Block' numbers, e.g., Block 10, Block 20, Block 30, etc.

[3]In submitting its bid, Northrop Grumman has built its program around six MP-RTIP equipped Block 40 Global Hawks [2]. Nevertheless, NAGSMA questions the bid and remains committed to a program consisting of eight Unmanned Aerial Vehicles (UAVs).

1.3 Study Objective

The objective of this report is to present the ICE for the NATO AGS team based on NATO Research & Technology Organization (RTO) System Analysis and Studies (SAS) task group (SAS-054) guidelines for best practice. Since this is a new acquisition with contract expected to be awarded in 2011 and AGS operational by 2014, this ICE focuses exclusively on development and production costs only.

1.4 Scope

Per demand from the NATO AGS Management Agency (NAGSMA), the SAS-076 Task Group focused its work on generating an independent cost estimate (ICE) on the acquisition phase of the program. This phase represents over 80% of the cost of the contract to be awarded to Northrop Grumman.

The ICE, in turn, was based on:

- Historical costs of Global Hawk production (Blocks 30 and 40),
- An analogy for the new radar (Multi-Platform Radar Technology Improvement Program), based on the AESA radar on the F/A-18 E/F aircraft,
- Cost Estimating Relationships (CERs) for software development.

Operating and support costs for the in-service portion of the program were not formally proffered although one national participant in the group did some rough-order-of-magnitude estimates.

The Task Group conducted risk and uncertainty analysis for the acquisition program using benchmark coefficients of variation (CV) coupled with a point estimate to generate a cumulative probability distribution, or S-curve.

Results of the analysis were completely documented with the ICE delivered to NAGSMA.

1.5 Outline

After a detailed introduction into the AGS system (including the historical background and core overview), and the objectives for SAS 076 as they apply to the NATO AGS portion of task group,

Section 2 presents the AGS program baseline including the detailed cost breakdown structure. The entire report is structured along the lines of the AGS program baseline (see Figure 3), where the main cost drivers are first specified, followed by the detailed cost estimates for each component described by the cost breakdown structure, and finally concluding the study with the risk and uncertainty analysis. In this sense, a logical step-by-step approach was taken that could be applied to future programs of this nature.

Section 3 presents the main financial aspects of the study, including inflation rates, definitions for *constant year* and *then year* dollars, and the conversions from *Raw Aircraft Procurement* to *Weighted Aircraft Procurement*. Section 3 concludes with a discussion on foreign exchange rates and the forecasted USD/Euro exchange rate out to January 2015.

Section 4 is the main analysis portion of the study. In this section detailed cost modelling is performed on all system components based on the cost breakdown structure of Table 1. For most components where actual costs existed, learning curves were established from the U.S. Global Hawk RQ-4 production line. In other cases where statistical significance of the regression components was lacking, mean values of the Lot 4, 5 and 6 unit costs defined the mean unit cost of the component.

Section 5 concludes the analysis portion of the report with a detailed risk and uncertainty analysis using the Enhanced Scenario-Based Method (eSBM) for the major risk elements of this study under three scenarios: “Baseline” (Most likely to occur), “Pessimistic”, and “Resource Constrained”.

Section 6 provides a conclusion to the report with a point discussion on the main limitations for the study.

2.0 THE AGS PROGRAM BASELINE

Developing an ICE for a major acquisition programme consists of a number of steps, with checks and balances established at each milestone. Figure 3 presents a five-step program which could be used for any life cycle cost estimate where, at each step, activities are defined and outputs are realized. Some steps could be completed within a few months, e.g., *Establish Needs with Customer*, whereas others could take years, e.g., *1.3 Develop Cost Estimate*, where issues with gathering and validating data of un-fielded systems, or developing an uncertainty profile far into the future, hamper the development of a viable cost estimate.

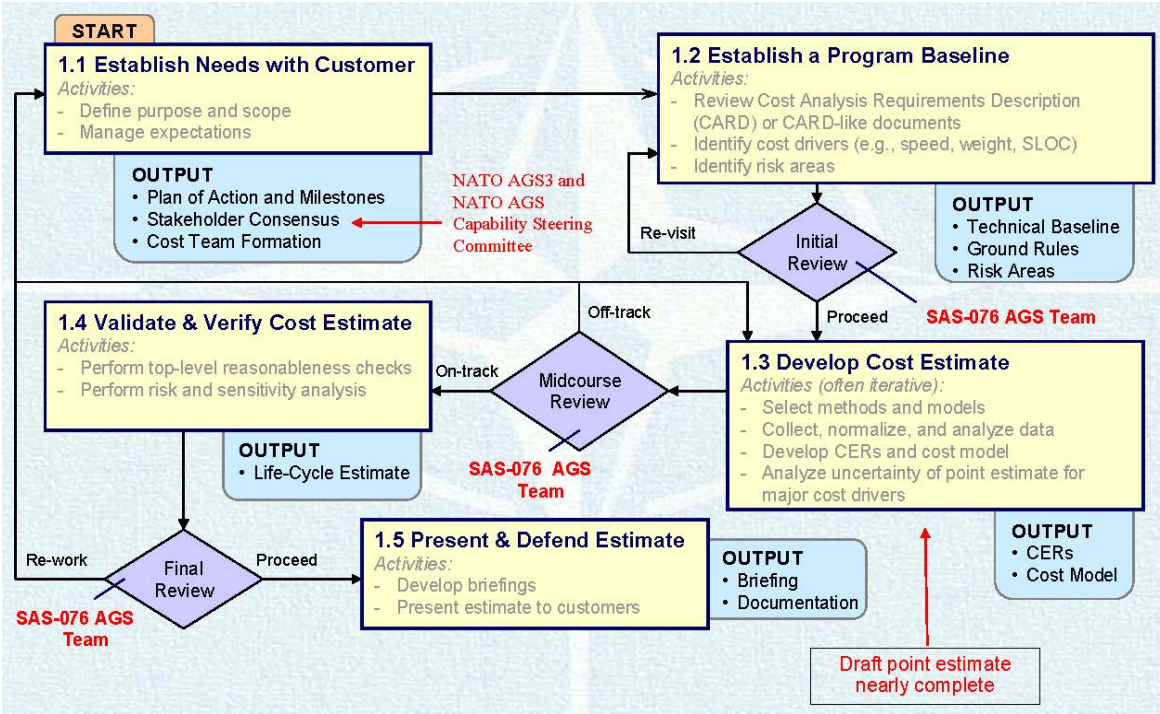

Figure 3: Methodology for the NATO AGS independent cost estimate

2.1 General Assumptions

The AGS cost team estimated the program of record, as defined by the NATO AGS Management Agency, as it evolved over the course of the study. As requested by NAGSMA, costs were estimated in both constant and then-year dollars and Euros.

2.2 The Cost Breakdown Structure (CBS)

The NATO AGS ICE used a product oriented breakdown structure according to the data available, which was fairly limited considering that the system is still in development. The cost breakdown structure that the team developed consists of 12 elements that define the cost drivers for the NATO AGS system. These can be seen listed in Table 1.

Table 1: The cost breakdown structure for NATO AGS

WBS #	Cost Element	WBS #	Cost Element
1	**NATO AGS UAV System**	1.3	**Ground/Support Segment**
1.1	**Air Vehicle**	1.3.1	**Hardware**
1.1.1	**Airframe**	1.3.1.1	Main Operating Station (MOS)
1.1.1.1	Wing	1.3.1.2	Mobile General Ground Stations (MGGS)
1.1.1.2	Fuselage	1.3.1.3	Mobile General Communications Stations (MGCS)
1.1.1.3	Empennage	1.3.1.4	Transportable General Ground Stations (TGGS)
1.1.1.4	Subsystems	1.3.1.5	UAV Command and Control Elements
1.1.1.4.1	Nacelle	1.3.1.6	Remote Workstations
1.1.1.4.2	Fairings	1.3.1.7	UAV Flight Trainers
1.1.1.4.3	Landing Gear + "Other"	1.3.1.8	Ground Station Test & Integration
1.1.2	**Propulsion**	1.3.2	**Software Development**
1.1.3	**Communications**	1.3.2.1	Air Vehicle/Payload
1.1.3.1	DataLinks Link 16 included here? Or under payload?	1.3.2.2	Mission Operations Support
1.1.3.2	Satellite Communications	1.3.2.3	Transportable General Ground Stations
1.1.3.2.1	Ku Satellite Radio	1.3.2.4	Mobile General Ground Stations
1.1.3.2.2	Satellite Communications (SATCOM) Voice	1.3.2.5	Mobile General Communications Stations
1.1.3.2.3	International Maritime SATCOM	1.3.2.6	CSOP
1.1.3.3	UHF/VHF Communications	1.3.2.7	UAV Command and Control Elements
1.1.3.3.1	UHF/VHF Radios	1.3.2.8	System Test & Integration
1.1.3.3.2	UHF Demand Assigned Multiple Access (DAMA) SATCOM	1.4	**Systems Engineering/Program Management**
1.1.4	**Navigation/Guidance**	1.4.1	**Systems Engineering (SE)**
1.1.4.1	(2) Global Positioning Systems	1.4.2	**Program Management (PM)**
1.1.4.2	OmniStar Differential Global Positioning System (DGPS)	1.5	**Systems Test & Evaluation**
1.1.4.3	IFF Transponder/ Traffic Alert Collision (TCAS-II)	1.6	**Training**
1.1.4.4	Worldwide Operations Hardware Suite	1.7	**Data**
1.1.5	**Central Computer**	1.8	**Peculiar Support Equipment**
1.1.6	**Auxiliary Equipment**	1.9	**Common Support Equipment**
1.1.7	**Integration, Assembly, Test Checkout**	1.1	**Operational/Site Activation**
1.2	**Payloads**	1.11	**Industrial Facilities**
1.2.1	**Reconnaissance**	1.12	**Initial Spares and Repair Parts**
1.2.1.3	MP-RTIP		
1.2.2	**NATO AGS Unique**	Add-on	General and Administrative
1.2.2.1	Electronic Support Measures (ESM)		Facilities Capital Cost of Money
1.2.2.2	Radar Warning Receiver (RWR)		Profit
1.2.2.3	IFF Interrogator		
1.2.6	**Payloads Integration Assembly and Checkout**		

2.2.1 The Air Vehicle Segment

The air vehicle segment is comprised of:

1. Eight “Off-the-shelf” (OTS) RQ-4B Global Hawk Block 40 UAVs made up of an airframe, i.e., wings, fuselage, empennage, landing gear and subsystems, its propulsion system and navigation/guidance systems;
2. An OTS Ku-band SATCOM package for the transmission of high volumes of data to multiple users within a large area;
3. A wide-band line-of-sight datalink package capable of simultaneous broadcast and directional operation [1];
4. A Link 16 datalink package intended for use in the transmission of highly filtered data to external users;
5. VHF/UHF Saturn radio communications for integration within European Airspace;
6. OmniSTAR wide-area differential global positioning system (DGPS) using satellite broadcast techniques;
7. Identification Friend or Foe (IFF) interrogator.

2.2.2 The Payload Segment

The payload segment is comprised of:

1. Northrop Grumman/Raytheon's new MP-RTIP active electronically scanned array (AESA) technology for long range, very high-resolution, simultaneous synthetic aperture radar (SAR) and ground moving target indicator (GMTI) capabilities;

2. Electronic Intelligence (ELINT) sensors including emitter detection and identification through Electronic Support Measures (ESM) and Radar Warning Receivers (RWR).

2.2.3 The Ground/Support Segment

The ground/support segment comprises two areas for costing: one for hardware and another for software development. The hardware components have already been discussed in detail in section 1.2 and consist of:

1. 5 OTS Command & Control Units (Unit Control Elements);

2. 11 Mobile General Ground Stations (MGGS);

3. 16 Mobile General Communications Stations (MGCS);

4. 4 Transportable General Ground Stations (TGGS);

5. 22 Remote Workstations;

6. OTS UAV Flight Trainers;

7. Deployable Operator Trainers.

Software is a vital part of the air and ground segments and its level of complexity is usually expressed in terms of operational environment and application domain. For the operational environment, software drives the avionics for the air platform including control, monitoring, communication and navigation. Also, ground-based mission critical software for fixed and mobile sites all lie within the operational environment [6].

Within the application domain, complex software algorithms are required for signal processing of large volumes of data from command, control and communications systems. Included in this domain is software used for the development, testing and support of applications including trainer software.

Software development for both domains consists of Equivalent Source Lines of Code (ESLOC) that is typically used to predict the amount of programming that will be required in the development effort, as well as to estimate programming productivity or maintainability once the software is produced.

2.2.4 Miscellaneous Support Elements 1.4 – 1.12

The remaining cost elements from Systems Engineering/Program Management (1.4) to Initial Spares and Repair Parts (1.12) provide support to the main systems and subsystems. Each element's cost is based on a percentage of the total estimated cost for the AirVehicle + Payload + GroundSegment.

3.0 FINANCIAL CONSIDERATIONS

Prior to developing the AGS cost estimate, we need to develop cost models that reflect all prior year, current and future costs at the level of prices of a base year, which in our case is 2010. Termed *constant year (CY) dollars*, they capture the time value of money by adjusting through compounding and discounting cash flows to reflect the increased value of money.

Costs in *then year (TY) dollars*[4] reflect the purchasing power of the dollar in the year the costs are incurred. Prior year costs given in then year dollars are the actual costs incurred in those years. Future year costs are the projected values that will be paid out in future years.

3.1 Inflation

Inflation rates for AGS design, development, and production will likely differ from values recently experienced in the aerospace industries in the United States, Canada, and Europe. The ICE team is using a baseline value of 3% inflation per annum for outyear projections, weighted according to the relative contributions of the 14 NATO countries participating in the program. However, inflation as measured by the consumer price index seems to be accelerating in Europe as the economic recovery gains traction[5]. Defense inflation generally runs higher than economy-wide figures by perhaps 100 to 300 basis points per year, but follows the same trend. An uptick in rates is a risk in the next few years.

3.2 Raw Aircraft Procurement

Table 2 lists the U.S. constant year dollars relative to the base year 2010. For the raw aircraft procurement numbers from FY 2002 – FY 2010, the discounted present value (PV) costs in 2010 dollars are determined by

$$\mathrm{PV} = \sum_{t=0}^{t=8} \frac{\mathrm{FV}_{Base}}{(1+r)^t} \ , \tag{1}$$

where $\mathrm{FV}_{\mathrm{Base}}$ is the future cash flow in the base year 2010, r is the average inflation rate of 3% per annum for the U.S., Canada and Europe, and the sum is over the 9-year period from FY 2010 ($t = 0$) to FY 2002 ($t = 8$).

For the raw aircraft procurement (RAP) numbers from FY 2010 – FY 2020, relative to the base year, the future value (FV) of the cash flow is obtained by

$$\mathrm{FV} = \sum_{t=0}^{t=10} \mathrm{PV}_{\mathrm{Base}} \, (1+r)^t \ , \tag{2}$$

where FV is now the future cash flow relative to the constant base year 2010, and the sum is over the 11-year period from FY 2010 ($t = 0$) to FY 2020 ($t = 10$).

3.3 Weighted Aircraft Procurement

The above calculations are simply a prerequisite to determining the estimated TY to CY dollar conversions for U.S. procurement costs of NATO AGS. In the U.S., Total Obligational Authority (TOA) funding is the most accurate reflection of program spending. It is the amount of money received in a fiscal year (01 October to

[4] U.S. terminology. In Canada, TY dollars are referred to as budget year (BY) dollars.

[5] Euro area annual inflation was 2.7% in March 2011, up from 2.4% in February. A year earlier the rate was 1.6% [7].

