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I am submitting herewith a thesis written by Ward Andrew Huffine entitled "Adapting a Tier 2 Unmanned Aerial Vehicle to Provide an Electronic Surveillance and Geolocation Capability". I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

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Adapting a Tier 2 Unmanned Aerial Vehicle to Provide an Electronic
Surveillance and Geolocation Capability

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Ward A. Huffine
August 2009

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Dedication

This thesis is dedicated to my wife Joy, whose support was my foundation, to my classmates Lieutenant Commanders Jeffrey “Stinky” Kjenaas and Matthew “Fredo” Bogue, whose challenges were my stepping stones, and to the memory of my father Clayton, whose stories of flying have always been my inspiration.

Acknowledgements

I would like to thank:

My advisor Dr. Peter Solies and my committee members, Professor Richard Ranaudo and Professor John Muratore, for their instruction, help and guidance during the writing of this paper.

The Staff at UTSI particularly Ms. Laura Horton and Ms. Rebecca Layman for their friendly and thoughtful assistance.

Ms. Kim Rusk, my supervisor and Assistant Chief Operational Test Director at VX-9 for her encouragement and support.

Captain Daniel “Cheese” Doster, Commanding Officer of VX-9, China Lake, CA

Dr. Jay Smith, Center for Naval Analysis, VX-9 Analyst, China Lake, CA

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Mr. Matthew Keehen and Ms. April Nelson, Advanced Weapons Laboratory, (AWL) NAWS, China Lake, CA (MIDS points of contact)

Mr. Ken Mathiasmeire Institute of Defense Analysis supporting Director of Operational Test and Evaluation, The Pentagon Washington DC

Commander Alan “Newt” Bradford, EW Branch Head VX-9, China Lake, CA

And others have my gratitude.

Abstract

The purpose of this thesis was to investigate if it would be possible to integrate a developmental Radar Warning Receiver named “The *Puffer*” onto a Tier 2 Unmanned Aerial Vehicle, and incorporate the Multifunctional Information Display System/Low Volume Terminal into the UAV’s ground control station. This integration of systems would become a low cost platform that could provide an Electronic Surveillance and geolocation capability of known mobile threat systems. The results of this investigation showed that the *Puffer* could be integrated on to the Tier 2 UAV with minor modifications. To control and fully integrate the downlink messages from multiple UAVs plus add the capability to send the information out to other units over Link16 would require a major hardware effort with a sizable software integration effort. While this would be an extensive project, the results could be done at a significant cost saving compared to the manned platforms in use today.

Disclaimer

This thesis is Unclassified. All information has been obtained through open sources, and released documents in the public domain. A concerted effort has been made to give credit to those sources used to provide background information. This paper does not represent the opinion of the Office of the Secretary of Defense, the Naval Air Systems Command, Commander Operational Test and Evaluation Force, or any other organization currently researching the possible uses of Unmanned Airborne Systems. There is currently no program known to the author that this research paper might apply to, nor has the author been involved in any such program.

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1. Purpose

The purpose of this thesis is to investigate the challenges involved in adapting a Tier 2 Unmanned Aerial Vehicle (UAV) to perform an Electronic Surveillance (ES) and Geolocation mission, providing a passive, real-time targeting capability of mobile electronic threat emitters to combat commanders in the field. This capability would be provided by integrating the *Puffer* Radar Warning Receiver (RWR) on the aircraft and a Multifunctional Information Display System/Low Volume Terminal (MIDS/LVT) into the UAV's Ground Station. Additional displays and software would be added to the payload/mission commander's station to provide situational awareness through an analysis of received threat signals Direction of Arrival (DOA). The resulting analysis of threat DOAs in the form of an emitter identification and location would then be transmitted to the combat commanders and other theater assets via the MIDS/LVT using Link16 messaging.

2. Relevance

This investigation was originally prompted by the Office of the Secretary of Defense (OSD) desire to provide an Airborne Electronic Attack (AEA) capability using UAVs.

The OSD Unmanned Aircraft Systems (UAS) Roadmap, 2005-2030 (4 August 2005)¹ states as its number one goal in the Executive Summary:

“1. Develop and operationally assess for potential fielding, a joint unmanned combat aircraft system capable of performing Suppression of Enemy Air Defenses (SEAD), Strike/Electronic Attack (EA)/Intelligence, Surveillance and Reconnaissance (ISR) in high threat environments. (OSD, USAF, USN).”

Additionally in “Appendix A: Missions of the Roadmap” the roadmap’s author asks that several “themes” be taken into consideration when assessing the use of UAVs across mission areas. One of these themes is that the planner should look to commercially available solutions to strategic questions. Because technology is progressing so fast “a 50 percent solution tomorrow may be better than a 70-80 percent solution in three years or a 95 percent solution in 10 years.”

In the Executive Summary of the OSD Unmanned Systems Roadmap (2007-2032) 10 December 2007, states that “Unmanned systems are highly desired by combatant commanders (COCOMs) for the many roles these systems can fulfill.” Included in a subsequent list of tasks, “signals intelligence” and “precision target designation” are in the top three².

UAS usage has increased at an accelerated pace because of the Global War on Terror (GWOT) both internationally and domestically³. In an article, the Associated Press (AP) reported that UAV usage in all areas swelled to over 500,000 hours of flight time, mostly due to the troop surge in Iraq. Further in the article, it was noted that UAV flight time for all of the military services rose from 165,000 flight hours in FY 2006 to 258,000 hours in

¹ Office of the Secretary of Defense (OSD), “Unmanned Aircraft Systems (UAS) Roadmap, 2005-2030”, 4 August 2005

² Office of the Secretary of Defense (OSD), “Unmanned Systems Roadmap, 2007-2032”, 10 December 2007

³ Associated Press, “Rise of the Machine: UAV use Soars”, 02 Jan 2008

FY 2007. UAS assets have traditionally been used as photo reconnaissance vehicles; however there has been an ongoing effort to employ these systems in an offensive role as well⁴. “By all predictions, the US military’s interest in electronic warfare (EW) and signals intelligence (SIGINT) payloads for unmanned aerial vehicles (UAVs) will continue to increase.” This opening sentence of an article entitled “EA/SIGINT Payloads for UAVs” in the June 2008 issue of The Journal of Electronic Defense confirms that the development and deployment of these types’ of payloads are an international effort. The article continues to explain how this effort has become a balancing act of providing a wider range of capabilities in lighter payloads while keeping the cost of the payload down.

This Investigation explores the possibility of using currently available UAV assets to provide an additional ES capability to combat commanders that could be brought to the fight and meet the intent of the OSD UAV Roadmaps.

⁴ “EA/SIGINT Payloads for UAVs”, The Journal of Electronic Defense, Vol. 31 – No. 6, June 2008, pp. 32-40.

3. Investigation Question

This thesis is an investigation of alternatives that explores the possibility of combining a combat proven Tier 2 UAV, the MIDS/LVT communications system, with a developmental UAV RWR system. The resulting system would provide an enhancement, if not an actual alternative, to the current manned AEA Platforms in the area of threat emitter geolocation. This investigation would be a qualitative study that applies analysis techniques to available information to draw viable conclusions.

The primary investigation question is **“Would a Tier 2 UAV combined with the *Puffer* RWR and MIDS/LVT systems, provide a real-time threat emitter geolocation and targeting capability to field combat commanders?”**

Obtaining the answer to this question involves identifying the modifications required:

- For the UAV to carry the *Puffer*
- To integrate the MIDS/LVT into the ground control station, and
- To systems and software needed to analyze and disseminate threat data collected by the UAV platform to combat commanders.

Areas that may be investigated for modification include, but are not limited to,

- aircraft structure and design,
- aerodynamic properties and flight envelop impacts,
- electro-magnetic interference,
- crew station integration, and
- crew resource management (CRM) and human factors.

Two Tier 2 UAV systems have been identified as possible candidates for this effort, the Aeronautics Defense Systems LTD “*Aerostar*” and the Geneva Aerospace “*Dakota*”.

Both of these systems are combat proven, widely used, relatively inexpensive, and readily available.

Additionally, this thesis identifies a Concept of Operations (CONOPS) where the new system might be logically deployed and missions it may support. With the mission known, the feasibility of the modification to deploy the system are determined.

In keeping with the theme referenced in section 2, this investigation will focus on feasible modifications (actually could work), which could be made quickly (low modification-schedule), economically (cost), and would provide combat commanders with an additional capability (performance).

4. Systems Descriptions

This section presents the three systems under investigation, that when integrated, will provide an additional ES and targeting capability to COCOMs for use in the battle space.

4.1 Tier 2 UAV Systems

Tier 2 UAV systems are described in the 2007 OSD UAS Roadmap as a medium altitude UAV capable of high endurance missions. Medium altitude is defined as 10,000 to 25,000 feet and high endurance is greater than 6 hours.

4.1.1 Aeronautics Defense Systems LTD “*Aerostar*” UAV

The *Aerostar* UAV (figure 4-1) has been in service since 2000. It is a multi-mission system capable of carrying various payloads⁵. The current configuration under test at NAVAIR, NAS Patuxent River, MD contains a POP-200 Electro-Optic/Infra-Red (EO/IR) camera and an Automatic Identification System (AIS) ship identification system. Within 18 months of entering service, the Israeli Defense Forces logged in excess of 10,000 operational flight hours. At present, the *Aerostar* has accumulated over 40,000 operational flight hours with a Mean Time Between Mission Failures (MTBMF) of 12,000 hours⁶. The *Aerostar* is a high wing, pusher aircraft. Dual booms support twin vertical stabilizers with a connecting horizontal stabilizer placed above the wing plane. Table 1 contains operational parameters of the *Aerostar* UAV. Additional measurements for the *Aerostar* may be found in Appendix D.

⁵*Aerostar* UAV Sales Brochure by Aeronautics Defense Systems Limited

⁶ Email from Andy Pontzer Additional *Aerostar* information Received 30 January 2009, 060155 PST



Figure 4-1. Aerostar UAV

Table 1. ADS Ltd *Aerostar*^{5,6,7,8}

Dimensions	Measurement
Wing span	21.0 ft (6.5 m)
Wing mean cord	21.6 in (54.9 cm)
Length overall	15.0 ft (4.5 m)
Fuselage: Max width	14.0 in (35.6 cm)
Fuselage: Max depth	12.0 in (30.5 cm)
Height Overall	4.0 ft (1.2 m)
Tailplane span	5.3 ft (1.6 m)
Wheel Track	5.1 ft (1.5 m)
Wheelbase	3.5 ft (1.1 m)
Payload Volume	2.33 ft ³ (0.066 m ³) 14"x24"x12"
Weights	
Weight empty	220 lbs (100 Kgs)
Max Fuel weight	110 lbs (50 Kgs)
Max Payload	110 lbs (50 Kgs)
Max T-O and Landing weight	440 lbs (200 Kgs)
Performance	
Max Level Speed	110.0 kts (203.5 km/hr)
Cruise Speed	62.0 kts (114.7 km/hr)
T-O Speed	60.0 kts (111.0 km/hr)
Landing Speed	50.0 kts (92.5 km/hr)
Stall Speed	49.0knts (90.7 km/hr)
Max rate of climb at sea level	1000 ft/min (304.8 m/min)
TO Distance	975 ft (300 m)
Landing Distance	Arrested
Service Ceiling	10,000 ft MSL
Operational Radius	279 nm (516.2 km)
Endurance	7-9 hrs
Power Plant	
490 IA flat twin 2 stroke	38 hp (50.96 kW)
Fuel Capacity	15.8 US gal (60.0 ltr)
Payload Power	400 watts @ 28V and 75 watts @ 12V
Sensenich W29KH-18 Propeller	2 blade 18 in (45.7 cm) Pusher
Replacement cost	\$250,000
Abbreviations: cm – centimeters ft – feet gal – gallons hp – horsepower hrs – hours in – inches Kg - kilogram km – kilometers knt – nautical miles per hour kW – Kilowatts ltr - liters m – meters MSL – Mean Sea Level	

7 Email request to Andy Pontzer at NAVAIR Pax River for additional *Aerostar* measurements. Received 20 January 2009, 13:13
See Appendix D for attachment information

8 Raymer, Daniel P., *Aircraft Design: A Conceptual Approach*, 4th ed. American Institute of Aeronautics and Astronautics, Inc.
Reston, VA 2006

4.1.2 Geneva Aerospace *Dakota*TM UAV

The *Dakota*TM UAV (figure 4-2)⁹ is used by several military agencies for surveillance and other missions. It has also been used as a sensor platform for the testing of an UAV aircraft avoidance system. This Tier 2 UAV has a payload capacity of 80 pounds (36.2Kgs) which can be carried for 4.5 hours with the standard fuel tank configuration of 7.0 gallons US (26.5 liters). The *Dakota* pictured is a tractor aircraft with a high wing, conventional aft tail arrangement, and conventional (tail dragger) landing gear. The *Dakota* that was used for measurements and subsequent calculations had a tricycle landing gear configuration. Table 2 shows the *Dakota*'s dimensions, weights and performance parameters.