Table 2: U.S. constant year dollars (base year highlighted)

	FY02[a]	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14
Raw Aircraft Procurement	0.789	0.813	0.837	0.863	0.888	0.915	0.943	0.971	1.000	1.030	1.061	1.093	1.126
Weighted Aircraft Procurement	0.824	0.849	0.874	0.901	0.928	0.955	0.984	1.014	1.044	1.075	1.108	1.141	1.175

[a]01 October 2001 to 31 September 2002

31 September) from Congress to spend on defense programs. The spending profile (outlays) we use for NATO AGS is based on the time span of U.S. Navy aircraft procurement outlays of 15%, 40%, 28.6%, 10%, 4.5%, and 1.9% of TOA funding in each buy year. In our case, we use a four year outlay profile and truncate the spending to 15%, 40%, 28%, and 17%, where the percentages reflect the % of TOA spending in the 1st to the fourth year respectively.

Table 2 lists the weighted aircraft procurement (WAP) costs based on the four year spending profile. This is a rolling calculation, i.e.,

$$\mathrm{WAP_t} = 1 \Big/ \left(\frac{15\%}{RAP_t} + \frac{40\%}{RAP_{t+1}} + \frac{28\%}{RAP_{t+2}} + \frac{17\%}{RAP_{t+3}} \right) , \tag{3}$$

where the WAP in year t is a function of the RAP in year t and the next three future years, i.e., $t+1 \ldots t+3$.

3.4 Foreign Exchange Rate

The foreign exchange rate is a major area for cost risk and uncertainty. The NATO AGS contract will be a firm-fixed price direct commercial sale to Northrop Grumman, with a ceiling price denominated in 2007 base-year euros, but with much of the work done in the United States. Converting from dollars to euros, then, is a major issue.

The prevailing view in the international finance community is that exchange rates are not predictable, especially at short horizons. There is really no reliable method to forecast exchange rates. Models for exchange rate movements are largely driven by changes in macroeconomic factors like unexpected economic or political events, interest rates, the pattern of trade between one country and another and what is known as absolute purchasing power parity (PPP) which holds that goods-market arbitrage will tend to move the exchange rate to equalize prices between countries.

For forecasting, the random walk model remains appealing because it leads to smaller forecasting errors than most other exchange rate models. In simple terms, the exchange rate is, at any moment of time, as likely to rise as it is to fall. For a simple random walk, the best forecast of tomorrow's rate is today's rate, i.e.,

$$X_t = \mu + X_{t-1} + \sigma\varepsilon_t \ , \tag{4}$$

where X_t is the exchange rate at time t, μ is the expected rate of growth, σ is the standard deviation, and ε_t is a random disturbance term. Figure 4 shows 100 possible sample paths for the U.S. dollar/euro exchange rate from January 2011, with the 95th percentile bounded by dashed lines. Although the exchange rate is varying wildly about an expected value of 1.3306 from January 2011, the U.S. currency has lost 13 percent of its value against the euro since the beginning of the year. Conversely, the euro has risen in value, and has even approached the symbolic $1.50 threshold. For this analysis, we have fixed the U.S./euro exchange rate at $1.40/euro with the variability forming a large part of the risk analysis for this study.

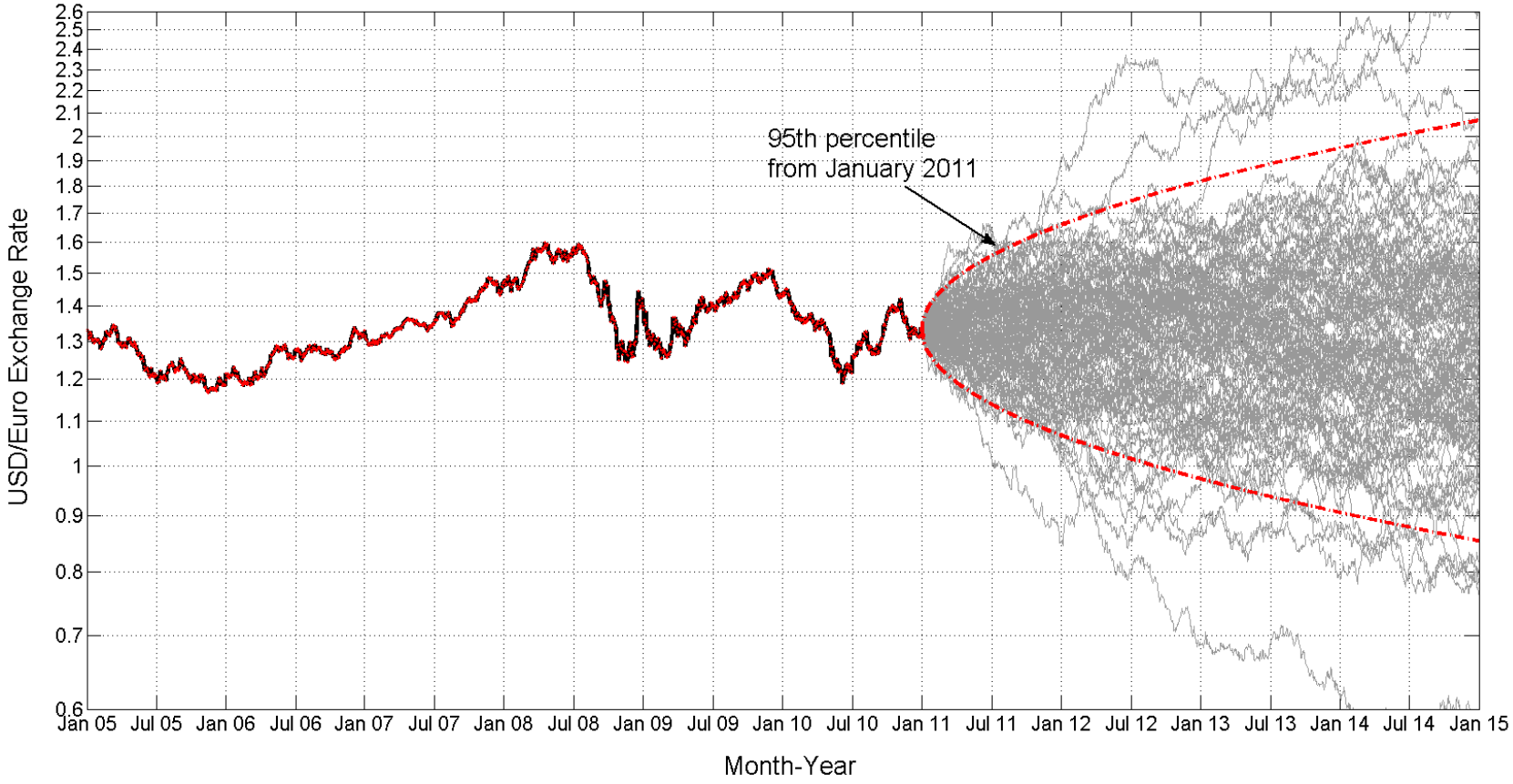

Figure 4: U.S. dollar/euro historical and forecasted exchange rate

4.0 THE AGS COST ESTIMATE

The next, and probably the most critical, step in formulating the ICE consists of developing the cost estimate, which is often seen as an iterative process as costs are refined through time and previously unknown sources become available. The latter becomes particularly acute in developing the ICE for a system that is still only in the development phase.

The steps involved include:

1. Select methods and models
2. Collect, normalize and analyze data
3. Develop Cost Estimating Relationships (CERs)
4. Develop cost model
5. Analyze uncertainties

Each segment of the cost breakdown structure (Table 1) will be analyzed in turn.

4.1 The Air Vehicle

Cost Element 1.1 in Table 1 is the air vehicle. To cost the air vehicle, we start by breaking down each unit into its various components: wing, fuselage, empennage and subsystems, i.e., nacelle, fairings, landing gear, etc (see Figure 5 for an early production RQ-4 schematic). The cost of each component is based on the production schedule for the block 40 UAV with baseline cost adjustments to account for inflation within a staggered production line.

Table 3 shows the Global Hawk low rate initial production (LRIP)[6] with phased deliveries as vehicles advance in technologies[7]. For example, Block 10 aircraft (Basic RQ-4A) consists of seven air vehicles with basic imagery sensors, whereas the Block 40 advanced RQ-4B (Phase 4) will feature MP-RTIP sensor technology, increased payload, wingspan and length, although the range has been reduced due to the increased size and payload [8].

We model air vehicle costs based on Global Hawk Block 30 and 40 actual costs using learning curves[8] , i.e.,

$$\hat{Y} = a x^{b} \,, \tag{5}$$

where $\hat{Y}$ is the cost associated with lot midpoint quantity x, the coefficient a is the cost associated with the first production unit, and b, the natural learning curve slope in log-space, is always negative implying that unit costs decrease as production increases.

The lot midpoint is a single point that represents the entire lot, and not simply the middle point of the lot. An estimate for the lot midpoint is defined by the equation [9]:

$$\left(U_F + U_L + 2\left(U_F \times U_L\right)^{\frac{1}{2}}\right) \Big/ 4 \,, \tag{6}$$

[6]Low rate initial production (LRIP) is used in U.S. military procurement programs to indicate the phase of initial, small-quantity production of a weapon system.

[7]The acquisition of NATO AGS has continually slipped. Further delays will increase then-year dollar and euro costs due to inflation.

[8]A learning curve, also known as cost improvement curve (and probably better suited to our analysis since there is really no learning involved), states that the cost of delivering items that are produced later in the project should be less than the cost of producing similar items early in the project.

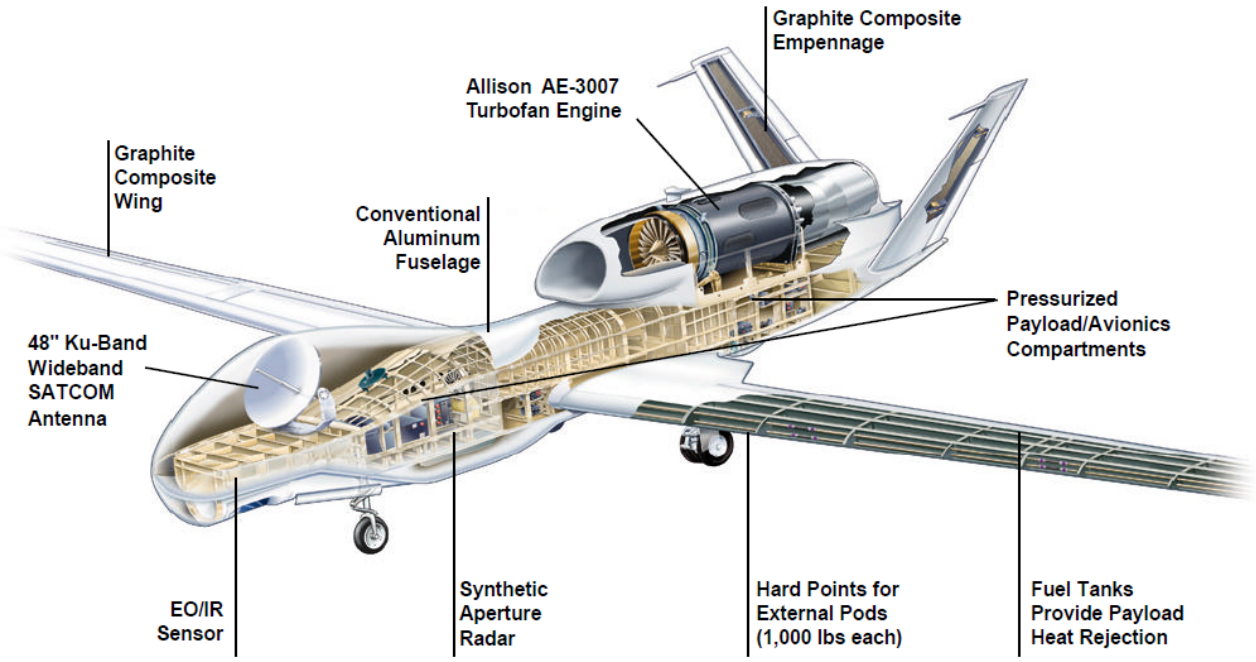

Figure 5: Northrop Grumman Global Hawk air vehicle features. Northrop Grumman approved for public release August 12, 1999 (Distribution Unlimited)

where U_F and U_L denote the first and last units produced respectively in that year. Values for the midpoint can be found in the last line of Table 3.

4.1.1 The Airframe Wing

In September 2002, Triumph Aerostructures - Vought Aircraft Division was selected by Northrop Grumman to build an enhanced wing for the RQ-4 Global Hawk. The division is responsible for wing fabrication, assembly and structural testing. Delivery of the first enhanced wing occurred in July 2005 for LRIP Lot 4. Unit costs for Lots 4, 5 and 6 Block 30 and 40 were used together with the lot midpoints to establish the form of the learning curve based on eqn. (5). Table 4 lists the unit costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2.

Regressing the natural logs of the FY 2010 unit costs against ln(Lot Midpoint) yields a straight line with R^2 of 0.974, Mean Squared Error of 5.069×10^{-4}, and test statistics found in Table 5. Converting back from log-space yields the learning curve[9]

$$\hat{Y} = \text{[redacted]} \times (\text{Lot Midpoint})^{\text{[redacted]}}. \tag{7}$$

Equation 7 is plotted in Figure 6[10] with the actual Lots 4, 5 and 6 costs highlighted as "Actual Unit Costs". Knowing the lot midpoints for AGS production (Table 3), we can extract the estimated AGS unit wing costs, highlighted in red as "Estimated Unit Costs".

[9] Values have been sanitized due to business sensitivity.
[10] The Y-scale has been removed due to business sensitivity.

Table 3: U.S. Global Hawk RQ-4 production line

	FY02[a]	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14
U.S. Global Hawk LRIP	Lot 1	Lot 2	Lot 3	Lot 4	Lot 5	Lot 6	Lot 7	Lot 8	Lot 9	Lot 10	Lot 11	Lot 12	Lot 13
Block 10 Aircraft	3	3	1										
Block 20 Aircraft			3	3									
Block 30 Aircraft				1	4	5	2	2	2	2	3	3	3
Block 40 Aircraft					1		3	3	2	2	2	2	2
Department of the Navy BAMS													
SDD Units[b]									2				
LRIP APN[c]												3	
FRP[d] APN													4
NATO AGS													
DDQ[e]										**2**			
Production											**2**	**2**	**2**
Block 30 and 40 Yearly Totals				1	5	5	5	5	6	6	7	10	11
Block 30 and 40 Cumulative				1	6	11	16	21	27	33	40	50	61
First unit in lot				1	2	7	12	17	22	28	34	41	51
Last unit in lot				1	6	11	16	21	27	33	40	50	61
Approximate lot midpoint				1	3.7	8.9	13.9	18.9	24.4	30.4	36.9	45.4	55.9

[a]01 October 2001 to 31 September 2002
[b]System development and demonstration (SDD) contract awarded to Northrop Grumman in April 2008 [10].
[c]Air Procurement Navy (APN), represents the type of money or appropriation the U.S. is using to buy the UAVs.
[d]Full rate production (FRP)
[e]Design, Development & Qualification

Table 4: U.S. Global Hawk RQ-4 wing costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)	Lot Midpoint
2005	4	[redacted]	[redacted]	1
2006	5	[redacted]	[redacted]	3.7
2007	6	[redacted]	[redacted]	8.9

Table 5: U.S. Global Hawk RQ-4 wing regression statistics

	Coefficient	Standard Error	p-value	t-value
Constant	[redacted]	1.23×10^{-2}	0.0009	722.15
ln(Lot Midpoint)	[redacted]	8.31×10^{-3}	0.0600	-10.57

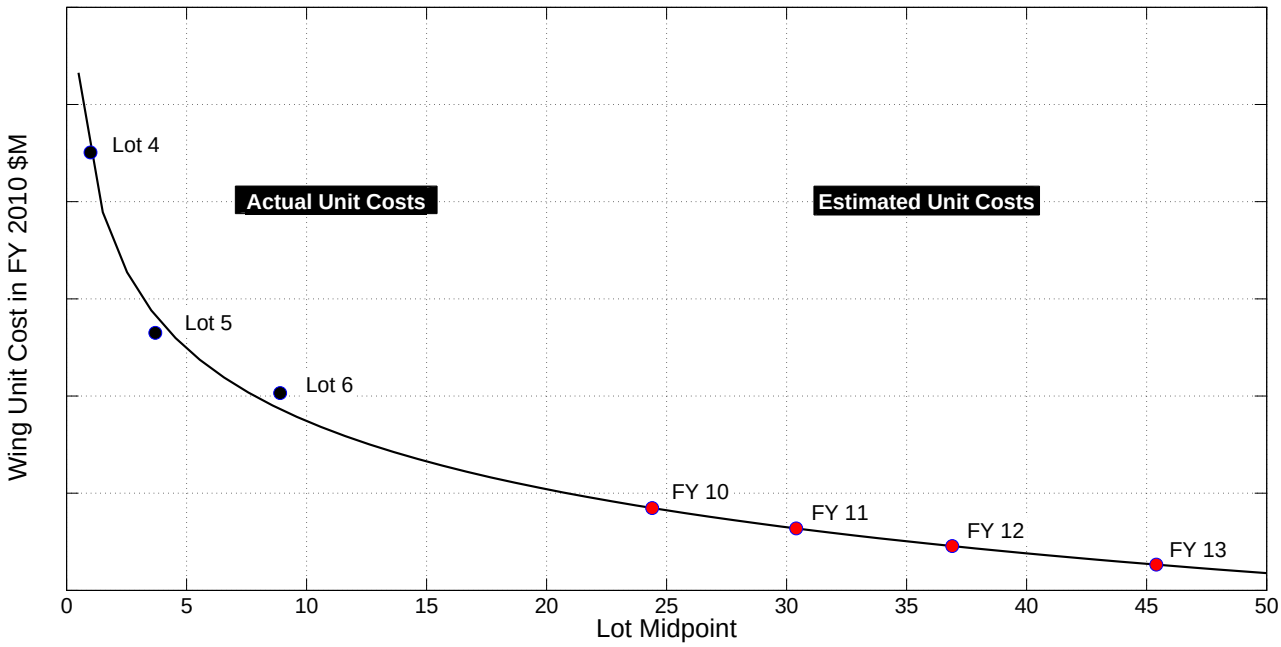

Figure 6: Estimated air vehicle wing unit costs in U.S. FY 10 $M

4.1.2 The Airframe Fuselage

Global Hawk's fuselage consists of three pieces: forward-section, mid-section and aft-section. All three sections are fabricated and mated at Northrop Grumman's Moss Point, Miss. Unmanned Systems Center.

As for the airframe wing, unit costs for Lots 4, 5 and 6 Block 30 and 40 were used together with the lot midpoints to establish the form of the learning curve based on eqn. (5). Table 6 lists the unit costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2.

Table 6: U.S. Global Hawk RQ-4 fuselage costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)	Lot Midpoint
2005	4	[redacted]	[redacted]	1
2006	5	[redacted]	[redacted]	3.7
2007	6	[redacted]	[redacted]	8.9

Regressing the natural logs of the FY 2010 unit costs against ln(Lot Midpoint) yields a straight line with R^2 of 0.841, Mean Squared Error of 4.22×10^{-3}, and test statistics found in Table 7. Converting back from log-space yields the learning curve

$$\hat{Y} = \text{[redacted]} \times (\text{Lot Midpoint})^{\text{[redacted]}}. \tag{8}$$

Equation 8 is plotted in Figure 7 with the actual Lots 4, 5 and 6 costs highlighted as "Actual Unit Costs".

Table 7: U.S. Global Hawk RQ-4 fuselage regression statistics

	Coefficient	Standard Error	p-value	t-value
Constant	[redacted]	3.54×10^{-2}	0.0031	202.59
ln(Lot Midpoint)	[redacted]	2.40×10^{-2}	0.1564	-3.99

Knowing the lot midpoints for AGS production (Table 3), we can extract the estimated AGS unit fuselage costs, highlighted in red as "Estimated Unit Costs".

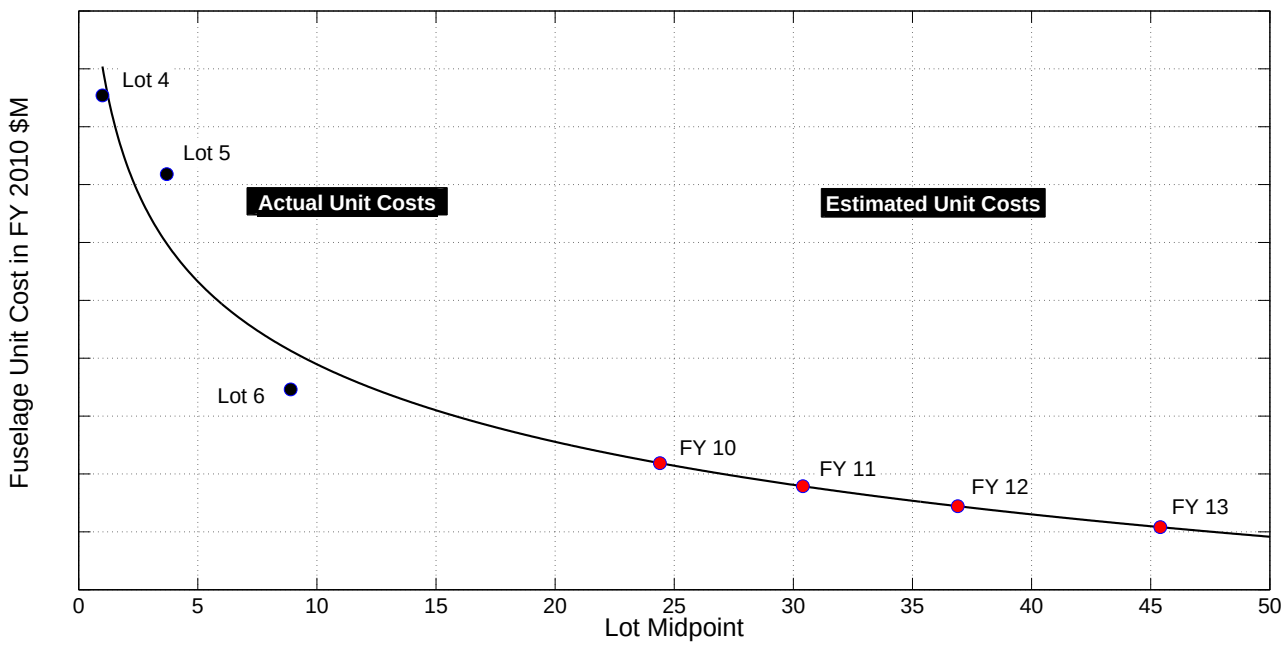

Figure 7: Estimated air vehicle fuselage unit costs in U.S. FY 10 $M

4.1.3 The Airframe Empennage

Since 1995, Aurora Flight Sciences composite manufacturing plant in Bridgeport, W.Va. has been responsible for the fabrication and assembly of the two-spar cantilevered V-tail empennage structure and nacelles systems, and since 2003 has also built most of the composite parts on the Global Hawk fuselage [11].

The unit costs for Lots 4, 5 and 6 Block 30 and 40 were used together with the lot midpoints to establish the form of the learning curve based on eqn. (5). Table 8 lists the unit costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2.

Regressing the natural logs of the FY 2010 unit costs against ln(Lot Midpoint) yields a straight line with R^2 of 0.995, Mean Squared Error of 1.31×10^{-4}, and test statistics found in Table 9. Converting back from log-space yields the learning curve

$$\hat{Y} = \text{[redacted]} \times (\text{Lot Midpoint})^{\text{[redacted]}}. \tag{9}$$

Table 8: U.S. Global Hawk RQ-4 empennage costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)	Lot Midpoint
2005	4	[redacted]	[redacted]	1
2006	5	[redacted]	[redacted]	3.7
2007	6	[redacted]	[redacted]	8.9

Table 9: U.S. Global Hawk RQ-4 empennage regression statistics

	Coefficient	Standard Error	p-value	t-value
Constant	[redacted]	6.23×10^{-3}	0.0006	1111.75
ln(Lot Midpoint)	[redacted]	4.22×10^{-3}	0.0255	-24.94

Equation 9 is plotted in Figure 8 with the actual Lots 4, 5 and 6 costs highlighted as "Actual Unit Costs". Knowing the lot midpoints for AGS production (Table 3), we can extract the estimated AGS unit empennage costs, highlighted in red as "Estimated Unit Costs".

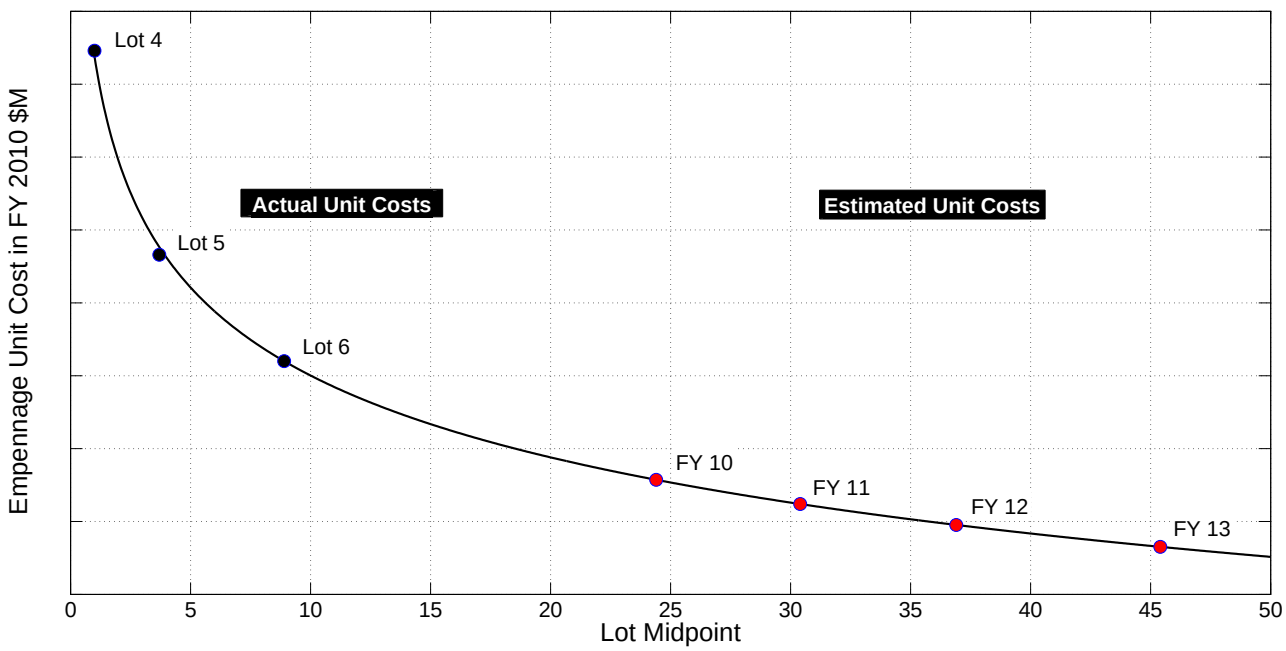

Figure 8: Estimated air vehicle empennage unit costs in U.S. FY 10 $M

4.1.4 The Airframe Subsystems

Global Hawk subsystems include nacelles, fairings, landing gear and other miscellaneous components. Table 10 lists the unit costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY

dollars using the WAP rates of Table 2. Results for a learning curve analysis were not statistically significant, consequently the subsystems costs were estimated using the mean value of the costs in lots 4 through 6.

Table 10: U.S. Global Hawk RQ-4 subsystems costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)
2005	4	[redacted]	[redacted]
2006	5	[redacted]	[redacted]
2007	6	[redacted]	[redacted]
		Mean Unit Cost =	[redacted]

4.2 Global Hawk Propulsion

Cost Element 1.1.2 in Table 1 is the powerplant. With 8,600 lbs of thrust, Global Hawk uses the Rolls Royce AE 3007 turbofan engine. The AE3007H is a military variant of the commercial engine that is installed on air vehicles such as the Embraer RJ 145, ERJ 135, ERJ 140, and Cessna Citation X [12].

Table 11 lists the unit costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2. Results for a learning curve analysis were not statistically significant, consequently the engine cost was estimated using the mean value of the costs in lots 4 through 6.

Table 11: U.S. Global Hawk RQ-4 powerplant costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)
2005	4	[redacted]	[redacted]
2006	5	[redacted]	[redacted]
2007	6	[redacted]	[redacted]
		Mean Unit Cost =	[redacted]

4.3 Communications

Cost Element 1.1.3 in Table 1 are communications, which includes an L3 Communications Integrated Communications System (ICS) as a multi-link wideband communication system. The ICS provides a Common Data Link compatible, full duplex wideband air-to-ground and satellite data link, and redundant full duplex UHF satellite and/or Line-of-Sight (LOS) links for command/control. The ICS consists of a Common Airborne Modem Assembly, a SATCOM Radio Frequency Assembly (RFA), a SATCOM antenna, a LOS RFA, a LOS dual-band antenna, two UHF Receiver/Transmitters, two UHF Power Amplifiers, and two UHF antennas [13].

4.3.1 Datalinks

Table 12 lists the unit costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2. Results for a learning curve analysis were not statistically significant, consequently the datalink costs were estimated using the mean value of the costs in lots 4 through 6.

Table 12: U.S. Global Hawk RQ-4 datalinks costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)
2005	4	[redacted]	[redacted]
2006	5	[redacted]	[redacted]
2007	6	[redacted]	[redacted]
		Mean Unit Cost =	[redacted]

4.3.2 Ku Band Satellite Radio

The Global Hawk Mission Control Centre has data up- and down-links to the Global Hawk vehicle directly and via the Ku satellite and the UHF satellite systems.

The unit costs for Lots 5 and 6 Block 30 and 40 were used together with the lot midpoints to establish the form of the learning curve based on eqn. (5). Table 13 lists the unit costs for lots 5 and 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2.

Table 13: U.S. Global Hawk RQ-4 Ku band satellite radio costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)	Lot Midpoint
2006	5	[redacted]	[redacted]	3.7
2007	6	[redacted]	[redacted]	8.9

Regressing the natural logs of the FY 2010 unit costs against ln(Lot Midpoint) yields a straight line with coefficients 6.970 for the Constant and -0.053 for the ln(Lot Midpoint). Converting back from log-space yields the learning curve

$$\hat{Y} = \text{[redacted]} \times (\text{Lot Midpoint})^{\text{[redacted]}}. \tag{10}$$

Equation 10 is plotted in Figure 9 with the actual Lots 5 and 6 costs highlighted as “Actual Unit Costs”. Knowing the lot midpoints for AGS production (Table 3), we can extract the estimated AGS unit Ku band satellite radio costs, highlighted in red as “Estimated Unit Costs”.