Figure 4-2. Geneva Aerospace *Dakota*

⁹ *Dakota* UAV Sales Brochure by Geneva Aerospace

Table 2. Geneva Aerospace *Dakota*^{TM 9, 10}

Dimensions	Measurement
Wing span	15.6 ft (4.76 m)
Wing mean cord	1.58 ft (0.48 m)
Airfoil	Eppler 560 (root and tip)
Length overall	9.5 ft (2.9m)
Fuselage: Max width	1.12 ft (0.34 m)
Fuselage: Max depth	1.64 ft (0.5 m)
Height Overall	3.42 ft (1.4 m)
Tailplane span	5.25 ft (1.6 m)
Wheel Track	3.41 ft (1.04 m)
Wheelbase	3.08 ft (0.94 m)
Payload Volume	2.33 ft ³ (0.066 m ³)
Weights	
Weight empty	160 lbs (72.7Kgs)
Max Fuel weight	48 lbs (21.8 Kgs)
Max Payload	80 lbs (36.4 Kgs)
Max T-O and Landing weight	240 lbs (109.1 Kgs)
Performance	
Max Level Speed	100 kts (185 km/hr)
T-O Speed	55 kts (101.75 km/hr)
Landing Speed	50 kts (92.5 km/hr)
Stall Speed	40 kts (74 km/hr)
TO Distance	
Landing Distance	
Max rate of climb at sea level	1000/ft/min (304.8 m/min)
Operational Radius	170 nm (314.5 km)
Service Ceiling	12,000 ft MSL
Endurance	4.5 hrs
Power Plant	
3W-240iB2TS flat twin 2stroke	22 hp (16.4 kW)
Fuel Capacity	7.0 US gal (26.5 ltr)
Payload Power	300 W
H. Fuch CFK Propeller	2 blade 34.1 in (86.7 cm)

¹⁰ Lednicer, David, "The Incomplete List of Airfoil Usage"

4.2 “Puffer” RWR

4.2.1 *Puffer* Development

The following description of the *Puffer* is taken from an article by Pete Bartolomeo in the Fall 2005 issue of *Aircraft Survivability*¹¹.

The *Puffer* (figure 4-3) was developed as a light weight RWR for UAVs. UAVs used as a reconnaissance platform have been a casualty of war since their early deployment during the Viet Nam conflict¹² and Operation Allied Force in 1999¹³. Currently, British UAV losses stand at 30 from missions flown during Operation Enduring Freedom and Operation Iraqi Freedom¹⁴. Several of these losses can be directly attributed to strikes from ground launched missiles. As UAV usage grows and the aircraft becomes more sophisticated and expensive, some kind of self protection from hostile fire will be required. The *Puffer* was developed in partnership between NAVAIR’s Survivability Division and BAE Systems of Nashua, NH; to fill this expected requirement for a low cost, light weight RWR meeting the strict size, weight and power constraints of an unmanned system.

The *Puffer* has the ability to provide ground operators with the identity, the quadrant of arrival and power output of threat signals in relation to the aircraft, by relaying this information from the aircraft through the UAV’s standard downlink transmitter¹¹. Table 3 identifies the physical properties of the *Puffer*. Flight test of the *Puffer*’s detection capabilities was conducted at the Electronic Combat Range (ECR), China Lake, CA in 2007. Figure 4-4 shows the proposed configuration of the *Puffer* to be installed on the Tier 2 UAV Platform.

¹¹ Bartolomeo, Pete, “Survivability Initiatives for Unmanned Aerial Vehicles (UAVs)”, *Aircraft Survivability* – Fall 2005, pp. 26-27

¹² Wikipedia, “UAV usage in Viet Nam”,

¹³ Wikipedia, “1999 NATO Bombing of the Republic of Yugoslavia”

¹⁴ Gobel, Greg, UAV Losses, “Modern Endurance UAV’s”,

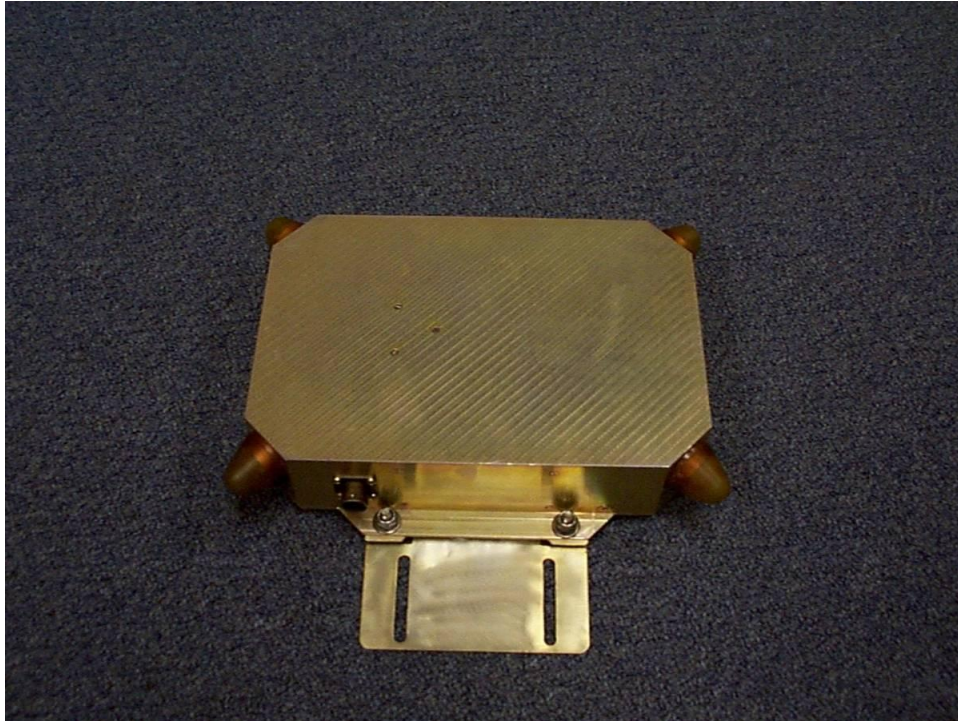


Figure 4-3. *Puffer* RWR

Table 3. *Puffer* Specifications ¹¹

Attribute	Measurement
Length	10 in (25.4 cm)
Width	7 in (17.78 cm)
Height	2 in (5.08 cm)
Weight (<i>Puffer</i> alone)	2.7 lbs (1.23 kg)
Weight (installed system)	Approx 4.0 lbs (1.82 kg)
Power draw	17 watts

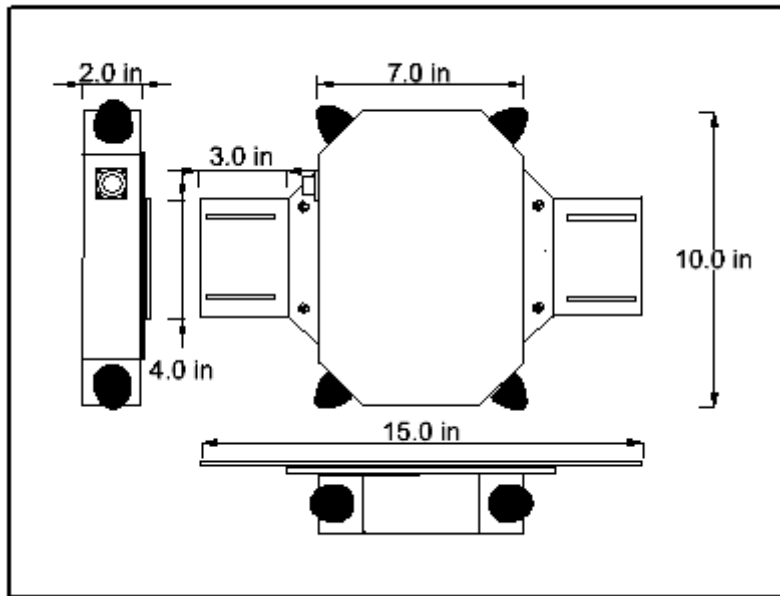


Figure 4-4. Proposed *Puffer* Configuration for Installation

4.2.2 *Puffer* Antenna Sensitivity Engineering

To implement the algorithm for refining the direction of arrival (section 7.2.3.2), the *Puffer* antennas will need to have a higher sensitivity to signals being detected in the main lobe and less sensitive to side lobe and back lobe acquisition. Because the back lobe detections would be 180° out from the main lobe of detection the signal detected on the back lobe would be cancelled and the power level set to null.

4.2.3 *Puffer* Wetted Surface Calculations

The wetted area of the *Puffer* will be calculated as a rectangular box that is 2 inches high by 7 inches long by 10 inches wide. The brackets that mount the *Puffer* to the aircraft are between .125 and .25 of an inch thick which are attached to the fuselage of the aircraft. Most of the area of the bracket will be covered by the *Puffer* itself. For this reason, the bracket's contribution to the overall *Puffer* wetted area is minor and will not be included in the *Puffer*'s wetted surface area calculations.

Sides

$$2\text{in} \times 7\text{in} \times 2 \text{ sides} = 28\text{in}^2$$

$$2\text{in} \times 15\text{in} \times 2 \text{ sides} = 60\text{in}^2$$

Bottom

$$7\text{in} \times 15\text{in} = 105 \text{ in}^2$$

Top

$$7\text{in} \times 15\text{in} = 105 \text{ in}^2$$

The top calculation will be included because the *Puffer* may not be mounted completely flush with the bottom of the fuselage. The mounting brackets will lower the *Puffer* from the bottom of the fuselage approximately .25 inches. By including this measurement, the bracket wetted surface area is compensated for.

$$\text{Total } Puffer \text{ wetted area } (S_{\text{wet}Puffer}) = 298\text{in}^2/144\text{in}^2/\text{ft}^2 = 2.1\text{ft}^2$$

4.2.3 Using the *Puffer* for Geolocation

The operational concept of the deployed *Puffer* system would be to install a *Puffer* system on, at least three UAVs (see section 6.1). The downlinked information would be combined and analyzed by a computer program resident in the ground station's Payload Commander's console computer. Using the quadrant of arrival of the threat system's signal, the UAV's position at the time of intercept, the received characteristics of the signal, and a dictionary of possible threat systems with these characteristics, the geolocation program would combine information downlinked from all of the UAVs, to develop a location for the threat. This location would then be transmitted to the COCOMs and other theater assets via standard Link16 messages through the MIDS/LVT for further dissemination and action.

4.3 MIDS/LVT and Crew Station Description

4.3.1 MIDS/LVT Description

The Link16 and the MIDS/LVT (figure 4-5) system has been so successful that it is the primary secure communication device for most of the US military in all areas of combat, land, sea and air. Additionally, MIDS/LVT is used by many North Atlantic Treaty Organization (NATO) allied countries in fighter, surveillance and patrol aircraft. Besides Link16 data transfer capabilities, MIDS/LVT provides secure voice and Tactical Air

Navigation System (TACAN) information¹⁵. Table 4 describes the MIDS/LVT capabilities and characteristics¹⁶.



Figure 4-5. MIDS/LVT Terminal

¹⁵ Link16 MIDS/LVT Reference Defense Industry Daily,

¹⁶ Rockwell Collins, MIDS/LVT Sales Brochure

Table 4. MIDS/LVT Characteristics ¹⁶

Attribute	Measurement
Length (includes connectors)	14.75 in (37.5 cm)
Width	7.5 in (19.5 cm)
Height	7.5 in (19.5 cm)
Weight	57 lbs (25.9Kgs)
Input Power Options	115 VAC 400 Hz 3 phase
	+140 V DC
	230 VAC 50 Hz single phase
	115 VAC 60Hz 3 phase
	23 VDC
Host Interfaces	Mil Std 1553
	Ethernet
	PhEN 3910
	X.25
Open Architecture	VME/RJ422 Buses
	SEM-E cards
Abbreviations: Hz – Hertz VDC – Volts Direct Current	
VAC - Volts Alternating Current	

At NAVAIR's Advanced Weapons Laboratory (AWL), a MIDS/LVT has been integrated into a ground station that is used to validate Link16 messaging in FA-18 (Legacy and E/F/G models) under test. This van is capable of receiving Link16 messages from aircraft in the network and generating and transmitting messages as well. This implementation is the model for MIDS/LVT integration into the UAV control station to provide a Link16 communications node for transmittal of *Puffer* derived geolocation information. For this application, the "J" variant of the MIDS/LVT is desired which contains Ethernet connectivity.

4.3.2 Aerostar Ground Control (GCS) Station Description

The *Aerostar* GCS consists of two separate, but integrated parts, the S-250 hand controller for launch and recovery operations, and the S-280 self contained ground shelter which includes all computer and communications systems. Operationally, the *Aerostar* is launched by the "External Pilot" using the S-250 hand-held controller (figure 4-6). After the *Aerostar* is airborne, the aircraft is handed off to the S-280 GCS (figure 4-7) for control by the Internal Pilot during the operational mission. When the mission is complete, the aircraft is landed by the External Pilot using the S-250 hand-held controller.



Figure 4-6. Using the S-250 Handheld Controller



Figure 4-7. Aerostar S-280 Ground Station shelter.

The interior of the S280 ground station includes positions for the Internal Pilot and the Payload Commander. The Internal Pilot controls the flight of the aircraft through commands uplinked from the command console to the aircraft.

The Internal Pilot develops an instrument scan similar to pilots in the cockpit. Aircraft pertinent data such as engine RPM, altitude, airspeed, heading, and attitude are all displayed. The pilot merely has to turn a knob to increase, or decrease speed and altitude, or to change headings. All sensor data is downlinked real time to the Payload Commander's console. The Payload Commander can ask the pilot to change the aircraft's flight path by pointing the sensors to an area of interest and then navigating to that point. A flight history is displayed on the pilot's console^{17,18}. Communications between the GCS and the aircraft is through a series of three antennas; an omni-directional antenna for close range, a horn antenna for medium range, and a dish antenna for long range. The data link has a 75 km range with a UHF and S band uplink and an L-band downlink¹⁹. Data products can be provided in a "Falconview" format. The GCS requires the following components to operate the *Aerostar* UAV:

- Three computers, one for primary controls for the Internal Pilot, one for the payload displays, and one as a backup. This includes display monitors for each station
- A control panel which includes a set of knobs for altitude, heading and speed control, the UHF data link processor for uplinks to the autopilot and downlinks for aircraft status
- A video monitor and recorder for the optical payloads
- A UHF radio for air traffic control communications.

4.3.3 Dakota Crew Station Description

The *Dakota* Crew Station consists of a single laptop computer that is used for both mission planning and mission conduct. Utilizing the *missionTEK*²⁰ software package,

¹⁷ Carlson, Ted, "UAV's at Patuxent River", *Wings of Gold* Summer 2005

¹⁸ Huffine, Ward A, Personal UAV flights during "Introduction to UAV Flight Test" course, May 2008 US Navy Test Pilot's School, NAS Patuxent River, MD

¹⁹ *Aerostar* Introduction packet by Mr. Andrew Pontzer, NAVAIR 5.1, June 2008.

²⁰ Geneva Aerospace *missionTEK* sales brochure. www.genareo.com

the *missionTEK* architecture supports the network communications which allows for the command and control of multiple *Dakota* UAV aircraft. The interface displays all of the UAVs on the Internal Pilot's situational display, while the software monitors the state and health of the entire UAV network. The Internal Pilot has the capability to take control of any one of the UAVs flying by merely clicking on the icon. The patented *missionTEK* system has the following key features:

- Multi-aircraft, single pilot/operator
- STANAG 486 messaging modules
- Falconview and Tactical Control Station Integration
- Flight status, payload management, and Cautions, Alerts and Warnings (CAWS) panel to alert of system malfunctions
- Airfield manager and pushbutton autonomous take off and landing capability.

Like the *Aerostar*, *Dakota* operations normally include an External and an Internal Pilot. The External Pilot taxis the aircraft on the ground and then takes it off using a radio control handheld device. After reaching the desired altitude, the aircraft is handed off to the Internal Pilot. The *Dakota* also supports an autonomous take off and landing capability. To utilize this capability, the *Dakota* is taken to the centerline at one end of the runway where a program named RealNav is engaged. This sets one of the runway end points in the *missionTEK* system. The aircraft is then taxied to the opposite end of the runway to mark the other end point. Once these points are entered into the *missionTEK* system, the *Dakota* is capable of totally autonomous takeoff and landing²¹

The *Dakota* control station requires the following operational modules:

- A PC computer with the *missionTEK* software loaded and Ethernet connections
- A *linkTEK*²² base unit for uplink and downlink communications
- A Satellite Communications (SATCOM) modem for beyond line of sight communications
- Antennas to support datalinks

²¹ *Dakota* control station orientation/interview with Mr. Andrew Tree on 13 February 2009

²² *linkTEK* sales brochure. www.genaero.com

5. Project Background

This thesis is based on two facts. The first is that electromagnetic waves, once transmitted, continue on indefinitely through space, and the detection of these waves is only limited by the ability of a receiver to detect the transmission. The second is that most objects will reflect the transmitted energy back in the direction of its origin²³. This very simple explanation of electromagnetic wave propagation provides the impetus for this project. In any conflict, some kind of radar system will be used to detect, identify and target aircraft, and that once transmitted, a signal may be detected by any receiver that is tuned to that frequency. For the *Puffer*/Tier 2 UAV system to be of any use to combat commanders, radars must transmit a signal. With no signals to receive, there is nothing to geolocate. Fortunately, the battlefield is a rich environment for electromagnetic waves that can be received and exploited.

5.1 RADAR History and Usage

5.1.1 Early Radar Development

While many novelists have led the public to believe that “intelligence” is usually obtained through “cloak and dagger” methods, the real fact is that “intelligence” simply is learning something that wasn’t known before. Early radar experiments centered on detecting objects that could not be seen, thus gaining intelligence. Table 5 is a timeline of early Radar development and summarizes the development of radar up to World War II. Experiments performed by German physicist Heinrich Hertz in 1897, proved that electromagnetic signals could not only be transmitted and received, but also that the same transmitted signal, after striking an object, would be “bounced” back at the same frequency and could be received at the source²⁴. Ironically, the proof that radio waves could detect objects came quite by accident when it was noted that radio communications links were disrupted when an object passed between the transmitter and receiver antennas. Early Radar development took place in Britain, France,

²³ Stimson, George W., “Chapter 1 Basic Concepts”, *Introduction to Airborne Radar*, 2nd ed., SciTech Publishing, Raleigh, NC., 1998 pp 4

²⁴ Wikipedia, “History of Radar”

Germany, Japan, the Netherlands, the Soviet Union, and the United States, through many experiments following parallel paths that provided different solutions. Each of these solutions led to a greater understanding of the phenomena and provided improved ways to detect objects using radio waves ²⁴.

5.1.2 World War II Radar Advances

As in any conflict, technology advances quickly to provide advantages to the participants. Radar and its usage, was no exception. Besides the obvious advances in the radar equipment itself, the usage of the system also evolved. This evolution included applying radar to the control and guidance of weapons, integration of radar information into the command and control structure and, radar's use as a force multiplier. Another application of radar techniques was demonstrated in the development of the proximity fuse²⁵ which used radar methods in the warhead of an anti-aircraft artillery round to sense the target, rather than striking it, to cause the detonation. Table 6 is a synopsis of the improvements to radar and its integration into the command, control and decision making process that affected the outcome of many campaigns. Just how important Radar would become during the war was very apparent following two early events of World War II. The Battle of Britain and the Attack on Pearl Harbor illustrated how radar could be utilized (or not) with two very different outcomes.

5.1.3 Post World War II to Present

The advantages of radar were proven during World War II as both a defensive and offensive weapon. In the years following the war, advances in computers, communications and electronics benefited radar development and usage as well. Rockets, once used as weapons of war, were researched and redesigned to be purveyors of peaceful exploration in the new frontier of space. New, more powerful, radars had to be developed to follow these new vehicles. Advances in microwave technology made possible by radar research, expanded our ability to communicate on earth and in space. Radars that were used to calculate the range of incoming bombers would now be used to measure distances to neighboring celestial bodies, Advances in

²⁵ US Navy usage of Proximity fuse during WWII,

aviation and the explosion of world commerce, showcased the airplane as a viable mode of transportation to quickly move business men and women from one place to another. With the increase in civil air traffic, came a greater need for better air traffic control. In this area, radar played a vital role in weather surveillance, storm and ice warnings, collision avoidance, and traffic management. On the military side, the development of Integrated Air Defense Systems (IADS) combined the great advances in communications and computers, with the capabilities of radar; to discriminate and identify objects at great distances. Advanced micro electronics allowed these systems to become mobile and more lethal. Table 8 outlines the many military and non-military applications radar technology was channeled through the research done at Lincoln Laboratories at Massachusetts Institute of Technology (MIT). This research is an excellent example of the major radar projects going on in many countries during the 60 plus years following World War II. As the 21st century begins, radar is again used as a means to observe celestial bodies but this time it is trained to map and catalog our own "Spaceship Earth."

Table 5. Early Radar Development Timeline²⁴

Era	Date	Country	Contribution
Pre 20th Century	1897	Germany	Heinrick Hertz proves electromagnetic waves can be transmitted, received and reflected.
	1898	United States	Nickola Tesla demonstrates radio controlled unmanned submersible “ <i>Telautomatron</i> ” at Madison Square Garden, NY City. ²⁶
Early 20th Century	1904	Germany	Christian Huelsmeyer demonstrates a product that used radio waves to detect ships so that collisions could be avoided.
	1915	Britain	Robert Watson-Watt developed the use of radio waves generated by lightening strikes to map out the position of thunderstorms. These experiments lead to the development of the rotating directional antenna and the use of an oscilloscope to display them.
	1917	United States	Nikola Tesla proposes principles regarding frequency and power levels of standing electromagnetic waves and pulsed reflective waves that could be used to determine relative position, speed and course of a moving object.
Pre- WW II	1922	United States	Albert Taylor and Leo Young effectively demonstrate continuous wave (CW) radar detection while conducting communications research at NRL.
	1927	France	Camille Gutton and Pierret conduct experiments with centimeter wave transmissions.
	1930	United States	Lawrence Hyland (NRL) detects an airplane using a CW radar advancing techniques of Taylor and Young.
	1930's	Japan	Hidetsugu Yagi researches magnetron and antenna designs for microwave power transmission.
	1931	France	Researchers Mesny and David notice aircraft disrupt communications while flying between transmitters and receivers.
	1932	United States	Allen DuMont at Ft Monmouth, NJ used radio wave distortions to locate objects on a cathode ray tube screen.
	1934	United States	Robert Page (NRL) begins experiments with pulsed radio wave systems.
	1934	Germany	Hans Hollman and Hans-Karl von Willisen build first commercial radar system for detecting ships at 10km.
	1934	France	Henri Gutton research improves magnetron transmitters and patents a device for detecting objects using pulsed centimetric wavelengths. The radar was tested between in Fall 1934 and deployed operationally in 1935.
	1934	Soviet Union	Soviet scientists successfully test an experimental radar system that detected an aircraft flying at an altitude of approximately 150 meters at a distance of 600 to 700 meters from the radar site.
	1935	Germany	Hollman and von Willisen further refine accuracy of pulsed radar capable of detecting a ship at 8 km with accuracy of 50m and an aircraft at a distance of 28km and an altitude of 500m.
	1935	Britain	Watson-Watt demonstrates a basic radar system that could detect an aircraft at ranges to eight miles. The “Davenport Experiment” led directly to the development of radar in Britain.
	1935	Germany	Hans Hollmann after working for several years in the field of microwaves with applications in communications field and publishes the book “Physics and Techniques of Ultra short Waves”.
	1940	Netherlands	Weiler and Gratema develop four working prototypes of a centimetric gun laying radar using wavelengths of 50cm with a practical range of 20 km.