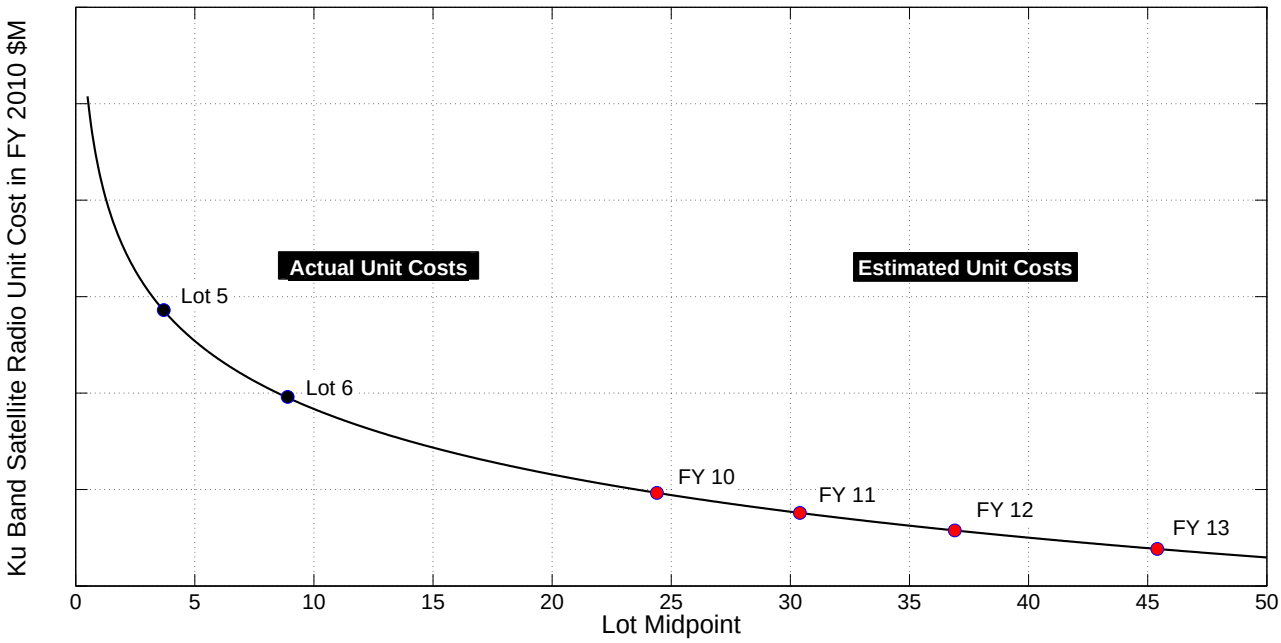

Figure 9: Estimated Ku band satellite radio unit costs in U.S. FY 10 $M

4.3.3 Satellite Communications (SATCOM) Voice

The unit costs for Lots 4, 5 and 6 Block 30 and 40 were used together with the lot midpoints to establish the form of the learning curve based on eqn. (5). Table 14 lists the unit costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2.

Table 14: U.S. Global Hawk RQ-4 SATCOM voice costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)	Lot Midpoint
2005	4	[redacted]	[redacted]	1
2006	5	[redacted]	[redacted]	3.7
2007	6	[redacted]	[redacted]	8.9

Regressing the natural logs of the FY 2010 unit costs against ln(Lot Midpoint) yields a straight line with R^2 of 0.937, Mean Squared Error of 4.12×10^{-3}, and test statistics found in Table 15. Converting back from log-space yields the learning curve

$$\hat{Y} = \text{[redacted]} \times (\text{Lot Midpoint})^{\text{[redacted]}}. \tag{11}$$

Equation 11 is plotted in Figure 10 with the actual Lots 4, 5 and 6 costs highlighted as “Actual Unit Costs”. Knowing the lot midpoints for AGS production (Table 3), we can extract the estimated AGS unit SATCOM voice costs, highlighted in red as “Estimated Unit Costs”.

Table 15: U.S. Global Hawk RQ-4 SATCOM voice regression statistics

	Coefficient	Standard Error	p-value	t-value
Constant	[redacted]	3.50×10^{-2}	0.0040	157.39
ln(Lot Midpoint)	[redacted]	2.37×10^{-2}	0.0943	-6.70

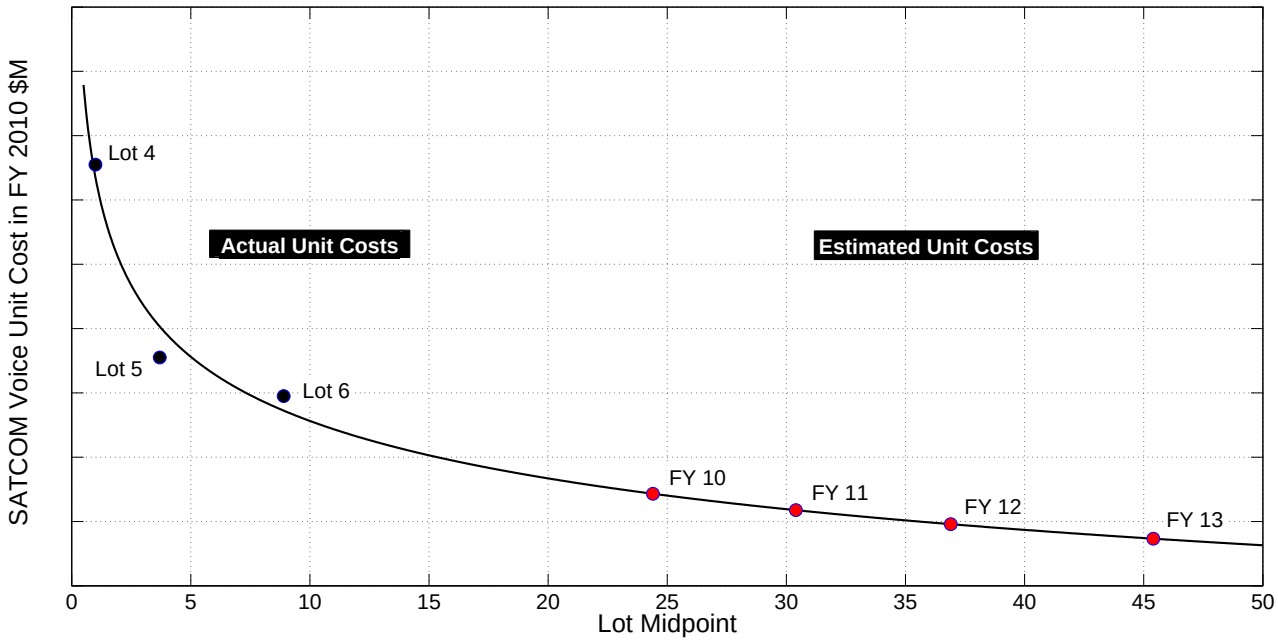

Figure 10: Estimated air vehicle SATCOM voice unit costs in U.S. FY 10 $M

4.3.4 International Maritime SATCOM

The unit costs for Lots 5 and 6 Block 30 and 40 were used together with the lot midpoints to establish the form of the learning curve based on eqn. (5). Table 16 lists the unit costs for lots 5 and 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2.

Table 16: U.S. Global Hawk RQ-4 Maritime SATCOM costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)	Lot Midpoint
2006	5	[redacted]	[redacted]	3.7
2007	6	[redacted]	[redacted]	8.9

Regressing the natural logs of the FY 2010 unit costs against ln(Lot Midpoint) yields a straight line with coefficients 5.348 for the Constant and -0.191 for the ln(Lot Midpoint). Converting back from log-space yields

the learning curve

$$\hat{Y} = \text{[redacted]} \times (\text{Lot Midpoint})^{\text{[redacted]}}. \tag{12}$$

Equation 12 is plotted in Figure 11 with the actual Lots 5 and 6 costs highlighted as "Actual Unit Costs". Knowing the lot midpoints for AGS production (Table 3), we can extract the estimated AGS unit Maritime band satellite radio costs, highlighted in red as "Estimated Unit Costs".

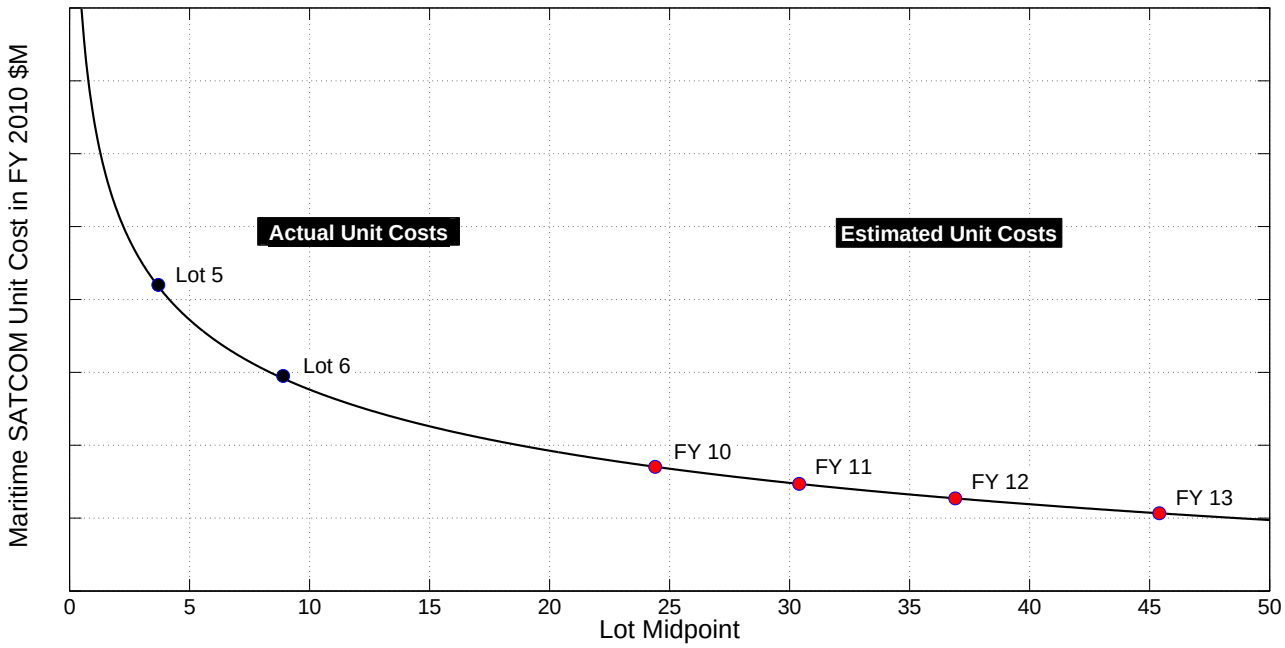

Figure 11: Estimated Maritime SATCOM unit costs in U.S. FY 10 $M

4.3.5 UHF/VHF Communications

The unit costs for Lots 4, 5 and 6 Block 30 and 40 were used together with the lot midpoints to establish the form of the learning curve based on eqn. (5). Table 17 lists the unit costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2.

Table 17: U.S. Global Hawk RQ-4 UHF/VHF communications costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)	Lot Midpoint
2005	4	[redacted]	[redacted]	1
2006	5	[redacted]	[redacted]	3.7
2007	6	[redacted]	[redacted]	8.9

Regressing the natural logs of the FY 2010 unit costs against ln(Lot Midpoint) yields a straight line with R^2 of 0.963, Mean Squared Error of 1.808×10^{-4}, and test statistics found in Table 18. Converting back from

log-space yields the learning curve

$$\hat{Y} = \text{[redacted]} \times (\text{Lot Midpoint})^{\text{[redacted]}}. \tag{13}$$

Table 18: U.S. Global Hawk RQ-4 UHF/VHF communications regression statistics

	Coefficient	Standard Error	p-value	t-value
Constant	[redacted]	7.32×10^{-3}	0.0009	695.41
ln(Lot Midpoint)	[redacted]	4.96×10^{-3}	0.0713	-8.89

Equation 13 is plotted in Figure 12 with the actual Lots 4, 5 and 6 costs highlighted as "Actual Unit Costs". Knowing the lot midpoints for AGS production (Table 3), we can extract the estimated AGS unit UHF voice costs, highlighted in red as "Estimated Unit Costs".

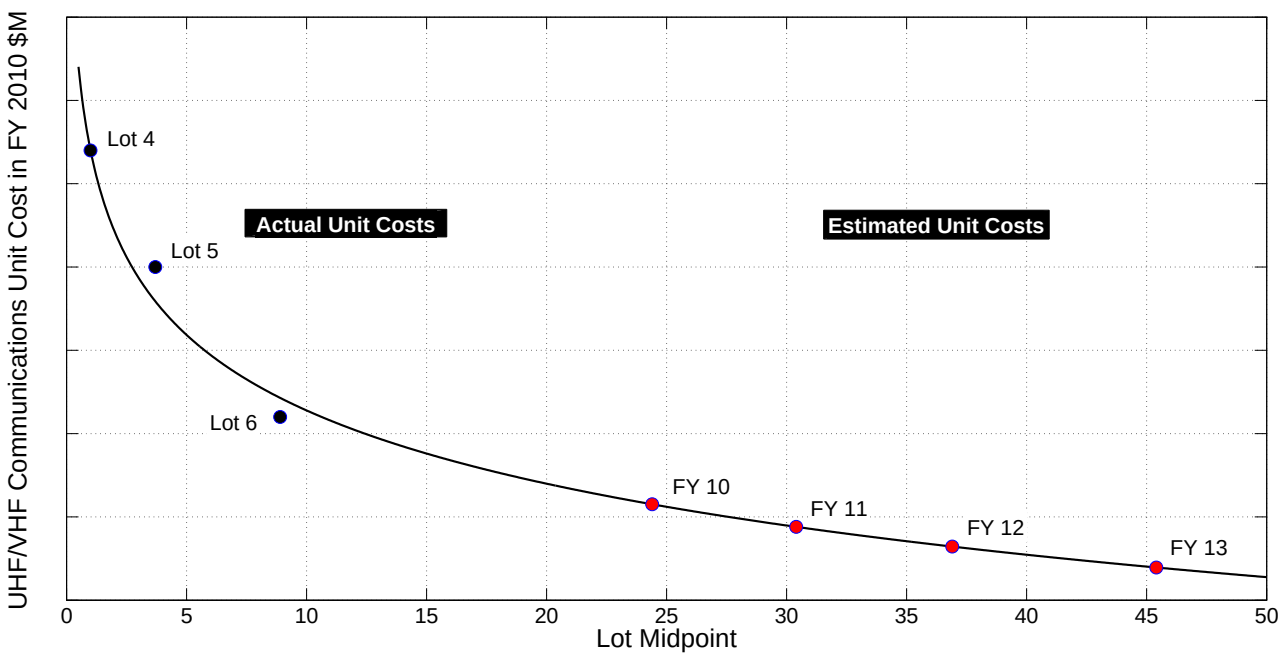

Figure 12: Estimated air vehicle UHF/VHF communication unit costs in U.S. FY 10 $M

4.4 Navigation/Guidance

Cost Element 1.1.4 in Table 1 is Navigation/Guidance, which is via inertial navigation with integrated Global Positioning System updates. Costs were estimated using learning curves and cost means where statistical significance was lacking.

4.4.1 Global Positioning Systems (GPS)

The costs for two GPS units from Lots 4, 5 and 6 Block 30 and 40 were used together with the lot midpoints to establish the form of the learning curve based on eqn. (5). Table 19 lists the two-unit costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2.