²⁶ Tesla’s research of unmanned remote controlled vehicles

Table 6. World War II Radar Development Timeline²⁴

Event	Date	Country	Contribution
Battle of Britain	1939	Britain	Airborne Intercept radar installed on British aircraft to detect incoming bombers during night and bad weather raids.
	1939	Germany	Installs Naxos ZR radar detectors to counter British AI radars.
	1940	Britain	Watson-Watt responsible for implementation of Chain Home Radar network. To reduce workload, a layered organization for passing information was developed. Use of this system allowed RAF to target incoming aircraft and concentrate the force to a single area. This allowed for crew rest rather than having to continually fly patrol sorties.
	1940	Britain	John Randall and Harry Boot develop Cavity magnetron transmitter. This was a much smaller device that was able to generate microwave frequencies much more efficiently.
	1940	United States	Robert Page (NRL) invents duplexer switch allowing radars to use the same antenna for transmitting and receiving.
	1940	Germany	Development of the "Kammhuber Line" a group of cells in Holland, Belgium, and France which contained a Freya Radar Station, a number of searchlights which were directed by the radar, and a night fighter to attack the incoming bombers.
	1940	Germany	Development of Wurzburg short range, narrow beam radars to accurately track incoming bombers and to guide interceptors to the target. Employed in "Kammhuber Line" to counter bad weather British raids. Because they were highly directional, the Wurzburg radars could only track one target. British countered by crossing the line <i>En masse</i> to minimize losses.
	1940	United States	Creation of MIT Radiation Lab to further develop cavity magnetron technology.
	1941	Britain	Chain Home Low radar developed with motorized antenna movements used to counter low-level attacks.
	1941	Britain	Developed Ground Control Intercept (GCI) displays to guide air defense fighters to incoming bombers.
Attack on Pearl Harbor	1941	United States	Army radar operators using a SCR-270 radar system observe a large formation of aircraft approaching Hawaiian Island at a range of 132 miles. Information is passed to commanders but not acted on.
	1941	Canada	National Research Council of Canada developed CSC and SW1C naval radars.
	1942	United States	RADAR (Radio Detection And Ranging) acronym coined by US. Navy.
		United States	Norton Bomb Sight
	1942	Germany	Lichtenstein BC Airborne radars deployed on JU88. The British develop jammer to foil the system.
	1943	Germany	SN-2 deployed, but large antennas slowed planes by as much as 50km/hr.
	1944	United States	US Navy develops radar proximity fuse for anti-aircraft artillery shells.
	1944	Japan	Highly miniaturized FD-2 AI Radars deployed on Gekko night fighters.
	1945	Germany	9-cm wavelength Berlin radar deployed during last months of war.

Table 7. Post World War II Radar Development Timeline at Lincoln Labs MIT ²⁷

Era	Date	Application	Contribution
1945-1949	1946	Space	A radar signal is bounced off of the Moon to determine the distance between the earth and the Moon ¹¹ The radar used was the same SCR-270 that initially detected the Japanese aircraft attacking Pearl Harbor, HI. ²⁴
1950's	1951 +	Air Defense	Lincoln Labs begins development of the Semi-Automatic Ground Environment (SAGE) air defense network for the USAF Air Defense Command. System used a wide variety of Radars and Computers.
	1952	Air Defense	The Distant Early Warning Line (DEW Line) concept is developed to detect Soviet Bombers that might travel over the North Pole to attack North America.
	1955	Missile Detection	Ballistic Missile Early Warning System (BMEWS) is deployed with radar sites in Thule Greenland; Clear, Alaska; and Fylingdales Moor, UK.
	1955	Missile Detection	AN-FPS-17 Radars are used in Turkey and Alaska to monitor Soviet Missile Development, Launches and reentries.
	1957	Space Surveillance	Radar at Millstone Hill (Westford, MA) is used to track first man made satellite Sputnik I, launched from the Soviet Union.
1960s	1960	Missile Detection	Radar used for target discrimination during reentry. Countermeasure developed to aid in identification of warheads in spite of active actions by the enemy to deny identification.
	1960s	Missile Detection	Radars installed on Wallops Island, VA to observe physical phenomena accompanying the warhead when reentering the atmosphere.
	1961-63	Space Surveillance	Radar used to track Project Mercury spacecraft
	1960's	Missile Defense	DoD establishes National Center for Ballistic Missile Testing on Kwajalein Atoll. Nike Zeus Surface to Air Missile tested as an ICBM defender. TRADEX (UHF/L-band) radar installed on Roi-Namur Island to track incoming warheads.
	1964-67	Space Surveillance	Radar used to track Project Gemini spacecraft.
	1965	Space Surveillance	Haystack facility (Tyngsboro, MA) originally designed as an 8-GHz space communications terminal modified to have a communications mode, radar mode or radio-astronomy mode. Addition of an X-Band Wide band transmitter allowed the imaging of satellites in geostationary orbits.
	1968	Tactical Battlefield Surveillance	Camp Sentinel radar developed and deployed, to see intruders through dense jungle growth in Viet Nam
	1968-72	Space Surveillance	Radar used to track Project Apollo spacecraft.
1970's	1970	Missile Defense	ALCOR (C-band) provides first high resolution range Doppler imaging of satellites in space.

²⁷ Delany, William P. and Ward, William W., "Radar Development at Lincoln Laboratory: An Overview of the first Fifty Years". *Lincoln Laboratory Journal*, Volume 12, number 2-2000

Table 7. Post World War II Radar Development Timeline at Lincoln Labs MIT ²⁷

Era	Date	Application	Contribution
	1971	Space Surveillance	Millstone Hill radar modified (HW and SW) to track objects in deep space (32,000km) geostationary orbits. These upgrades allowed the system to process large numbers of echo signals from a single object for high quality metric and cross-section information.
	1971	Air Traffic Control	Initial development of the Discrete Address Beacon System. This system was developed as the next generation beacon system and operationally known internationally as Mode S IFF.
	1972-76	Space Surveillance	Radar used to track Space Lab station in low earth orbit
	1975	Air Traffic Control	Research and development begins on the Beacon Collision Avoidance System (BCAS). This lead to the production of the Traffic Collision Avoidance System (TCAS) (1985) used today on every commercial carrier in the US.
	1975	Tactical Battlefield Surveillance	Multiple-Antenna Surveillance Radar demonstrated the application of the displaced-phased-center antenna technique used to cancel ground clutter and detect slow moving ground vehicles. With progressive refinements, this made the Joint Surveillance Target Attack Radar System (Joint STARS) possible.
	1975-1985	Tactical Battlefield Surveillance	Research and development of Airborne Laser radars used to identify trucks, tanks and artillery. This research culminated with the Infrared Airborne radar, which demonstrated high spatial and Doppler resolutions available from coherent laser radar.
	1975	Air Defense	Research begun to characterize air defense systems and a cruise missile's ability to defeat them.
	1980	Tactical Battlefield Surveillance	Development of a small, light weight K _u -Band Radar mounted on a UAV to detect and classify moving targets on the ground. Target discrimination was done onboard the UAV thereby reducing the data link traffic bandwidth requirements by three orders of magnitude.
1980's	1981	Missile Defense	Cobra Judy (S-band) phased-array radar deployed on USNS <i>Observation Island</i> stationed at Cape Canaveral, FL. Radar was used to observe physical phenomena of reentry vehicles in the area of impact.
	1981-present	Space Surveillance	Radar used to track Space Shuttle and International Space Station missions.
	1985	Air Defense	Research and development of radar systems that could be used to defeat cruise missiles.
	1986	Air Defense	Airborne Seeker Test Bed (ASTB) developed to characterize radar seekers on SAM missiles. The use of this test bed has played a key role in the development of tactics and countermeasure techniques for aircraft survivability.
	1987	Tactical Battlefield Surveillance	High-resolution, multiple-polarization, K _a -Band Synthetic-aperture Radar (SAR) called Advanced Detection Technology Sensor (ADTS) was developed under DARPA. Main focus of the program was the collection of SAR data on strategic and tactical targets for the development of a target detection and recognition algorithm for stationary targets.

Table 7. Post World War II Radar Development Timeline at Lincoln Labs MIT ²⁷

Era	Date	Application	Contribution
1990's	1993	Space Surveillance	Haystack Auxiliary Radar (HAX) (16GHz) becomes operational providing additional satellite imaging capabilities.
	1992-99	Missile Defense	Development of the AN-TPY-2 Ground Based Radar (GBR) radar system for Theater High Altitude Area Defense (THAAD) system radar. This radar was an I and J-band, 9.2m ² full field of view aperture phased array radar capable of tracking targets 1000 km and discerning individual re-entry vehicles. ²⁸
	1996	Missile Defense	Cobra Gemini features Wideband S-band and X-band radars for the Theater Ballistic Missile Defense Systems needs for a system to track and analyze missile data. System was air transportable, but was operationally deployed on the USNS <i>Invincible</i> in 1999.
2000's	2000	Space Surveillance	Shuttle Radar Topography Mission obtained elevation data on a near-global basis to generate the most complete high resolution topographical database of the Earth. The SRTM used a specially modified SAR radar system flying onboard the Space Shuttle Endeavour in February 2000. ²⁹
	2003	Tactical Battlefield Surveillance	NRL researches Space-Time Adaptive Processing (STAP) signal processing techniques to enhance a radar's ability to detect targets that might be obscured by clutter or jamming. This research has centered on STAP's ability to detect ground moving targets by airborne radar systems. ³⁰
	2006	Tactical Battlefield Surveillance	DARPA investigates handheld radar devices that could be used by ground troops to detect movements through walls in adjoining rooms. The "Radar Scope" is about the size of a telephone and can sense objects on the opposite side of a one foot thick concrete wall and 50 feet beyond. ³¹

²⁸ Army Technology.com, "Theater High Altitude Area Defense (THAAD) System Development"

²⁹ JPL NASA.gov "Shuttle Radar Topography Mission Homepage"

³⁰ NRL.navy.mil "Space-Time Adaptive Processing (STAP)" Research Programs Directory

³¹ DefenseLink.mil "New Device will Sense Through Concrete Walls"

5.2 Surface to Air Missile (SAM) Systems History and Usage

The proliferation of autonomous, highly mobile and lethal SAM systems makes the need for real time information on the emerging battle space paramount to the COCOMS. The Moscow Defense Brief provided a list of Contracts for exports of Russian SAM systems³² to 16 different countries (Europe, Asia and the Middle East) amounting to over \$11.8 billion between 1992 and 2007. In contrast, US Foreign Military Sales (FMS) amounted to \$12.2 billion in 1999 alone³³. This figure included all equipment sales for foreign governments, not just air defense systems. A second article from the Moscow Defense Brief titled "Russian Air Defense Weapons Have No Serious Competitors", Vitaly Nosov, the Director of Air Defense Department of Rosoboronexport when asked "Which Russian air defense systems are currently in demand?" answered, "... that Russia was and remains one of the few countries...that develops, manufactures and exports, the entire range of air defense systems..." He further states that because Russia exports the entire range of systems "... Russia is a very attractive partner for countries that need to deploy all-around air defense groups... they are interested in our entire air defense product range."³⁴ A review of the provided export list³² confirms that the contracts noted were for entire, recently developed integrated air defense systems. A review of Jane's 2000 *Radar and Electronic Warfare Systems*, "Radar: Battlefield Missile Control and Ground Surveillance" section³⁵ (appendix C) references not less than 12 mobile SAM systems available and fielded by nearly 54 different nations, many using multiple systems. Wikipedia, list of mobile SAM systems available³⁶ (appendix C) sets the number at over 28 with at least 91 countries fielding these systems. These two sources show that the past nine years alone, the use of mobile SAM systems has increased and are now being fielded by nearly every advanced country on earth. Allies

³² Moscow Defense Brief, "Contracts for exports of Russian Sam Systems 1992-2007"

³³ Cohen, William S. "Appendix M - Foreign Military Assistance ", *Secretary of Defense Annual Report to the President and the Congress 2000*".

³⁴ Moscow Defense Brief, "Russian Air Defense Weapons Have No Serious Competitors"

³⁵ Jane's Information Group Limited, "Radar: Battlefield, Missile Control and Ground Surveillance", Jane's 2000-2001 Radar and Electronic Warfare Systems, 12th ed., pp 67-118

³⁶ Wikipedia, "List of Surface to Air Missile systems",

yesterday, have become enemies today, using our own systems against us. These systems range from short range Infrared guided missiles to strategic systems capable of destroying incoming ballistic missiles.

5.2.1 Early SAM Systems

Originally, SAM systems were large and deployed on fixed, hardened sites. The mission of these missile systems were to detect, track, target, and destroy strategic bombers, probably carrying nuclear weapons. Deployed in “rings” outside of major military and population centers, the SAMs were designed to engage and destroy their targets far away so that any secondary damage caused by a possible weapon detonation, would be limited to unpopulated areas or over the oceans. While lethal to strategic threats, they were large, easy targets for tactical strikes.

To this day, Russia has continually upgraded the SAM defenses around Moscow with the latest systems. In 1953, the SA-1 Guild was installed to defend the city³⁷ and was later supplemented by the SA-2 Guideline. The SA-2 was the missile system that brought down U-2 Pilot Gary Powers in 1962, and was the bane of B-52 crews during the Viet Nam conflict³⁸. As new, more improved systems were developed, Russia has incorporated them into this defense ring. In an April 5, 2007 article, The Russian News and Information Service *NOVOSYI*³⁹ reported that the new S-400 Triumf (SA-21 Growler) would begin combat duties around Moscow in August 2007. This system was designed to detect and destroy airborne targets (including ICBMs) at 250 miles which is 2.5 times the range of the currently deployed S-300 (SA-10 Grumble). The S-400 will eventually replace the 30 S-300 (SA-10 Grumble) regiments around Moscow. Both the S-300 and S-400 are fully self-contained, mobile systems.

During the conflict in Viet Nam, anti-radiation missiles (SHRIKE)³⁸, airborne radar jamming platforms (EA-6B Prowler)^{40,41} and strike fighter tactics³² (Wild Weasel) were

³⁷ Wade, Mark, Astonautics.com, “Russian SAMs and ABMs”

³⁸ Wikipedia, “SA-2 History ‘Shoot down of Gary Powers’”,

³⁹ Russian News and Information Agency, “S-400 Air Defense System to be deployed in August 08”

⁴⁰ FAS Intelligence Resource Program, “EA-6B Prowler”

⁴¹ Wikipedia, “EA-6B Information”

developed to counter the large SAM capabilities. With the advanced capabilities of the newer systems, new suppression platforms and tactics will need to be developed.

5.2.2 Emergence of Mobile SAM systems

At the beginning of the 1973 war between Israel, Egypt and Syria, Israeli Air Forces sustained heavy losses from the highly mobile SA-6 Gainful missile systems, primarily because the Israeli's RWR gear did not identify when the aircraft was targeted by the SA-6's Straight Flush continuous wave illuminator system. Once the RWR was programmed to recognize the system, the Israeli's were able to change tactics to adjust to the new threat⁴².

The threat to aircraft by mobile missile defense systems is emphasized in the opening sentence of an article entitled "Needles in the Haystack, Hunting Mobile Electronic Targets" by Major Michael Pietrucha, USAF⁴³

"Radar defenses are very difficult targets; the addition of mobility to their arsenal has greatly complicated the problem of finding and killing the radars that serve as the backbone of both the surveillance and "shooter" portions of an integrated air defense system (IADS)."

Major Pietrucha sums up the paper in his third paragraph,

"... we must have the ability to find and suppress or destroy air defense systems. With increasing mobility, modern SAM threats are extremely fleeting targets- targets that cannot be allowed to roam the battle field unhampered. However, the ability to destroy these targets is predicated upon the ability to find them- a capability that must be greatly enhanced."

It is the capability to find and provide the information required to target these systems that is the focus of this thesis.

⁴² Wikipedia, "2K12 Kub Combat History"

⁴³ Pietrucha, Michael Major USAF, "Needles in the Haystack – Hunting Mobile Electronic Targets", *Air & Space Power Journal* , Spring 2003

5.3 The Integrated Air Defense System

In section 5.1, early radar development focused on the ability to detect aircraft further away than the human observer could see. These types of radars provided early warning (EW) capabilities to the field commanders. The EW radar could provide the Ground Control Intercept (GCI) operator with location and range data of incoming aircraft allowing them to vector interceptor aircraft to investigate and/or attack the intruders. Single EW radar may be able to track objects within an area of a 100 mile radius. However, during the Battle of Britain, the addition of wireless communications linked several “Chain Home” radar sites together, thus multiplying the systems ability to protect a much larger airspace than that of a single station ²⁴. The use of a communications system to link several radar sites together is the basis of the IADS.

5.3.1 Early IADS Structure

Section 5.1 also identified another area of radar used in guiding anti-aircraft artillery (AAA) weapons to their targets. These Target Tracking (TT) radars are very special in that they can precisely target an object by using a very narrow and concentrated beam of energy. The drawbacks of the TT radar are that an EW radar is needed to point out the target and the TT could only accurately track a single target. This limitation was usually overcome through a communications link with the AAA battery to pass range and azimuth data, and locating the target tracker with the AAA weapon itself ²⁴. With these two radar systems and a communications link between them, the basic IADS may be identified. This structure is depicted in Figure 5-1.

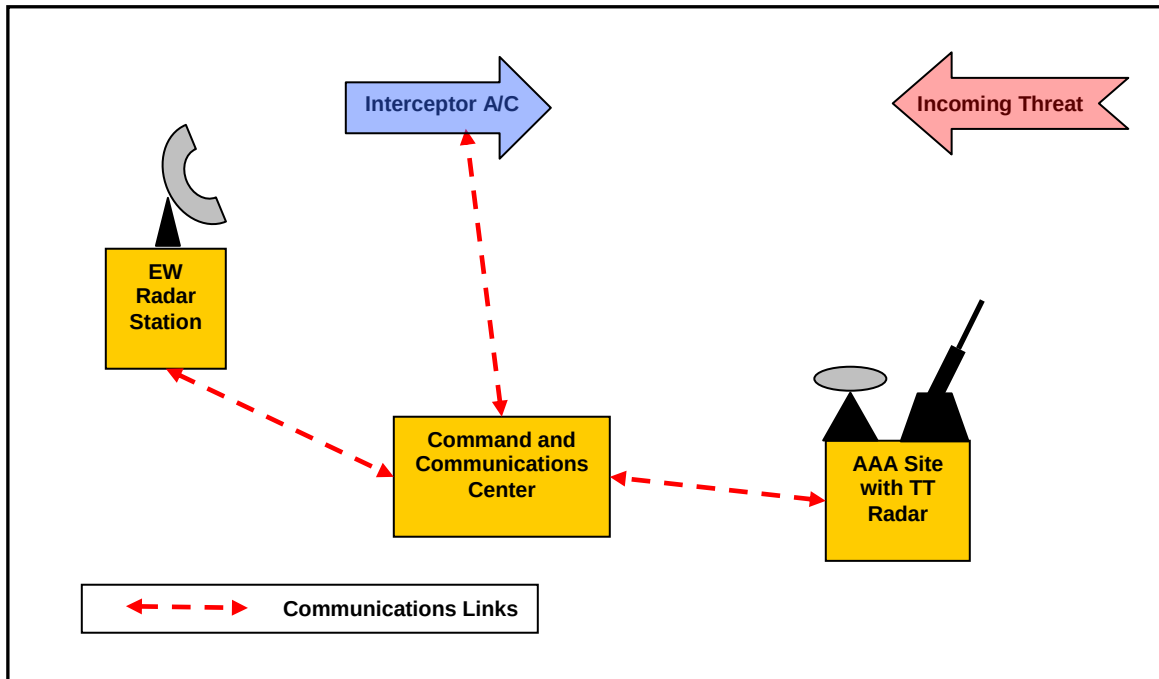


Figure 5-1. Early IADS Structure

A quick glance at Figure 5-1 shows that the system's vulnerability has shifted from the individual assets (radars, AAA and aircraft), to the communications center and links. By eliminating the ability to communicate between sites, the system may be degraded if not defeated.

5.3.2 SAMs and the Modern IADS Structure

Over the years, AAA batteries have been replaced by SAM Battalions. Besides the missiles and launch platforms, each battalion consists of Target Acquisition (TA), and any combination of Missile Guidance (MG), Target Illuminator (TI), and TT radars. While mobile, each of these assets are individual components of the larger SAM battalion. The battalions are integrated into the IADS which includes additional long range EW, Height Finder (HF), and GCI radars. All of these radar systems are used to identify, track, target, and guide SAMs and interceptor aircraft, to incoming, hostile airborne threats. Included in these battalions are the communications assets which filter and integrate the individual radar systems inputs, into a three dimensional

representation of the battle space which is transmitted to the combat commanders⁴⁴.

Figure 5-4 illustrates the Modern IADS Structure. While these systems are highly mobile, there are still many parts and communications links that must be operational for the system to be effective. As noted for the early systems, disruption of the communications links is a major vulnerability.

To provide a point defense for convoys and deployment of the Air Defense system, many of the rudimentary capabilities of the IADS, have been placed on a single mobile platform. Systems such as the Russian Tor (SA-15)⁴⁵ (Figure 5-2) and the French Roland⁴⁶ (Figure 5-3), include acquisition, targeting, and missile guidance capabilities on the same vehicle as the missile launcher. While mobile systems can obtain situational awareness from the IADS structure, these two systems are all fully capable to operate autonomously while on the move.

⁴⁴ Air Power Australia "Warsaw Pact/Russia Air Defense Command Posts"

⁴⁵ AW Enemy Forces "9M331 Tor SA-15"

⁴⁶ Army Technology. Com "Roland Short-Range Air Defense System, Europe"