Table 19: U.S. Global Hawk RQ-4 GPS two-unit costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)	Lot Midpoint
2005	4	[redacted]	[redacted]	1
2006	5	[redacted]	[redacted]	3.7
2007	6	[redacted]	[redacted]	8.9

Regressing the natural logs of the FY 2010 two-unit costs against ln(Lot Midpoint) yields a straight line with R^2 of 0.999, Mean Squared Error of 1.226×10^{-6}, and test statistics found in Table 20. Converting back from log-space yields the learning curve

$$\hat{Y} = \text{[redacted]} \times (\text{Lot Midpoint})^{\text{[redacted]}}. \tag{14}$$

Table 20: U.S. Global Hawk RQ-4 GPS two-unit regression statistics

	Coefficient	Standard Error	p-value	t-value
Constant	[redacted]	6.03×10^{-4}	0.0001	10183.08
ln(Lot Midpoint)	[redacted]	4.09×10^{-4}	0.0082	-77.67

Equation 14 is plotted in Figure 13 with the actual Lots 4, 5 and 6 costs highlighted as “Actual two-Unit Costs”. Knowing the lot midpoints for AGS production (Table 3), we can extract the estimated AGS two-unit GPS costs, highlighted in red as “Estimated two-Unit Costs”.

4.4.2 OmniStar Differential Global Positioning System (DGPS)

Table 21 lists the unit costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2. Results for a learning curve analysis were not statistically significant, consequently the DGPS costs were estimated using the mean value of the costs in lots 4 through 6.

4.4.3 IFF Transponder/Traffic Alert & Collision (TCAS-II)

Table 22 lists the unit costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2. Results for a learning curve analysis were not statistically significant, consequently the DGPS costs were estimated using the mean value of the costs in lots 4 through 6.

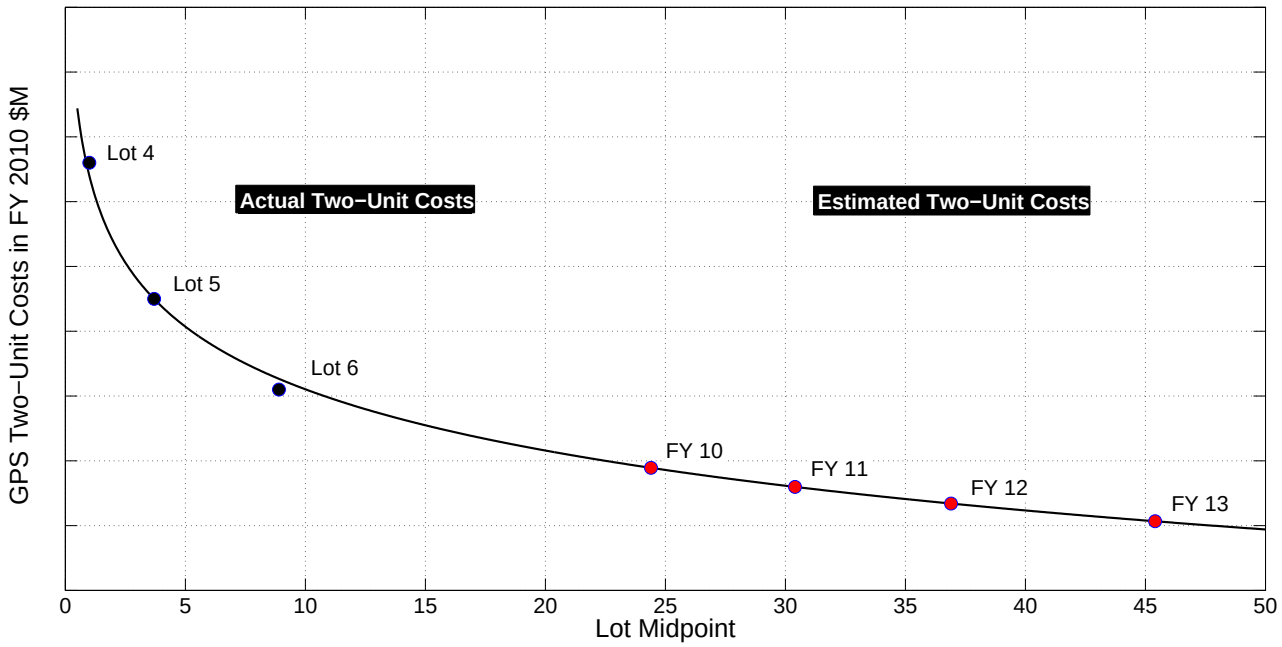

Figure 13: Estimated air vehicle GPS two-unit costs in U.S. FY 10 $M

Table 21: U.S. Global Hawk RQ-4 DGPS costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)
2005	4	[redacted]	[redacted]
2006	5	[redacted]	[redacted]
2007	6	[redacted]	[redacted]
		Mean Unit Cost =	[redacted]

Table 22: U.S. Global Hawk RQ-4 TCAS-II costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)
2005	4	[redacted]	[redacted]
2006	5	[redacted]	[redacted]
2007	6	[redacted]	[redacted]
		Mean Unit Cost =	[redacted]

4.4.4 Worldwide Operations Hardware Suite

Table 23 lists the unit costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2. Results for a learning curve analysis were not statistically significant, consequently the suite costs were estimated using the mean value of the costs in lots 4 through 6.

Table 23: U.S. Global Hawk RQ-4 operations hardware suite costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)
2005	4	[redacted]	[redacted]
2006	5	[redacted]	[redacted]
2007	6	[redacted]	[redacted]
		Mean Unit Cost =	[redacted]

4.5 Miscellaneous Air Vehicle Components

Cost Elements 1.1.5, 1.1.6 and 1.1.7 in Table 1 refer to the central computer, auxiliary equipment and integration, assembly, test and checkout respectively.

4.5.1 The Central Computer

The costs for the central computer from Lots 4, 5 and 6 Block 30 and 40 were used together with the lot midpoints to establish the form of the learning curve based on eqn. (5). Table 24 lists the central computer costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2.

Table 24: U.S. Global Hawk RQ-4 central computer costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)	Lot Midpoint
2005	4	[redacted]	[redacted]	1
2006	5	[redacted]	[redacted]	3.7
2007	6	[redacted]	[redacted]	8.9

Regressing the natural logs of the FY 2010 central computer costs against ln(Lot Midpoint) yields a straight line with R^2 of 0.927, Mean Squared Error of 1.079×10^{-3}, and test statistics found in Table 25. Converting back from log-space yields the learning curve

$$\hat{Y} = \text{[redacted]} \times (\text{Lot Midpoint})^{\text{[redacted]}}. \tag{15}$$

Equation 15 is plotted in Figure 14 with the actual Lots 4, 5 and 6 costs highlighted as “Actual Costs”. Knowing the lot midpoints for AGS production (Table 3), we can extract the estimated AGS unit Computer costs, highlighted in red as “Estimated two-Unit Costs”.

Table 25: U.S. Global Hawk RQ-4 central computer regression statistics

	Coefficient	Standard Error	p-value	t-value
Constant	[redacted]	1.79×10^{-2}	0.0015	417.37
ln(Lot Midpoint)	[redacted]	1.21×10^{-2}	0.1019	-6.19

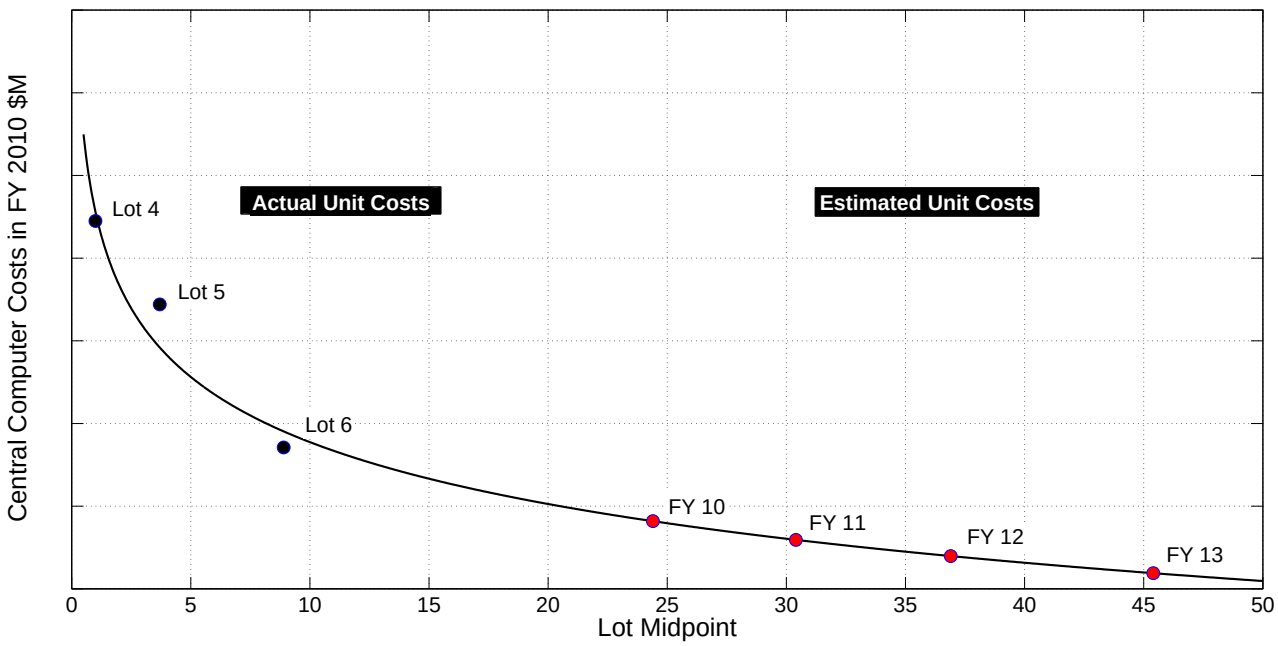

Figure 14: Estimated air vehicle computer two-unit costs in U.S. FY 10 $M

4.5.2 Auxiliary Equipment

Table 26 lists the unit costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2. Results for a learning curve analysis were not statistically significant, consequently the auxiliary equipment costs were estimated using the mean value of the costs in lots 4 through 6.

Table 26: U.S. Global Hawk RQ-4 auxiliary equipment costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)
2005	4	[redacted]	[redacted]
2006	5	[redacted]	[redacted]
2007	6	[redacted]	[redacted]
		Mean Unit Cost =	[redacted]

4.5.3 Integration, Assembly, Test & Checkout (IATC)

Sensor integration, assembly and full flight testing are major steps towards finalizing operational deployment of the NATO AGS system. The costs for the IATC from Lots 4, 5 and 6 Block 30 and 40 were used together with the lot midpoints to establish the form of the learning curve based on eqn. (5). Table 27 lists the IATC costs for lots 4 through 6 in thousands of TY dollars (col. 3), which were converted to 2010 CY dollars using the WAP rates of Table 2.

Table 27: U.S. Global Hawk RQ-4 Integration, Assembly, Test & Checkout costs

FY	Lot	Unit Costs (TY $000)	Unit Costs (FY10 $000)	Lot Midpoint
2005	4	[redacted]	[redacted]	1
2006	5	[redacted]	[redacted]	3.7
2007	6	[redacted]	[redacted]	8.9

Regressing the natural logs of the FY 2010 IATC costs against ln(Lot Midpoint) yields a straight line with R^2 of 0.958, Mean Squared Error of 2.446×10^{-3}, and test statistics found in Table 28. Converting back from log-space yields the learning curve

$$\hat{Y} = \text{[redacted]} \times (\text{Lot Midpoint})^{\text{[redacted]}}. \tag{16}$$

Table 28: U.S. Global Hawk RQ-4 Integration, Assembly, Test & Checkout regression statistics

	Coefficient	Standard Error	p-value	t-value
Constant	[redacted]	2.69×10^{-2}	0.0018	346.71
ln(Lot Midpoint)	[redacted]	1.83×10^{-2}	0.0765	-8.28

Equation 16 is plotted in Figure 15 with the actual Lots 4, 5 and 6 costs highlighted as “Actual Costs”. Knowing the lot midpoints for AGS production (Table 3), we can extract the estimated AGS IATC costs, highlighted in red as “Estimated Costs”.

4.6 The Payloads

Cost Element 1.2 in Table 1 are the payloads, which include MP-RTIP radar, Electronic Support Measures (ESM), Radar Warning Receiver (RWR), Identification Friend or Foe (IFF) Interrogator, and Payloads Integration Assembly and Checkout.

4.6.1 Multi-Platform Radar Technology Insertion Program (MP-RTIP)

Since December 2000, Raytheon and Northrop Grumman have coordinated the design, development and production of MP-RTIP. Its X-band Active Electronically Scanned Array (AESA) radar uses beam steering that can couple electronic and mechanical options. Since costing for the MP-RTIP sensor is not available to NATO, the ICE team based its estimate on an analogous AESA system currently fielded on a variety of platforms

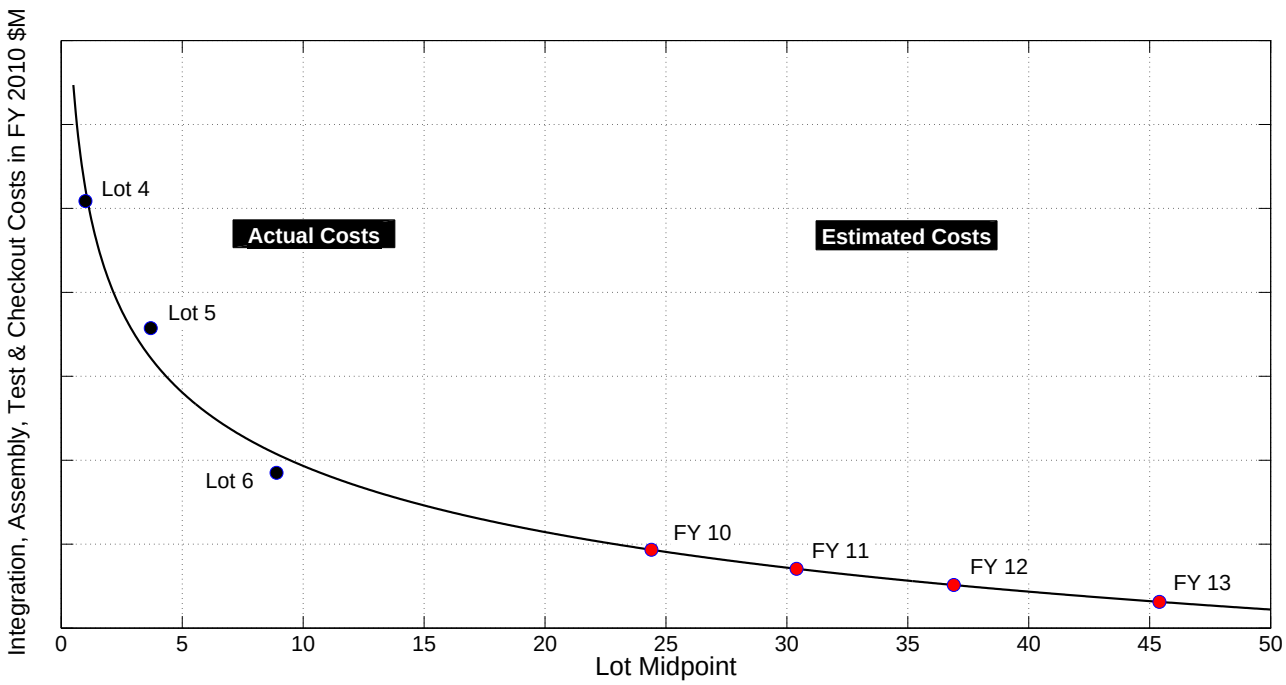

Figure 15: Estimated air vehicle Integration, Assembly, Test & Checkout costs in U.S. FY 10 $M

(including the F/A-18E/F Super Hornet), as a proxy variable for complexity and scale. Using a weight-based analogy, where it was assumed that the higher the weight the greater the cost, the ratio multiplication factor for AGS MP-RTIP (3,000 lbs) to AESA (650 lbs), was given as

$$\text{Ratio} = \frac{\text{MP} - \text{RTIP}}{\text{AESA}} = \frac{3000}{650} = 4.6\,. \tag{17}$$

From the theory of learning curves [9], each time the quantity of items produced doubles, the cost decreases by a constant percentage known as the *Learning Curve Slope (LCS)*. In log-space, equation (5) becomes a straight line with slope

$$b = \ln(LCS)/\ln(2)\,, \tag{18}$$

where the term $\ln(2)$ arises from the doubling of items.