Figure 5-2. Russian 9M331 Tor (SA-15) SAM



Figure 5-3. French Roland 2 SAM

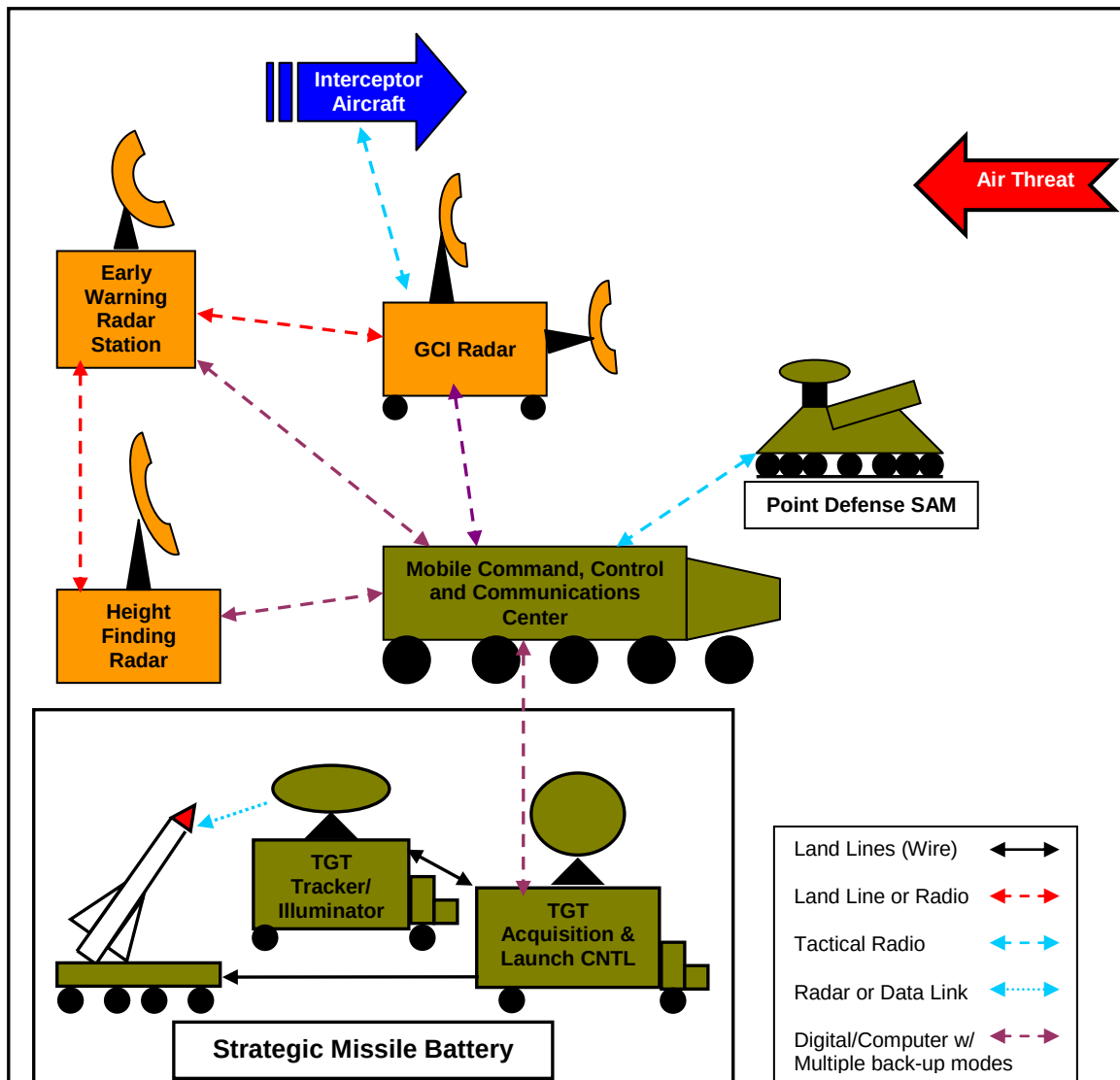


Figure 5-4. The Modern IADS Structure

5.4 Current AEA Platforms

The following airborne systems, are part of the US Military inventory and are currently used (or in test) as platforms to geolocate mobile SAM systems. The loss of any one of these platforms in combat would be costly in terms of lives and money.

5.4.1 Northrop Grumman EA-6B *Prowler* (USN)

The EA-6B *Prowler* (figure 5-5) is a twin engine variant of the A-6 Intruder mainframe manufactured by Northrop Grumman Aerospace. Introduced in 1971, the *Prowler* has been the US Navy's primary electronic warfare platform since that time. During the Viet Nam War, the US Marine Corp used the EA-6A "*Electric Intruder*" which took the basic two seat A-6 platform and added electronic warfare equipment. Since that time, the *Prowler* has been updated with new avionics, the offensive AGM-88 High-speed Anti Radiation Missile (HARM) and a highly effective ALQ-218 (v) 1 Receiver System for identifying and geolocating ground based emitter systems. The *Prowler* is currently the only Joint EW platform in the US inventory. Table 8 lists the performance capabilities of the *Prowler*.



Figure 5-5. Northrop Grumman EA-6B *Prowler*

USN *Prowler* squadrons are scheduled to begin replacement of the EA-6B in 2010 with the new EA-18G *Growler*. USMC *Prowler* squadrons will begin transitioning to EA-6B ICAP III *Prowlers* as they become available ^{34, 35}.

Table 8. Northrop Grumman EA-6B *Prowler* ^{34, 35}

Dimensions	Measurement
Wing span	53 ft (15.9 m)
Wing Area	528.9 ft ² (49.1 m ²)
Length overall	59 ft 10in (17.7 m)
Height Overall	16 ft 8 in (4.9 m)
Payload (Typical)	3 – ALQ-99 Tactical Jamming Pods
	2 – External Fuel Tanks
or	1 – External Fuel Tank
	1 – AGM-88 HARM
Weights	
Weight empty	31,160 lbs (15,130 kg)
Max Fuel weight (Internal + 5 tanks)	25,400 lbs (11,521 kg)
Typical Fuel weight (Internal + 2 tanks)	19,400 lbs (8800 kg)
Thrust to Weight Ratio	0.34
Wing Loading	116 lb/ft ² (560 kg/m ²)
Max T-O and Landing weight	61,500 lb (27,900 kg)
Performance	
Max Level Speed	566 kts (1,050 km/hr)
Cruise Speed	418 kts (774 km/hr)
T-O Speed	155 kts (287 km/hr)
Minimum T-O Distance	2,750 ft (838m)
Landing Speed	120 kts (222 km/hr)
Minimum Landing Distance	2,185 ft (666m)
Stall Speed	141 kts (262 km/hr)
Max rate of climb at sea level	12,900 ft/min(65 m/sec)
Service Ceiling	37,600 ft MSL (11,500m)
Operational Radius	850 nm (1574 km)
Endurance	7-9 hrs
Power Plant	
2x Pratt & Whitney J52-P408A	10,400 lbf (46kN) each
Crew	4 – 1 Pilot, 3 Electronic Countermeasures Officers (ECMO)
Replacement Cost	\$52 M

5.4.2 Boeing EA-18G Growler (USN)

The EA-18G *Growler*⁴⁷ (figure 5-6) is the fourth variant of the FA-18 family of USN Attack aircraft and is scheduled to enter the fleet in 2010 when the transition of EA-6B squadrons to EA-18G platforms begins. The EA-18G combines the combat capabilities of the FA-18F *Super Hornet* with those of the EA-6B ICAP III *Prowler* to provide both EA and ES capabilities on a common aircraft carrier capable airframe. While having the capability to geolocate and electronically attack a wide range of ground based radar and communication systems, the EA-18G will also be able to provide a wide range of SEAD and battle management capability through Link16, APG-79 Active Electronic Scanned Array (AESA) Radar and, AGM-88 HARM Missiles. Additionally, the *Growler* has an inherent air-to-air capability with the AIM-120 Advanced Medium Range Air to Air Missile (AMRAAM) which will allow the *Growler* to join the strike group and suppress enemy radar systems all the way to the target and provide for its own defense. Table 9 shows the performance characteristics of the *Growler*. The *Growler* entered Initial Operational Test and Evaluation (IOT&E) in September 2008 with an estimated Initial Operational Capability (IOC) scheduled for September 2009.

⁴⁷ Boeing Integrated Defense Systems Backgrounder Boeing EA-18G Growler



Figure 5-6. Boeing EA-18G Growler

Table 9. Boeing EA-18G Growler⁴¹

Dimensions	Measurement
Wing span	44.9 ft (13.7 m)
Wing Area	528.9 ft ² (49.1 m ²)
Length overall	60.2 ft (18.3 m)
Height Overall	16 ft (4.9 m)
Payload (Typical)	3 – ALQ-99 Tactical Jamming Pods
	2 – External Fuel Tanks
	2 – AIM-120 AMRAAM
	2 – AGM-88 HARM
Weights	
Weight empty	33,094 lbs (15,011.2 kgs)
Max Fuel weight (Internal + 5 tanks)	24,684 lbs (10,742.9 kgs)
Thrust to Weight Ratio	0.34
Wing Loading	116 lb/ft ² (560 kg/m ²)
Max T-O Weight	57,778 lb (25,754.1 kgs)
Max Recovery Weight	48,000 lbs (21,772.4 kgs)
Performance	
Max Level Speed	566 kts (1,050 km/hr)
Cruise Speed	418 kts (774 km/hr)
T-O Speed	155 kts (288 km/hr)
Minimum T-O Distance	2,750 ft (841 m)
Landing Speed	150 kts (279 km/hr)
Minimum Landing Distance	2,185 ft (668 m)
Stall Speed	141 kts (262 km/hr)
Max rate of climb at sea level	12,900 ft/min(65 m/sec)
Service Ceiling	37,600 ft MSL (11,500m)
Operational Radius	850 nm (1574 km)
Endurance	7-9 hrs
Power Plant	
2x General Electric F414-GE-400	44,000 lbs each
Crew	2 – 1 Pilot 1 Weapon Systems Officer (WSO)
Replacement Cost	\$52 M

5.4.3 Lockheed Martin F-16CJ *Viper* (Wild Weasel) (USAF)

The F-16 CJ *Viper*^{48, 49} (Figure 5-7) is the Block 50D-52D of the original F-16 Fighting Falcon currently in use by the US Air Force. The *Viper* fully integrates the AGM-88 HARM and Shrike anti-radiation missiles. The Raytheon AN/ASQ-213 HARM Targeting System (HTS) provides the geolocation of threat emitters. The pod is mounted on the starboard (right) intake hardpoint for release 6 and the port (left) intake hardpoint for release 7.⁵⁰ The HTS consists of the receiver that detects, classifies, and ranges threat emitters and software that passes the information to the HARM and the cockpit displays. With the HTS, the *Viper* has full autonomous HARM targeting capability. HARM targeting information can also be obtained from the RC-135 Rivet Joint aircraft which can support the F-16 in sorting and prioritizing targets in a dense threat environment.

The F-16 CJ is the fourth platform to provide USAF Wild Weasel support by targeting and launching anti-radiation missiles at enemy SAM systems⁵¹.



Figure 5-7. Lockheed Martin F-16 CJ *Viper*

⁴⁸ F-16.net, "F-16 CJ"

⁴⁹ Wikipedia, "F-16 Fighting Falcon"

⁵⁰ US Air Force Fact Sheet "High Speed Anti-Radiation Missile Targeting System"

⁵¹ Everything2.com "Wild Weasel"

Table 10. Lockheed Martin F-16 CJ *Viper*^{42, 43, 52}

Dimensions	Measurement
Wing span	32.6 ft (9.8 m)
Wing Area	300.0 ft ² (27.87 m ²)
Length overall	49.4 ft (14.8m)
Height Overall	16.7 ft (4.9 m)
Payload (Typical)	1 – AN/ASQ 113 HTS
	2 – External Fuel Tanks
	2 – AIM-9 Sidewinder
	2 – AGM-88 HARM
Weights	
Weight empty	18,900 lbs (8,670 kgs)
Max Fuel weight	15,800 lbs (7,181.8 kgs)
Thrust to Weight Ratio	0.9 lbf/lb
Wing Loading	88.3 lb/ft ² (431 kg/m ²)
Max T-O Weight	42,300 lb (19,200 kg)
Performance	
Max Level Speed	915 kts (1,470 km/hr)
Cruise Speed	418 kts (774 km/hr)
T-O Speed	155 kts (288 km/hr)
Minimum T-O Distance	2,750 ft (841 m)
Landing Speed	145 kts (270 km/hr)
Minimum Landing Distance	2,185 ft (668 m)
Stall Speed	140 kts (260 km/hr)
Max rate of climb at sea level	50,000 ft/min (254m/sec)
Service Ceiling	60,000 ft MSL (18,000 m)
Operational Radius	295 nm (550 km)
Endurance	7-9 hrs
Power Plant	
Blk 50 – 1 General Electric F110-GE-129 turbofan	17,155 lbs s. t. or 28,984 lbs s. t. in afterburner
Blk 52 – 1 Pratt and Whitney F100-PW-229	17,000 lbs s. t. or 28,000 lbs s. t. in afterburner
Crew	1 Pilot
Replacement Cost	\$18.8 M

⁵² Solar Navigator, "Lockheed Martin F-16 CJ History",

6. Operational Assessment

This section will describe the CONOPS for the Tier 2/*Puffer* UAS, the capability that would be brought to the COCOMs and the mission areas which the Tier 2/*Puffer* UAS would contribute to.

6.1 Tier 2 – *Puffer* UAS CONOPS

The Tier 2/*Puffer* UAS would be deployed in the Forward Edge of Battle Area (FEBA) in a flight of three to four vehicles. The Tier 2/*Puffer* UAS would be used to detect mobile threat emitters in areas where survivability of manned electronic surveillance aircraft systems may be questionable. The threat systems that would be of primary interest would be those mobile systems which are self contained and could attack strike aircraft autonomously. As noted in section 5.3.2, these systems which include surveillance and engagement radars. The surveillance radars tend to be in the “L” through “C” band (1.0 to 8.0 GHz) but the engagement radars tend to be in the much higher Ku through Ka Bands (12.0 to 40.0 GHz)³⁵. Frequencies of interest for these systems would be preprogrammed in the Crew Station Analysis Software (CSASW) on a priority basis scheme. As *Puffer* receives hits from the threat radars, the information from all aircraft are downlinked to the ground station and are assembled into a database in date, time order. The CSASW scans the database for different priority frequencies. When a priority frequency is noted, the CSASW checks the downlinked data from all aircraft in the formation. As the DOAs are accumulated, a geolocation fix is attempted based on the received DOAs and the aircrafts’ positions at the time of the frequency detection. Once computed, the emitter geolocation data is passed to a software module to format the data into a Link16 message that is transmitted over the MIDS/LVT to other air assets and COCOMs for targeting. If required, an electro-optics equipped UAV may be flown to the location to confirm the presence of the SAM system. Figure 6-1 graphically depicts the Tier 2 UAV/*Puffer* CONOPS and data flow.

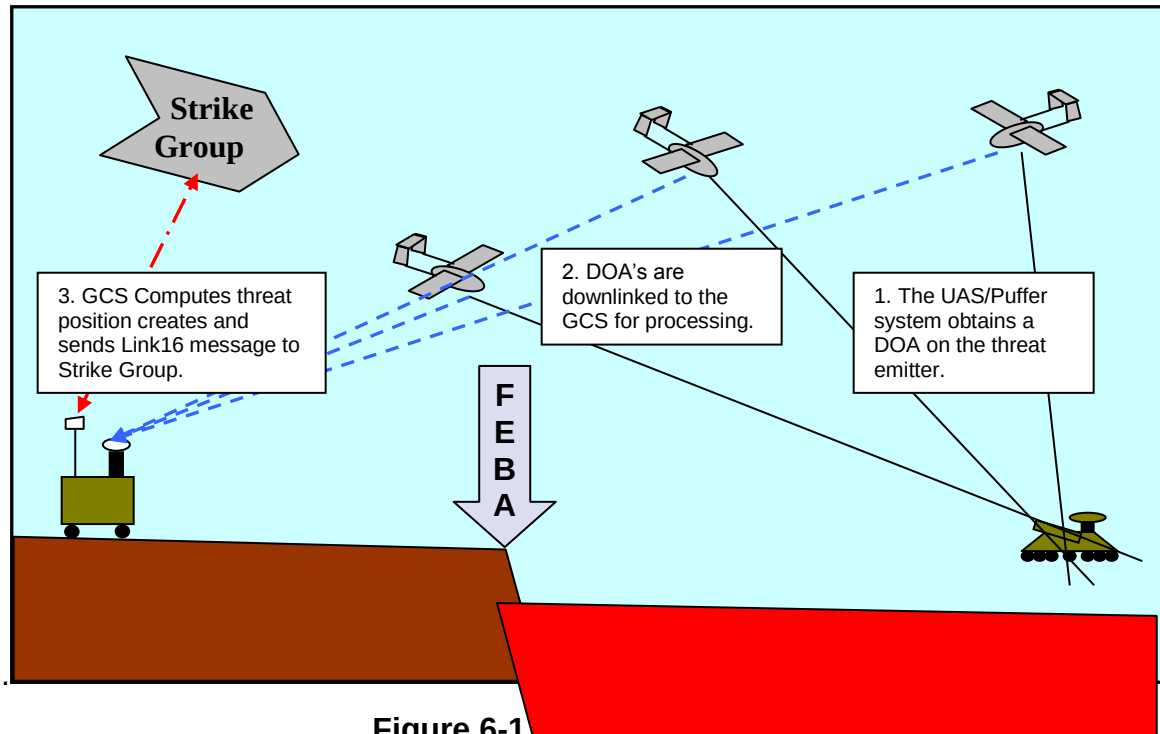


Figure 6-1. Tier 2/Puffer UAS Mission Flow

6.2 Mission Areas Supported by Tier 2/Puffer UAS

The Tier 2/Puffer UAS CONOPS could support the COCOMs by contributing to the following mission areas.

1. Strike Warfare (STW). The Tier 2/Puffer UAS would contribute to the Strike Warfare mission area by providing geolocation and targeting information to support the Suppression of Enemy Air Defense (SEAD) assets and Electronic Support to the Intelligence, Surveillance, and Reconnaissance units, plus force numbers and Bomb Damage Assessment (BDA).
2. Amphibious Warfare (AMW). The Tier 2/Puffer UAS would contribute to the AMW area by providing point defense information to Close Air Support (CAS) Forward Area Controller-Airborne (FAC-A). In the area of Combat Search and Rescue (CSAR), the Tier 2/Puffer UAS would provide additional situational awareness information on enemy forces attempting to apprehend downed aircrews. The Tier 2/Puffer could also be used to help locate special targets or convoys which include point defense SAM systems.

3. Surface Warfare (SUW). The Tier 2/Puffer UAS could support the SUW mission area by providing Maritime Air Surveillance of Littoral Surface combat forces employing seaborne SAM systems.

6.3 Tier 2/Puffer Mission Profile

The Tier 2/Puffer UAS Mission profile consists of five distinct phases,

1. Take off and Climb to Cruise altitude
2. Cruise to Mission Area
3. Perform Mission Operations
4. Return to Base
5. Landing.

Figure 6-2 illustrates the basic mission segments and Figure 6-3 illustrates the Mission Profile based on the Tier 2/Puffer UAS CONOPS.

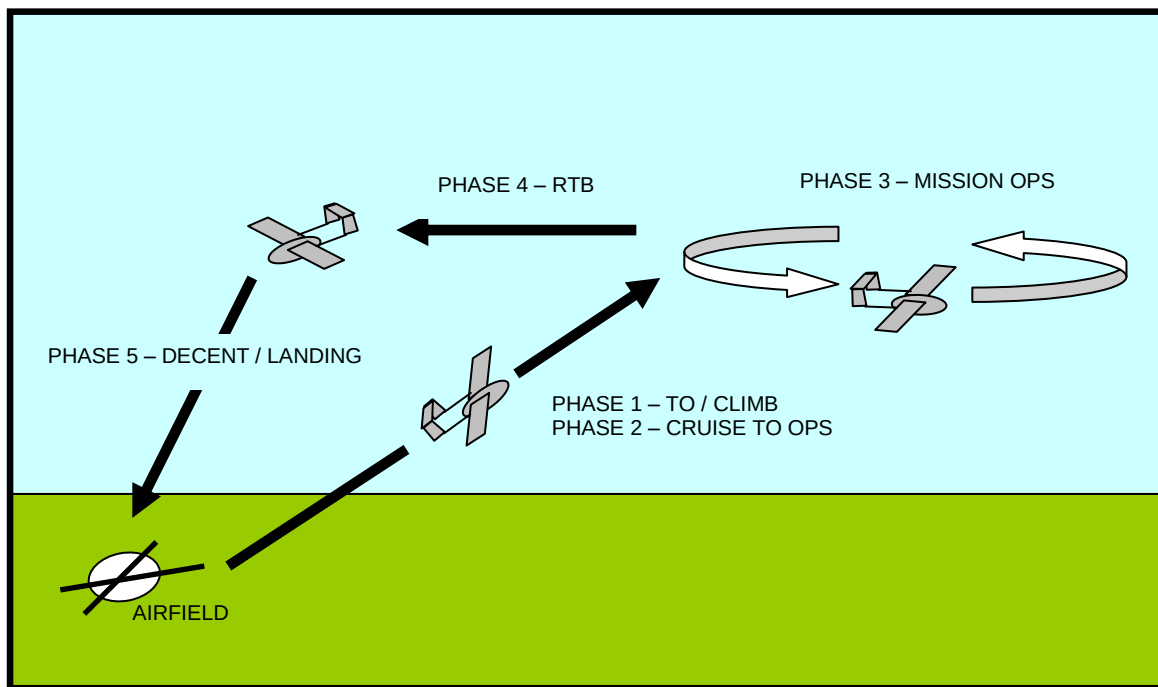


Figure 6-2. Tier2/Puffer UAS Mission Segments

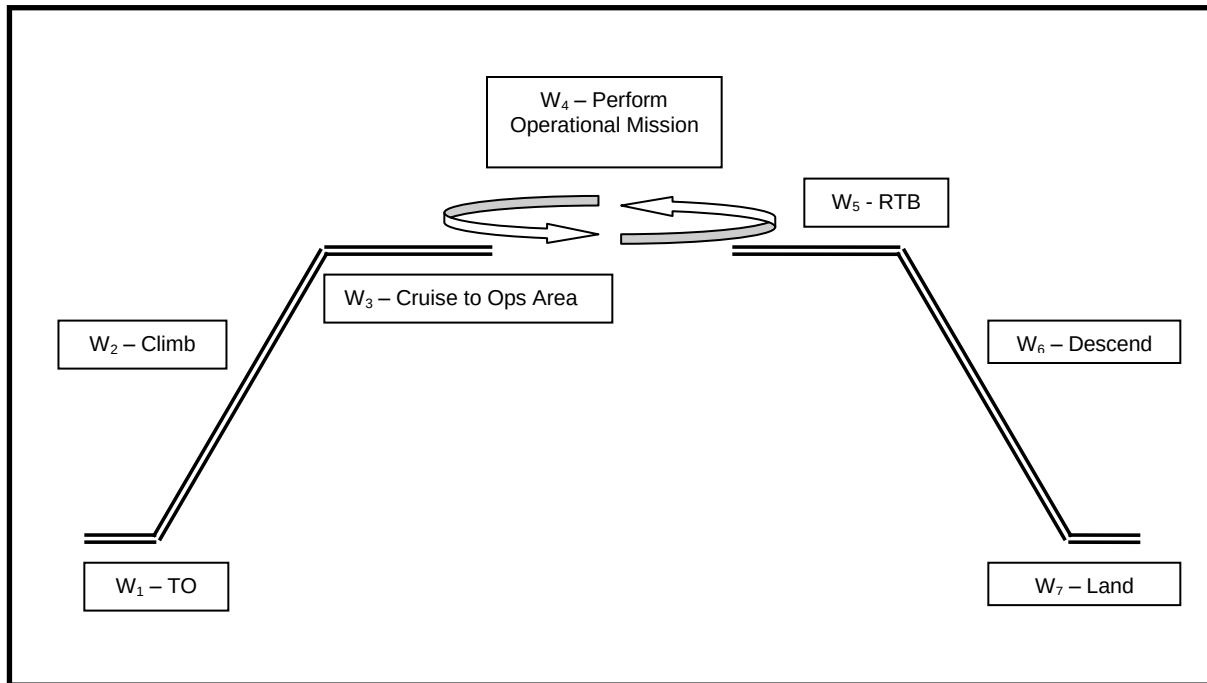


Figure 6-3. Tier 2/*Puffer* UAS Mission Profile for Fuel Consumption

Operationally, both the *Aerostar* and *Dakota* are towed to their take off point and started. Fuel use before the actual take off roll is limited so each aircraft would begin with a full tank of fuel. W_0 is therefore the total take off weight (from Tables 1 and 2) of the aircraft. There is an exception to this scenario, with the *Dakota*, a taxi run starting at one end of the runway and continuing to the opposite end is done to fix the end points of the runway for the automatic take off and landing capability of the aircraft. The fuel consumption for the mission profile will initially be computed without the *Puffer* so that a comparison may be made with the additional drag of the *Puffer* contributing to fuel usage.

7. Feasibility/Impact Analysis

This section contains the discussions and analysis of the modifications required to integrate the *Puffer* RWR with the Tier 2 UAV and integrate the *Puffer* data stream and MIDS/LVT into the GCS, resulting in an operational configuration.

7.1 *Puffer* Integration on to Aircraft

The initial testing of the *Puffer* was done on an *Aerolight* UAV (Figure 7-1) and was mounted on the lower portion of the fuselage. This is the preferred mounting location for both the *Aerostar* and the *Dakota* UAVs.