From the contractor cost data report for LRIP AESA production, the total TY 2003 price for eight units is [redacted]. The U.S. independent cost estimate on AESA determined a learning curve slope of 90%, which gives a value for b of [redacted]. Equation (5) can therefore be re-written as

$$\hat{Y} = \sum_{i=1}^{8} \alpha\, Q_i^{\text{[redacted]}}\,, \tag{19}$$

where $\hat{Y} =$ [redacted] is the total Lot 1 cost, Q_i is the ith unit of production, and α is the first unit cost, which is

$$\alpha = \frac{\hat{Y}}{\sum_{i=1}^{8} Q_i^{\text{[redacted]}}} = \frac{\text{[redacted]}}{\left[1^{\text{[redacted]}} + 2^{\text{[redacted]}} + \cdots + 8^{\text{[redacted]}}\right]} = \text{TY}\ \text{[redacted]} = \text{[redacted]}\ \text{in FY 2010}\,, \tag{20}$$

where the TY cost was converted to 2010 CY dollars using the WAP rates of Table 2.

The final MP-RTIP estimated unit cost is given by

$$\text{Ratio} \times \alpha \times 0.90 = \text{[redacted]} \text{ in FY 2010 }, \tag{21}$$

where the factor of 0.90 accounts for the learning on the AESA radar for the F/A-18 E/F Super Hornet aircraft.

4.7 The Ground/Support Segment

The system architecture and the configuration of the NATO AGS ground segment are especially developed to accommodate a network centric approach, with emphasis on a local area network design and real-time exchange of data between AGS users. Also, the use of standardization will ensure system interoperability, not only with the NATO C3I systems, but also national ISR systems. Through the AGS ground segment, NATO forces will also have access to nationally acquired reconnaissance and surveillance data [14].

The following elements of the AGS Ground System (GS) are based on information from the NATO Alliance Ground Surveillance Management Agency (NAGSMA). They reflect the assumed numbers to be purchased.

- Main Operating Station (MOS) (1 Element)
  - Located at Sigonella Air Base in Italy, the Main Operating Station (MOS), together with training and logistic support elements, provides the virtual aircrew for UAV and ground entity coordination for multiple air vehicles within different theatres of operations. This capability provides UAV command and control as well as information management with interoperable NATO and National C2ISR systems.
  - Costs for the operator and UAV flight trainers are included in the overall costs for the MOS.
- Mobile General Ground Stations (MGGS) (11 Elements)
  - Includes 11 all terrain vehicles with shelters.
- Transportable General Ground Stations (TGGS) (4 Elements)
  - Includes 4 transportable shelters with workstations and communications equipment.
- Mobile General Communications Stations (MGCS) (15 Elements)
  - 11 all terrain communications vehicles with SATCOM and wide band datalink packages are included in the costs for the MGGS.
  - 4 all terrain communications vehicles with SATCOM and wide band datalink packages are included in the costs for the TGGS.
- UAV Command and Control Elements (UCE) (5 Elements)
  - The UCE provides aircraft control, communications, navigation plan modification, and differential global positioning system equipment to support aircraft takeoff and landing, sensor task scheduling and management. Included are the costs for five transportable shelters with workstations and communications equipment.
- Remote Workstations (22 Elements)

– Costs for the 22 remote workstations are included in the overall costs for the MGGS.

The AGS GS is partially comparable to the GS for the U.S. Global Hawk. The U.S. Standard Ground System consists of the Ground Station Launch and Recovery Element (LRE) and the Mission Control Element (MCE), whereas the LRE GS is quite comparable to the UCE from AGS, the elements and functions from the MCE are distributed to the MOS and other mobile GS.

Typically, the hardware components the stations consist of shelters, controls and displays, exterior equipment for electrical power and environmental control and also communication devices for SATCOM (UHF, Ku-Band, Inmarsat for mobile voice and data communications), tactical common data, wideband datalink line-of-sight (WBDL-LOS) capability and air traffic control communications.

The basis for the estimation of the AGS Ground Segments has been generated by available information from U.S. Global Hawk Ground Stations. It is assumed that there is a comparable use of components as utilized in the U.S. GS, e.g., work stations, radios, and antennas for the different communication channels.

4.7.1 AGS Ground Segment Parametric Cost Estimation

The SAS 076 task group decided to carry out the cost estimation for the Ground Stations via a parametric cost estimation model. Parametric estimating is a technique that uses validated relationships between a project's known technical, programmatic, and cost characteristics and known historical resources consumed during the development, manufacture, and/or modification of an end item. A number of parametric techniques exist that practitioners can use to estimate costs. These techniques include cost estimating relationships (CERs) and parametric models. Parametric models are more complex than CERs because they incorporate many equations, ground rules, assumptions, logic, and variables that describe and define the particular situation being studied and estimated.

Parametric cost estimation models are designed so that they can conduct cost estimation with less hardware information. Therefore they are an appropriate tool to estimate the AGS GS. Missing input values can be replaced by internal default values or tabular values. For the AGS GS, the cost estimation model "Advanced Cost Estimating Systems (ACES)" was used[11]. A general description of the model is provided in Appendix A1.

4.7.2 Ground Segment Hardware

A work breakdown structure for the Ground Stations (Table 29) has been derived via a top down approach from documents of the default Global Hawk GS, where it has been assumed that the systems in the AGS GS are the same as in the default Global Hawk GS. This can be derived from the communication channels (Ku SATCOM, INMARSAT, UHF SATCOM, Common data link (CDL) line of sight, UHF/VHF voice) as they are implemented in both systems.

The basic configuration of the stations is described in documents from the U.S. Ground Stations, but without any specifications. Input values for elements of the GS have been compiled by expert interviews, internet research, and from national documents. If no references have been specified, the input values should be treated as best assumptions.

The following information is required for the cost estimation:

- Physical Characteristics (mechanical / electronic item; weight; volume)

[11] The analysis in this section was completed by Germany. Consequently, translation from German to English was required for input and output ACES software screenshots.

Table 29: The cost breakdown structure for NATO AGS ground Segment

WBS #	Cost Element	WBS #	Cost Element
1.3	**AGS Ground Segment (GS) and Support Segment Hardware**	1.3.1.2.1.4.1	Antenna Unit
1.3.1		1.3.1.2.1.4.2	Trailer
1.3.1.1	**Main Operation Support (MOS) [1x]**	1.3.1.2.1.5	MGGS Terrain Communication Equipment
1.3.1.1.1	MOS Operation Equipment	1.3.1.2.1.5.1	MGCE Communication Vehicle
1.3.1.1.1.1	MOS Crew Workstations (30 Workstations)	1.3.1.2.1.5.2	MGCE VHF/UHF Communication and SATCOM
1.3.1.1.1.2	MOS Displays	1.3.1.2.1.5.3	MGCE HF Communication
1.3.1.1.1.3	MOS Processing Unit	1.3.1.2.1.5.4	Other Communication Equipment
1.3.1.1.1.4	MOS Printer	1.3.1.2.1.6	MGGS Miscellaneous / Cabling
1.3.1.1.2	MOS Sensor Communication	1.3.1.2.1.7	I&T MGGS
1.3.1.1.2.1	Antenna Unit	1.3.1.3	**Transportable General Ground Station (TGGS) [4x]**
1.3.1.1.2.2	Ku-Antenna Unit	1.3.1.3.1	TGGS Shelter
1.3.1.1.2.3	Wideband Modem Assembly (WMA)	1.3.1.3.2	TGGS Crew Workstations (3x)
1.3.1.1.2.4	CDL Interfacebox (CIB)	1.3.1.3.2.1	TGGS Processing Unit
1.3.1.1.2.5	DC Control / Amp assy	1.3.1.3.2.2	TGGS Map Computer
1.3.1.1.2.6	AC Power Control	1.3.1.3.2.3	TGGS Antenna Controller
1.3.1.1.2.7	Gigabit Switch	1.3.1.3.2.4	TGGS Monitor (2x)
1.3.1.1.2.8	Internal Cables and Wiring	1.3.1.3.2.5	TGGS Printer
1.3.1.1.2.9	Computer	1.3.1.3.2.6	TGGS Software
1.3.1.1.2.10	Cables	1.3.1.3.3	TGGS Sensor Communication System
1.3.1.1.3	MOS Communication Equipment	1.3.1.3.3.1	TGGS Transit Package No. 1
1.3.1.1.3.1	MOS VHF/UHF Communication and SATCOM	1.3.1.3.3.2	TGGS Transit Case No. 2
1.3.1.1.4	MOS Other Equipment	1.3.1.3.3.3	TGGS Antenna Subsystem
1.3.1.1.5	MOS Training Facility	1.3.1.3.4	TGGS Terrain Communication Equipment
1.3.1.1.5.1	AGS Operator Trainer	1.3.1.3.4.1	TGGS Communication Vehicle
1.3.1.1.5.2	UAV Flight Trainer	1.3.1.3.4.2	TGGS VHF/UHF Communication and SATCOM
1.3.1.1.5.3	MOS Training Processing Unit	1.3.1.3.4.3	TGGS HF Communication
1.3.1.1.6	MOB Software	1.3.1.3.4.4	Other Communication Equipment
1.3.1.1.7	MOB Test & Integration	1.3.1.3.5	TGGS Environmental Control System
1.3.1.2	**Mobile General Ground Station (MGGS) [11x]**	1.3.1.3.6	TGGS Electrical System
1.3.1.2.1	MGGS All Terrain Vehicle /w Shelter	1.3.1.3.7	TGGS Miscellaneous / Cabling
1.3.1.2.1.1	MGGS Terrain Vehicle	1.3.1.3.8	I&T TGSS
1.3.1.2.1.2	MGGS Shelter	1.3.1.4	**UAV Command & Control Element (UCE) [5x]**
1.3.1.2.1.2.1	MGGS Container (protected)	1.3.1.4.1	UCE Shelter
1.3.1.2.1.2.2	MGGS Crew Workstations (5 incl. 2 Remoteable Workstations)	1.3.1.4.1.1	UCE Container (protected)
1.3.1.2.1.2.3	MGGS Sensor Communication (indoor unit)	1.3.1.4.1.2	UCE Crew Workstations (2x)
1.3.1.2.1.2.4	MGGS Environmental Control System	1.3.1.4.1.3	UCE and Communication Equipment
1.3.1.2.1.2.5	MGGS Software	1.3.1.4.1.4	UCE Software
1.3.1.2.1.3	MGGS Electrical System	1.3.1.4.2	UCE Electrical System
1.3.1.2.1.3.1	Power Supply Generator	1.3.1.4.2.1	Power Supply Generator
1.3.1.2.1.3.2	Power Distribution Unit	1.3.1.4.2.2	Power Distribution Unit
1.3.1.2.1.3.3	Trailer	1.3.1.4.3	UCE Int & Test
1.3.1.2.1.4	MGGS Antenna Subsystem (outdoor unit)	1.3.1.5	**GS Test & Integration**

- Quantity (Production Quantity, Lot Quantity)
- Quality (operating environment factor, Technology difficulty Index of the mechanical or electronics portions).
- Economic (currency, escalation, Year of Economics, Country of Production, G&A Profit, Cost of money)
- Development (Engineering Difficulty; quantity of prototypes)
- System relationship (integration complexity)

4.7.3 Sample Calculation: VHF/UHF Antenna

To understand how ACES was used in this context, we present the case for the VHF/UHF ground station antenna. The manufacturer is unknown at this stage, however the Harris RF-9070 is a militarized, vertically polarized, omnidirectional transportable antenna designed for ground-to-air communication for use in other UAVs [15], and as such was used as a proxy for the AGS ground stations.

Figure 16 provides the technical specifications for the RF-9070. From the parameters, input values for the ACES estimation tool were generated. In this case, the weight and type of the antenna is linked with inherent tool values (e.g., production complexity, integration complexity, operational environment) as shown in Figure 17. The tool then generates the probable production costs, and on higher integration levels, the costs for

integration and test (see Figure 18 and Appendix A2 for translation from German to English). Generally the estimation is based on the assumption that military off-the-shelf components will be used.

The final estimated cost for the VHF/UHF antenna can be found in Figure 18 in the row labelled, in German, "Gesamtkosten" (Total Sum) (See Appendix A2 for definitions). These costs include, in 2009 USD, $27,415 for development, $115,991 for production, for a total cost of $143,406 for 11 units, or $13,037 per unit.

Specifications for the RF-9070

Electrical

- **Frequency Range**
  100 to 400 MHz (usable 90 to 470 MHz)
- **RF Power Capacity**
  400 watts
- **Input Impedance**
  50 ohm, nominal
- **Radiation Pattern**
  Omnidirectional
- **Polarization**
  Vertical
- **VSWR**
  ≤2.1 typical, 2.5:1 maximum
- **Gain**
  >2 dBi

Environmental

- **Temperature**
  Operating: –40° to +55° C (–40° to +131° F) Storage: –60° to +70° C (–76° to +158° F)
- **Relative Humidity**
  0 to 100%

Mechanical

- **RF Connector**
  Female, Type N
- **Deployed Dimensions**
  76H x 60D in (193H x 152D cm)
- **Finish**
  E512 per MIL-F-14072
- **Weight**
  20 lb (9.1 kg)
- **Mounting Interface**
  1.3 inch (3.3cm) threaded hole in center hub
- **Installation time**
  10 minutes, 2 people

Options

- RF-9071 Mounting Mast — A 6.5-foot (2-m) length of 1.3-inch (3.3-cm) diameter mast complete with mounting clamps. The mast is threaded at one end with an 11-1/2 NPT thread to match the antenna hub.

Figure 16: Harris RF-9070 parameters

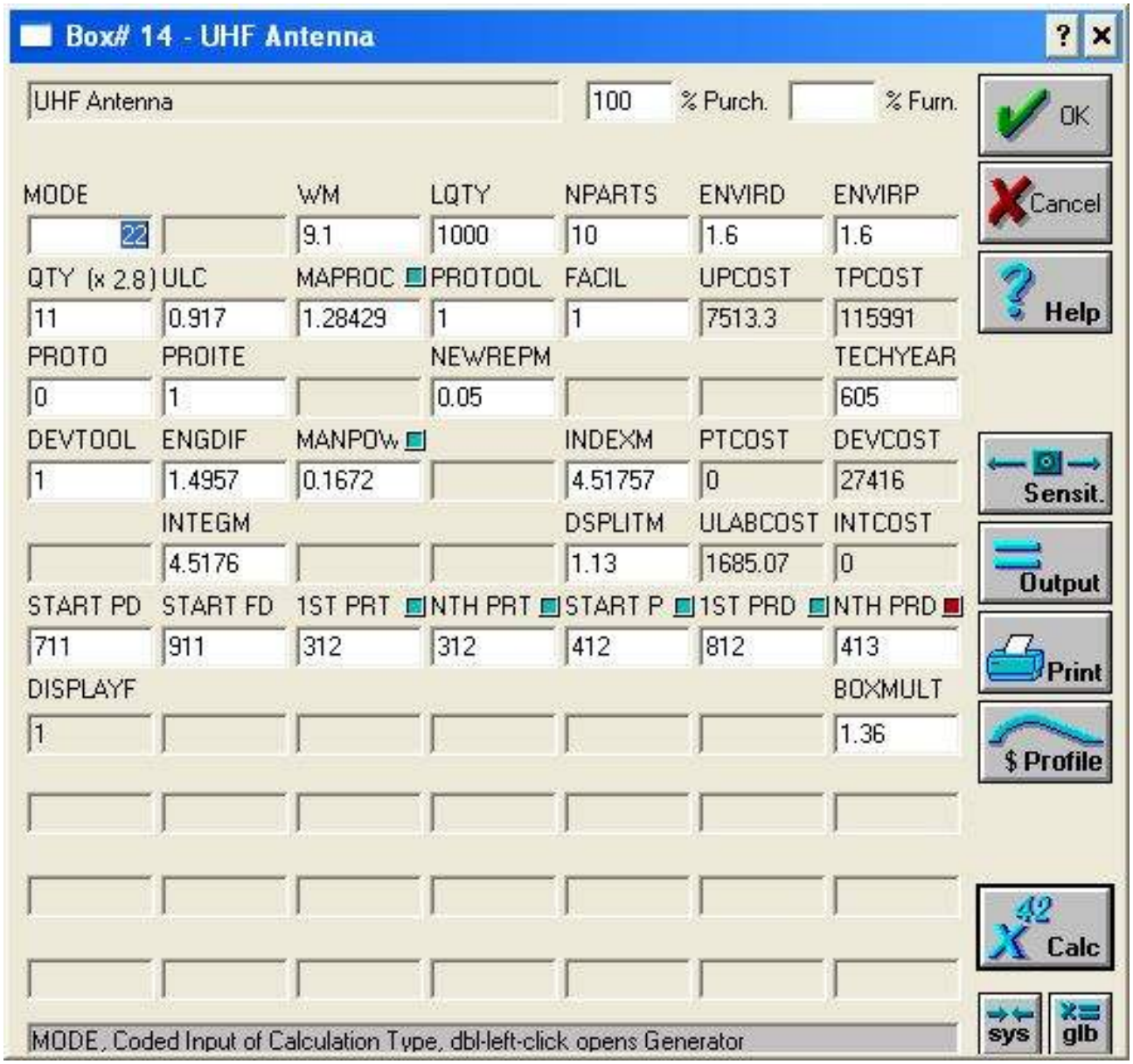

Figure 17: Harris RF-9070 input to ACES

Output Screen - UHF Antenna / $ (1209) / Skin Type 1

✔ Comb. Output
Decim. Output
✔ incl.Integ.Cost

		SOFTWARE	HW-DEVELOPMENT	HW-PRODUCTION	TOTAL COST
Analyse			361		361
Konzept Entwurf	Concept Draft		462		462
Zeichnungssatz	Concept Design		4,309	33	4,342
Detailkonstrukt.	Detailed Design		14,292	80	14,371
Systementwickl.	System		4,554	2,804	7,358
Prjt-Management	Project Management		1,825	16,154	17,980
CTV					
Dokumentation	Documentation		1,613	4,925	6,538
1. Zw-Ergebnis	Subtotal 1		27,416	23,996	51,412
Enhancement	Enhancement				
Produktion	Production				
Demonstrator	Prototype				
Kaufteile	Purchase			82,645	82,645
FertSoKos	Tooling			9,348	9,348
2. Zw-Ergebnis	Subtotal 2			91,994	91,994
Gesamtkosten	Total Sum		27,415	115,991	143,406
Integration Beistellung	Integration & Testing				

WE	-	WM	9.100	ENVIRD	1.600	ENVIRP	1.600	T-1 Cost	15,605
QTY	11	ULC	0.917	MAPROC	1.284	TSoA	605	HK1/Stk	7,513
PROTO	0.0	PLC	0.900	INDEXE		INDEXM	4.518	HK2/Stk	10,545
PSF		MANP	0.17	DSPLTE	1.000	DSPLTM	1.130	HK2+Sw	10,545
INP		OUTP		OBJECTS		UINT		Ges/Stk	13,037
SMFRAC	1.000	NEWDSFT		BOXMULT	1.360	MTBFE	0	Unit M	5,828
IMPR	ON	ESC	OFF	DISPLAYF	1	MTBFM	313012	Unit L	1,685

DEV-SCHEDULE

PRD-SCHEDULE

SW-SCHEDULE

SP 412 — 1U 812 — EP 413

Edit Skin

Figure 18: Harris RF-9070 output from ACES

5.0 RISK AND UNCERTAINTY ANALYSIS FOR NATO AGS

5.1 Background

The SAS-076 Task Group used Enhanced Scenario-Based Method (eSBM) [16] to perform risk and uncertainty cost analysis for the AGS acquisition. To conduct eSBM, the Task Group needed to

- Generate a point estimate for acquisition costs,
- Identify the position of the point estimate on the S-Curve,
- Identify and analyze major elements of risk and uncertainty,
- Select an appropriate Coefficient of Variation (CV),
- Develop scenarios, and
- Combine these components into an integrated whole.

5.2 Point Estimate and Position on S-Curve

The Task Group employed a number of techniques to estimate the costs of AGS system. These included learning curves, averages of historical data, CERs, and analogies. In many cases, cross checks were developed based on German experience with Eurohawk. Since it's necessary in eSBM to anchor a cost estimate to a point on a cumulative probability distribution, baseline costs were generated, by design, at the *median*, or the 50th percentile. Another choice could have been the *mean*. Generally, there's flexibility in choosing either, or perhaps a point in-between.

In the case of AGS, many items in the Cost Element Structure (Table 1), were estimated using unit learning curves or power-function CERs with a multiplicative random error term (e.g., $Y = \alpha Q^{\beta} e^{\varepsilon}$, where $Y =$ unit cost, $Q =$ lot-midpoint quantity, α and β are parameters, i.e., first unit cost on the learning curve (T1) and elasticity respectively, and $\varepsilon = N(\mu, \sigma^2)$ is the error distribution, where we assume the errors are normally distributed with mean μ and standard deviation σ.

Examples include the wing, fuselage, and empennage of the UAV, and final assembly, integration, test and check out (see section 4.1). In these cases, inserting a value of an explanatory variable into the equation yields an estimated median rather than a mean value [17]. In other cases, such as for software development where representatives from several participating nations each generated a cost estimate independently, a middle value (median) was selected as the baseline. Moreover, the CERs employed in producing the middle value were themselves median-yielding power-function equations. In other cases where costs appeared normally distributed, the choice of median or mean was a moot point since the values were equal. Examples include systems engineering and program management, initial spares, and support equipment.

5.3 Risk Elements

Next, the Task Group identified these major areas of cost risk and uncertainty[12]:

[12] Areas of risk were identified based on general knowledge of defense acquisition programs and the discipline of international economics, site visits to Northrop Grumman's International Program Office in Florida and to NATO's AGS Management Agency in Brussels, and on meetings with other key AGS acquisition officials, including the Chairman of the Board of Directors of the NATO AGS Management Organization.

- **Exchange Rate:** The AGS contract will be a firm-fixed price direct commercial sale to Northrop Grumman, with a ceiling price denominated in 2007 base-year euros, but with much of the work done in the United States. Converting from dollars to euros, then, is a major issue. Unfortunately, currency exchange rates are notoriously difficult if not impossible to predict accurately and consistently. The projections of Figure 4, using random walk theory, don't exactly inspire confidence in anyone's ability to hone in on the future value of the $/€ exchange rate.

  Since its introduction roughly a decade ago, the value of the euro has varied from a low of $0.83/€ in 2000 to a peak of $1.60/€ in 2008, a swing of 93%. More recently, during the height of the Greek credit crisis in early 2010, the euro fell to $1.18/€. It then returned to pre-crisis levels only to fall once again with the Irish debt crisis.

- **Inflation:** Inflation rates for AGS design, development and production will likely differ from values recently experienced in the aerospace industries in the United States, Canada, and Europe. The ICE team used a baseline value of 3% inflation per annum for out-year projections, weighted according to the relative contributions of the 14 NATO countries participating in the program. However, as Figure 19 shows, inflation as measured by the consumer price index, seems to be accelerating in Europe as the economic recovery gains traction. Defense inflation generally runs higher than economy-wide figures by perhaps 100 to 300 basis points per year, but follows the same trend. An increase in rates is a risk in the next few years.

Figure 19: Euro area inflation rate (actual change on consumer price index). Source: TradingEconomics.com

- **Schedule:** The acquisition of NATO AGS has continually slipped. Further delays will increase then-year dollar and euro costs due to inflation.

- **Software:** European participants in the AGS program, and Canada, are responsible for ground segment design, development, and build. Elements of the ground segment include several types of ground vehicles, command and control units, training equipment, and an extensive software development effort. The *baseline* count of equivalent source lines of code (ESLOC) is unusually large from a U.S. perspective[13], and includes no factor for *growth*. However, as Figure 20 shows, code growth on defense software development projects has been the norm.

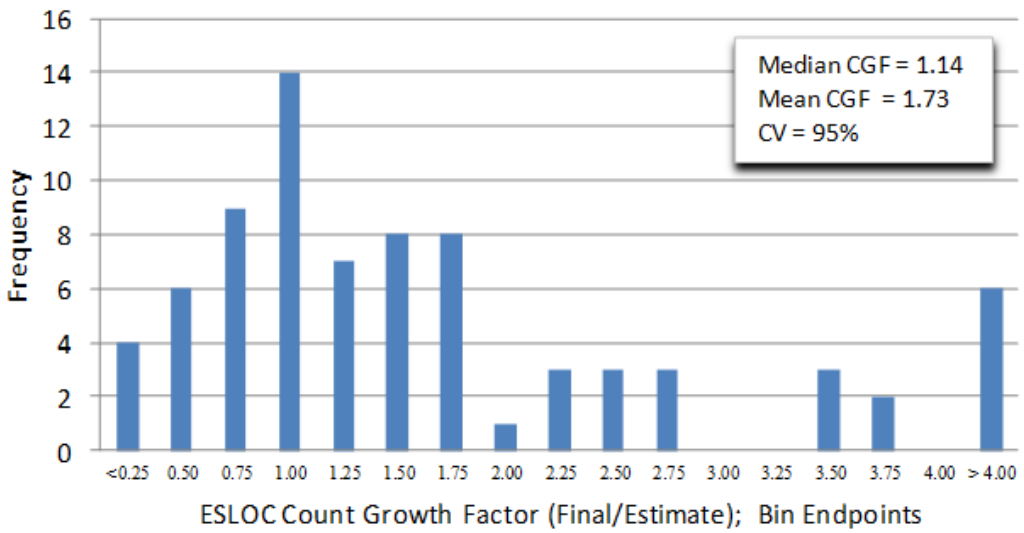

Figure 20: Growth count in estimated lines of code

- **Software (cont'd):** In the case of AGS, software will be developed in many different countries by many different companies, possibly using different computer languages and even operating systems. Levels of Capability Maturity Model Integration (CMMI) certification vary among vendors. Integration of software modules, hardware with software, and AGS with other ISR assets such as ASTOR from the U.K. and Global Hawk from the U.S. will all be required. Configuration management and software integration will be major issues. The AGS ICE team uses the *average* historical growth in ESLOC count as a proxy variable for risk for the entire software development effort.

- **Radar:** The MP-RTIP payload uses advanced electronically scanned array (AESA) technology currently employed on the F/A-18, among other platforms. However, the MP-RTIP development program has experienced significant cost and schedule growth which might translate into higher unit production costs.

- **Int'l. Participation:** 14 NATO countries intend to fund the acquisition of AGS. In return, each demands a fair share of the work. NATO intends to award a contract to Northrop Grumman Integrated Systems Sector International, Inc (NGISSI) who will have total system performance responsibility (TSPR) and will subcontract work to vendors in various countries, with some of the potential firms shown in Figure 21. Developing and producing hardware and software under this work-share constraint in such a multi-cultural, geographically-dispersed environment runs the risk of introducing inefficiencies into the program.

Prime	2nd Level Subs	Country
NGISSII USA	Northrop Grumman Systems Corp (NGSC)	USA
	CASSIDIAN (EADS)	Germany
	Potential subs to Cassidian: Retia ICZ (Czech Republic); Aktors (Estonia); Dati (Latvia); Elsis (Lithuania); Konstrukta (Slovakia); Hermes Soft Lab (Slovenia)	
	Selex Galileo	Italy
	General Dynamics Canada	Canada
	Kongsberg	Norway

3rd Level Subs Nations
Bulgaria
Czech Republic
~~Denmark~~
Estonia
Latvia
Lithuania
Luxemburg
Romania
Slovakia
Slovenia

Figure 21: International participation

- **Affordability:** Fitting the desired numbers and capabilities of UAVs and ground-segment elements under the NATO's ceiling price remains a challenge. A few years ago NATO and industry envisioned a mixed fleet of manned and unmanned air vehicles to perform the ground surveillance mission. However, that option was scrapped because of cost. Affordability continues to be an issue as many European nations struggle to reduce budget deficits and national debt. Denmark, for example, announced its intention in 2010 to withdraw from the program because of budget tightening.

5.4 Selection of CV

With a point estimate generated and major elements of risk identified, the Task Group needed a CV to implement eSBM. NATO, it's important to note, uses the Phased Armaments Programming System (PAPS) as its acquisition framework. In PAPS, AGS is near what we call a Milestone (MS) B decision in the United States. Further, although AGS is an Alliance rather than a U.S. DoD acquisition program, the prime contractor will be Northrop Grumman, and close to two-thirds of the costs will be incurred in the U.S. The use of benchmark CV data from the U.S., then, seems appropriate, especially since none is available for NATO acquisitions.

The Task Group selected a MS B CV of 51% based on the full sample of data for quantity-adjusted then-year dollar acquisition outcomes. That is, the Task Group regarded the quantity of UAVs and ground vehicles as exogenous but the rate of inflation as random, for purposes of generating an S-curve. Given affordability and exchange rate issues, the massive software development effort, and extensive international participation with each country demanding "noble work," the Task Group judged the higher-end of Milestone B CV values to be appropriate.

5.5 Scenarios

The Task Group bundled risks and uncertainties into three scenarios: baseline, pessimistic, and resource-constrained. The baseline scenario used "likely-to-occur" values or assumptions as shown in Figure 22[14]:

- An exchange rate of $1.35 per euro;
- An inflation rate of 3% per annum, based on best-estimates of inflation in the aerospace industries of the U.S., Canada, and Europe, weighted according to program costs to-be-incurred by each;
- Procurement of 8 UAVs and 15 ground-segment vehicles in accordance with NATO's AGS Program Memorandum of Understanding;
- Contract award in late FY2011;
- 91% learning on MP-RTIP, based on analogy to the Advanced Electronically Scanned Array (AESA) radar on the F/A-18 E/F aircraft; and
- Built-in redundancies or contingencies for operating in a NATO acquisition environment.

Elements	Baseline					Pessimistic					Constrained				
Exchange rate	$1.35 per €					$x.xx per €					$x.xx per €				
Inflation rate	3.00%					x%					x%				
						slip in schedule									
Quantities/Schedule	FY11	FY12	FY13	FY14	FY15	FY11	FY12	FY13	FY14	FY15	FY11	FY12	FY13	FY14	FY15
UAVs	2	2	2	2	0										
Ground Stations															
Transportable	1	1	1	1	0										
Mobile	2	3	3	3	0										
											change in quantities and schedule				
ESLOC Count	No growth					x% increase					No growth				
Radar	91% learning					x% learning					91% learning				
Int'l Participation	Built-in redundancy					x% delta to SE/PM					Built-in redundancy				
Affordability	Unconstrained					Unconstrained					Constrained				

Figure 22: Task Group scenarios

In keeping with the tenants of eSBM, the non-baseline scenarios did not represent *extreme* cases, but rather a set of conditions that could easily occur in the future. For example, the *worst imaginable* case for the U.S. dollar or the Euro might be a severe devaluation of either[15]. On the other hand, modest appreciation or depreciation of the dollar or Euro is certainly plausible, depending upon circumstances.

[14] Data that might be construed as business sensitive are omitted from the display.

[15] Pundits in Europe and the U.S. speculated in February 2010, for example, that the European Union, and the Euro, might not survive. Other pundits project financial Armageddon for the U.S. because of our enormous direct national debt ($14 trillion) and unfunded liabilities for Social Security, Medicare, and other entitlement programs (another $50 trillion).

5.6 S-Curve

With a point estimate, CV, and anchored position on the S-curve in hand, Figure 23 shows eSBM results. Values on the X-axis could be construed as somewhat business-sensitive, prior to contract award, and are therefore not displayed.

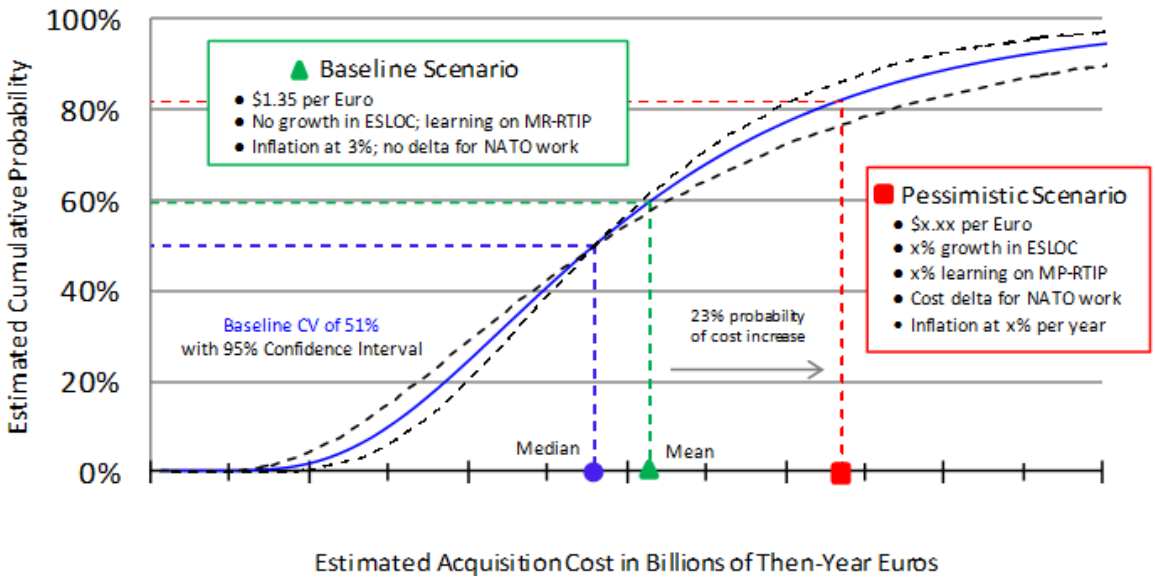

Figure 23: Estimated acquisition cost of NATO AGS (*Cost values are not displayed due to business sensitivity*)

Several points merit emphasis:

- Not all areas of risk and uncertainty are captured in the scenarios, nor do they need to be. That's the great advantage of employing a historically-based CV in computing an S-curve. The distribution implicitly captures the totality of events which will influence the cost of the acquisition. A maintained hypothesis, of course, is that historical variances will continue to hold.

- The scenarios reflect cost estimates for the events or assumptions they portray. In supporting the NATO AGS Management Agency (NAGSMA) in Brussels, the Task Group estimated and presented costs of each element of risk (e.g., the cost impact of a 50% increase in ESLOC count) within a scenario. The associated probabilities for the scenarios were simply read from the S-curve.

- The resource-constrained scenario was not displayed on the S-curve of Figure 6, and was instead regarded as a distinct, separate what-if drill. Estimating the risk and uncertainty of changes in acquisition quantity is generally beyond the purview of cost analysts. The changes often result from Congressional action, which can be hard to predict. The historical CVs presented here are all adjusted for quantity variation; if they weren't, they'd be far higher.

- The probability of NATO AGS acquisition costs increasing from the baseline to the pessimistic scenario is roughly one in four or five. Identification and quantification of this possibility can form the basis of risk-management planning by both the program office (NAGSMA) and the prime contractor.

5.7 S-Curve Excursion

To demonstrate the consequences of using an inaccurate CV, Figure 24 shows a second S-curve based on a hypothetical value of 10%.

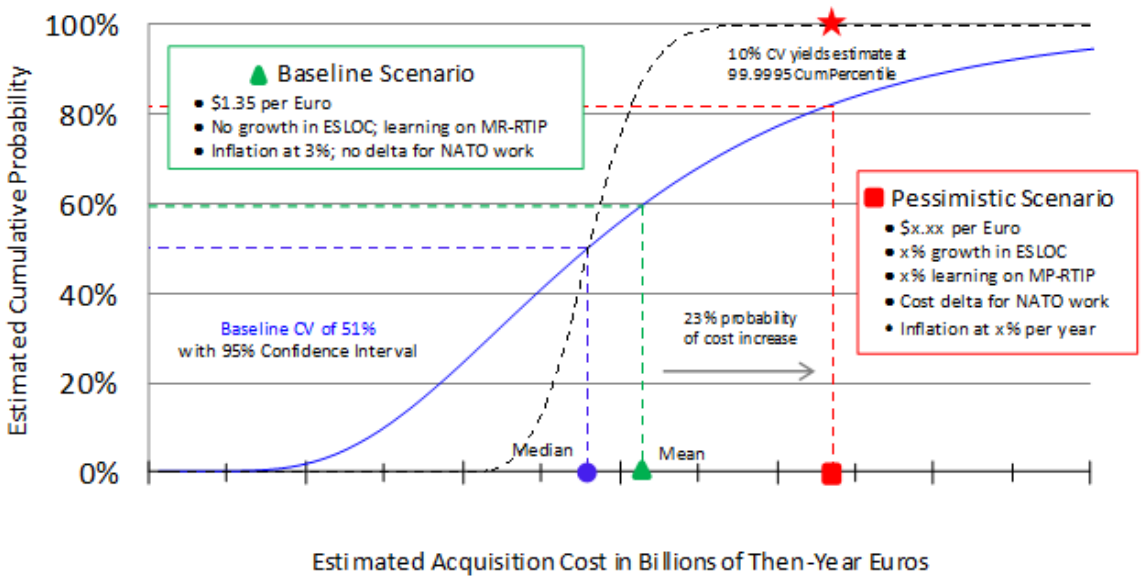

Figure 24: Estimated acquisition cost of NATO AGS (*Cost values are not displayed due to business sensitivity*)

If the 10% value had been used, the probability of costs reaching or exceeding the value of the pessimistic scenario would be calculated as only *five in one million*! Yet, to repeat, the parameters used in this scenario are realistic, modest deltas to the baseline. They include what the Task Group regarded as a very slight change in the exchange rate, a modest increase in the rate of inflation, use of a *mean* growth factor for number of equivalent source lines of code, and a percentage increase in the cost of system engineering/program management due to international participation that at least one member of the team thought was appropriate only if two rather than 14 nations were involved in AGS design, development, and build. In short, the steep S-curve would deceive stakeholders into believing that risk was slight and the probability of significant cost growth minimal.

Specification and adoption of a pessimistic scenario in eSBM, which can easily be adopted in Monte Carlo methodology, too, has the virtue of providing the means with which to perform a sanity check on the value of the CV. If the resulting S-curve is too steep to be plausible, then underlying risk and uncertainty distributions for major cost elements must not have been calculated correctly. Chances are that at least one was too narrow.

Finally, since the mean of a lognormal distribution involves a variance term, use of the steeper S-curve would have resulted in a lower value of expected cost.

6.0 CONCLUSIONS

Working as a coherent team, the Task Group was successful in generating a credible, complete, scientifically-sound independent cost estimate on the NATO AGS acquisition program. Specific cost estimates for the program are business-sensitive information and cannot be published. Nevertheless, these conclusions are offered:

- It is, in fact, possible to generate an ICE on a major acquisition program using an international team of dedicated cost analysts.
- It is difficult but not impossible to share cost data across nations. Non-disclosure forms need to be completed, and information closely held. Further, it is useful if not essential to obtain buy-in early on from major stakeholders. The SAS-076 team generated an ICE development plan and obtained signatures from the Chairman of the Board of AGS Management Organization (NAGSMO), the Director the AGS Management Agency (NAGSMA), and the Director the SAS-076 study group.
- Major elements of cost risk on the program are:
  - Software development;
  - International participation;
  - Exchange rate;
  - Inflation rate; and,
  - MP-RTIP radar.
- The SAS-054 guidelines on methods and models for cost analysis are, in fact, applicable in a cost-estimating environment. The SAS-076 Task Group followed these guidelines extensively and recommends no major changes.

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Appendix A-1: A GENERAL OVERVIEW OF THE ADVANCED COST ESTIMATING SYSTEMS (ACES)

The parametric hardware, software and built-in life cycle model ACES is a computerized method for deriving cost estimates of electronic and mechanical hardware assemblies and systems, as well as software programs and the complete life cycle analysis. The ACES model combines both hardware and software estimating in one model. The model is applicable to all aspects of hardware and software acquisition from preliminary design to development and production and life cycle costing analysis.

The model estimates the costs associated with design engineering, drafting, project management, documentation, system engineering, special tooling and test equipment, and material, labour and overheads. It also addresses the feasibility of a project by costing a preliminary design phase. Costs to integrate subsystems and assemblies into a system, and to test the system for required operation are also estimated by the model.

The model will compute and display the cost for development and/or production, as well as the software cost categories, separately for the mechanical and electronic parts of the hardware, and can be used to cost electronic or mechanical items individually.

The fundamental parametric data used by ACES are:

- Quantities of equipment to be developed, produced, or otherwise acquired.
- Schedules for preliminary development, full scale development, production, and integration and testing, including lead times for set-up, parts procurement (non-long lead items), and redesign.
- Manpower requirements for engineering and software.
- Hardware geometry consisting of size and weights of electronic and mechanical elements.
- Amount of new design required and complexity of the development engineering task.
- Operational environment and development and production specification requirements.
- Technology difficulty Index of the mechanical and electronics portions of the hardware.
- Fabrication process to be used for production.
- Pertinent escalation rates and mark-ups for general and administrative charges, profit, R&D, cost of money, and material handling.
- Technological state-of-the-art.
- Calculating technology based INDEX factors from any known cost.
- Estimating the individual costs of multiple lot productions.
- Calculating the costs for design integration of purchased equipment.
- Calculating the costs for design integration of furnished equipment
- Calculating technology based indices of non-homogeneous hardware items.
- Modelling any resource expenditure distribution desired.

- Calculating field reliability (MTBF) of electronic and mechanical assemblies.

All of the ACES parameters are dynamically linked to one or more other inputs in computing model results. Usually, a change to one input will require a change to others as well. An example is production quantity. This variable has a direct effect on schedule and manufacturing process. These types of inter-dependencies are what distinguish a model from a calculator.

Appendix A-2: ACES INPUT AND OUTPUT PARAMETER DEFINITIONS

Tables 30–32 define the input and output parameters as they apply to they apply to the Harris RF-9070 UHF/VHF antenna.

Table 30: Input definitions for ACES parameters as they apply to the Harris RF-9070 UHF/VHF antenna

Parameter	Value	Description	Specification
Mode	22	The MODE defines the input required to describe the hardware development and/or production scenario.	MODE 22 is used for an item that is mechanical or structural.
WM	9.1	WM is the weight of mechanical item in kilograms.	Value from the specification.
LQTY	1000	Lot quantity indicates the total size of a production lot when only a portion of the larger production lot is used by the element.	Assumption that the Antenna is part of a larger lot.
ENVIRD	1.6	In general this variable relates the cost of hardware development to the requirements of the environment in which the hardware must operate. It is a measure of the portability, reliability, structure, testing and documentation required for acceptable contract performance.	The recommended value for mobile military equipment.
ENVIRP	1.6	In general this variable relates the cost of hardware production to the requirements of the environment in which the hardware must operate. It is a measure of the portability, reliability, structure, testing and documentation required for acceptable contract performance.	The recommended value for mobile military equipment.
QTY	11	Production Quantity to indicate the number of production units. for the element.	Equal to the number of ground stations.
UCL	0.917	Unit Learning Curve	A typical value for military equipment.
PROTO	0	Number of prototypes	Assumes the antenna is a purchased item and no prototype was necessary.
PROITE	1	Prototype iterations indicate the number of design/redesign cycles needed to complete the final prototype	Using a standard factor for generating design integration cost.
NEWREPM	0.05	New/Repeat mechanical design	Using a low factor for generating design integration cost.
ENGDIF	1.4957	Engineering difficulty	Using recommended mean values
INDEXM	4.51	INDEXM is a measure of the equipment item's technology, its produceability (material, machining and assembly tolerances, machining difficulty and surface finish, etc.).	Using recommended values from an index table inside the tool or calibrated values from other sources.
INTEGM	4.51	Integration difficulty for mechanic. INTEGM defines the level of the structural contribution to the Integration and test effort for this element.	A Table and Generator from the tool is provided to suggest appropriate values.
START PD - NTH PRT		Start and end date for the development.	Dates from the program office.
START P - NTH P		Start and end date for the production.	Dates from the program office.

Table 31: Output definitions for ACES parameters as they apply to the Harris RF-9070 UHF/VHF antenna

Cost Element	Development	Production	Total Cost
Concept Draft, Concept Design, Full Draft, Detail Design	These cost elements contain all costs for drafting the Detailed Design in the development phase.	These cost elements contain all costs for drafting the Detailed Design in the production phase.	
System	This element encompasses the system engineering effort to define the system, and integrated planning and control of the technical program efforts of design engineering, logistic engineering, production engineering and integrated test planning.	Same as the development but limited to production needs.	
Project Management	Project Management includes administrative and technical management and other program-oriented personnel. These costs include all efforts to assure the proper and cost-effective performance of the contract between the customer, the company and its subcontractors.	This cost element is similar to the development effort but limited to monitoring and controlling production activities.	
Documentation	This cost element contains all costs associated with deliverable documentation.	This cost element is similar to the development effort but limited to production items.	
Prototype	These costs include all labour and material required to fabricate, assemble and test the prototypes.		
Tooling	This cost element contains all costs associated with the design, fabrication, purchase and calibration of all special tools, fixtures and test equipment required to handle, build and test prototype components.	Same as the development category but includes production related tooling.	

Table 32: Output definitions (Cont'd) for ACES parameters as they apply to the Harris RF-9070 UHF/VHF antenna

Cost Element	Development	Production	Total Cost
Production		This cost element includes all labour costs involved in the recurring manufacturing efforts to fabricate, assemble. It also includes all material that is contained in the completed article.	
Integration & Testing	This cost element includes all costs associated with the test and integration for this element into the system.	This cost element includes all costs associated with the test and integration for this element in the system.	
T-1 Cost	Cost for the first unit.		Cost for the first unit.
HK1/STk (Unit Production Cost (UPC))	Unit production cost (The unit production cost for the specified production quantity. It includes production labour, material and overhead.)		Unit production cost (The unit production cost for the specified production quantity. It includes production labour, material and overhead.)
HK2/STk (Amortized UPC/Quantity)	Amortized Unit Cost (The Amortized Unit Cost is calculated as Production Total Cost divided by Quantity)		Amortized Unit Cost (The Amortized Unit Cost is calculated as Production Total Cost divided by Quantity)
HK2+Sw (Amortized UPC + Software)	Amortized Unit Cost plus Software costs		Amortized Unit Cost plus Software costs
Ges/Stk (Total Sum/Quantity)			Total costs divided by the quantity