Figure 7-1. *Puffer* mounted on an Aerolight UAV

7.1.1 Payload Power, Weight and Structures Requirements

The following paragraphs outlines the Payload Power, Weight and Structures modifications required to incorporate the *Puffer* on the *Aerostar* and *Dakota* UAVs.

7.1.1.1 Payload Power and Weight Requirements to integrate *Puffer* on *Aerostar*

From Table 1 and Table 3, the complete *Puffer* (including mounting brackets), weighs 4 pounds and draws 17 watts of power. The *Aerostar* has a payload capacity of 110 pounds and generates 400 watts of power. The weight and power requirements of the *Puffer* RWR are within the baseline capabilities of the *Aerostar* UAV.

7.1.1.2 Payload Power and Weight Requirements to integrate *Puffer* on *Dakota*

From Table 2 and Table 3, the complete *Puffer* (including mounting brackets), weighs 4 pounds and draws 17 watts of power. The *Dakota* has a payload capacity of 80 pounds and generates 300 watts of power. The weight and power requirements of the *Puffer* RWR are within the baseline capabilities of the *Dakota* UAV.

7.1.1.3 Structural Integration of the *Puffer* onto the *Aerostar*

The *Puffer* has a mounting bracket that extent 4 inches fore and aft of the antenna box (Figure 4-4) having a total length of 15 inches. Mounting the *Puffer* requires that 5 holes be drilled through the payload bay for mounting screws and cable access. From Table 1 and Appendix D, the widest portion of the *Aerostar* fuselage is 16 inches. The payload bay is 24 inches long and extends from the nose wheel to the forward section of the wing, which is where the fuel tank is situated. The *Puffer* would be attached to the lower portion of the fuselage aft of the nose wheel strut and forward of the main landing gear. There are 14 inches of ground clearance on the *Aerostar* which exceeds the height (2 inches) required for the *Puffer*. The current configuration used at NAVAIR includes the POP EO/IR camera group. The distance between the nose wheel and the POP EO/IR camera is 30.2 inches. The *Puffer* could be mounted 6.5 inches forward of the POP EO/IR camera. In this configuration, the *Puffer* may obscure the camera's field of view when it is pointed towards the nose and parallel to the bottom of the fuselage. Figure 7-2 shows the conceptual installation of the *Puffer* on the *Aerostar*.

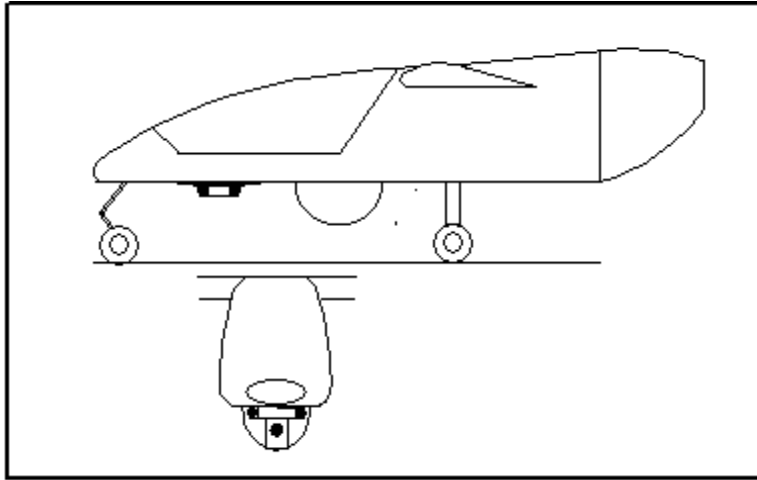


Figure 7-2. Aerostar with *Puffer* Installed

7.1.1.4 Structural Integration of the Puffer onto the Dakota

Figure 4-4 shows the dimensions and attach points for the *Puffer*. From Table 2, the widest portion of the *Dakota* fuselage is 1.12 ft (13.44 inches). The payload bay is 24 inches long and extends into the aft area of the fuselage behind the main landing gear. The area over the main landing gear houses the autopilot, the downlink transmitters and the Flight Termination Package (FTP). The *Puffer* would be attached to the lower portion of the fuselage approximately 4 inches aft of the main landing gear assembly. The main landing gear strut is a continuous piece of metal that attaches to the bottom of the *Dakota*'s fuselage and extends out and down to support the two main landing gear wheels. The forward portion of the *Puffer*'s mounting bracket could be placed between the strut and the fuselage and attached in that manner. There are 12 inches of ground clearance on the *Dakota* which is greater than the 2 inches required by the *Puffer*. Figure 7-3 shows the conceptual installation of the *Puffer* on the *Dakota*.

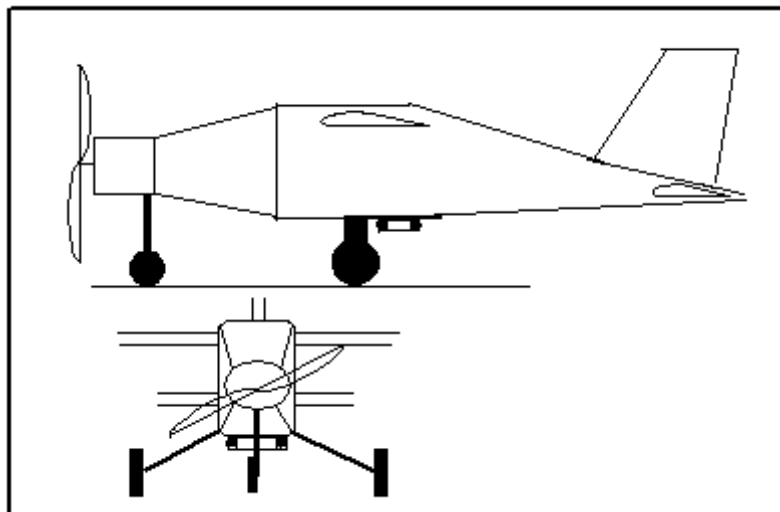


Figure 7-3. *Dakota* with *Puffer* Installed

7.1.2 Aerodynamics

The following paragraphs centers on the changes to the flight envelop that may occur because of the integration of the *Puffer* on the aircraft including:

- Additional Drag caused by the *Puffer* (Lift to Drag Ratio)
- Stall Angle of Attack (AOA) and speed affected by additional drag
- Wing Loading due to Weight of *Puffer*
- Thrust to Weight ratio
- Take off and Landing distances
- Center of Gravity (CG) and Aerodynamic Center (AC) locations
- Mission Endurance
- Flight Limitations

See appendix D for *Aerostar* measurements and calculations and appendix E for *Dakota* measurements and calculations.

7.1.2.1 Aerodynamic Impacts to *Aerostar* with *Puffer* Integration

The *Aerostar* is controlled by an onboard autopilot. All uplinked commands to the aircraft are passed through the autopilot which then acts on the inputs. The autopilot has a predetermined set of flight parameters which will not allow the aircraft to perform outside of the preset flight envelope. When the External or Internal Pilot provides an input to climb, descend, change headings, or airspeed, the autopilot executes the command within the flight envelope. The ground controller cannot override the speed at which the autopilot executes the command. In the case of loss of command uplink, the autopilot is pre-programmed to return to base.

7.1.2.1.1 *Aerostar/Puffer* Weight Impacts

From section 7.1.1.1, The *Puffer's* weight is well within the payload weight restrictions of the *Aerostar*. Normal operating procedures require that ballast be added to the payload weight to balance out the aircraft. The added ballast and the payload weights will not exceed the total payload capacity weight for the aircraft. Therefore, the addition of the *Puffer* should not require any increase in propulsion power.

7.1.2.1.2 Aerostar/Puffer Lift to Drag ratio and Thrust to Weight Ratio.

From section 7.1.1.3, the *Puffer* will be mounted externally on the *Aerostar*. This will directly impact the lift to drag ratio of the aircraft directly and the thrust to weight ratio indirectly. To determine the extent of the impact, the lift to drag ratio was obtained by computing the wetted aspect ratio of the *Aerostar* with and without the *Puffer* installed. From table 12, the total wetted area of the *Aerostar* is 165.5ft² with a lift to drag (L/D) ratio of 2.7. Adding the *Puffer* wetted area from section 4.2.2 to the *Aerostar* area give a total wetted area of 167.6 ft² with a lift to drag ratio (L/D) of 2.6 which is roughly a 4% change in the L/D ratio. However, expanding the calculations of the L/D ratio to two significant figures, the L/D for the *Aerostar* is 2.66 and the combined *Aerostar/Puffer* L/D is 2.63 which give a more tolerable increase of 1%. Taking this value directly to the endurance time of the *Aerostar* from table 1, the increase in drag would only be a reduction of 4 minutes and 45 seconds of mission time.

In the case of the Thrust to Weight Ratio (T/W) using Table 1 values, the computed value is 0.27 (see Appendix D) with a computed L/D of 3.70. Using the Wetted Aspect Ratio L/D value of 2.66, the *Aerostar* T/W would be 0.375. The T/W ratio for the *Aerostar/Puffer* would be 0.380. This is also only a 1% increase. While these differences seem relatively benign, using the 0.38 value for the T/W to compute a cruise speed, a greater disparity is found. The 0.27 value for the T/W was computed from the table values using a cruise speed of 62 knots. When the T/W value derived from the wetted aspect ratio L/D value (0.38) is used, a cruise speed of 43.3 knots is computed. This is a 30% reduction in the cruise speed and below the guessed the stall speed of the aircraft. However, taking the 1% increase in L/D and T/W that was found using the wetted aspect ratio and increasing the calculated T/W by 1% to include the *Puffer*, then a more realistic 60.3 knots cruise speed is calculated.

7.1.2.2 Aerodynamic Impacts to *Dakota* with *Puffer* Integration

The flight envelope of the *Dakota*, like the *Aerostar*, is controlled by an autopilot. Inputs from the ground controllers are filtered through the autopilot and are executed to keep the aircraft flying safely.

7.1.2.2.1 Dakota/Puffer Weight Impacts

From section 7.1.1.2, the weight of the *Puffer* is well within the payload weight limitations of the *Dakota*, Therefore, the addition of the *Puffer* should not require any increase in propulsion power. Like the *Aerostar*, ballast is added to balance the aircraft and keep the operating parameters of the aircraft within the flight expectations.

7.1.2.2.2 Dakota/Puffer Lift to Drag Ratio and Thrust to Weight ratio.

From section 7.1.1.4, the *Puffer* will also be mounted on the exterior of the aircraft and will have an effect on the drag parameters. Table 13 in appendix E lists the wetted area of the *Dakota* at 109.7ft². Using the wetted aspect ratio, the lift to drag ratio of the *Dakota* is 2.2. Re-computing this value by adding the wetted area of the *Puffer* gives an L/D ratio of 2.2 also. Expanding the L/D ratio out to two significant figures, the real impact of the added *Puffer* can be examined. Without the *Puffer*, the *Dakota* L/D is 2.22. With the *Puffer* the *Dakota* L/D is 2.18. This is a difference of 2%. While still a small value, in a relative sense, the *Puffer* has twice the effect on the *Dakota*'s L/D ratio than on the *Aerostar*. If this is taken directly to the endurance values from table 2, this could cause a decrease of 5 minutes and 20 seconds in mission time.

In the case of the Thrust to Weight Ratio (T/W) using Table 2 values, the computed value is 0.31 (see Appendix E) with a computed L/D of 3.23. Using the Wetted Aspect Ratio L/D value of 2.66, the T/W would be 0.45 for the *Dakota*. The T/W ratio for the *Dakota/Puffer* would be 0.458. This is also a 2% increase. As with the *Aerostar*, when the *Dakota/Puffer* T/W value of 0.458 is used to compute a cruise speed, a greater disparity is found. The 0.31 value for the T/W was computed from the table values using a cruise speed of 62 knots. When the T/W value derived from the wetted aspect ratio L/D value (0.458) is used, a cruise speed of 42.2 knots is computed. This is a 32% reduction in the cruise speed and also approaching the stall speed of the aircraft. However, taking the 2% increase in L/D and T/W that was found using the wetted aspect ratio and increasing the calculated T/W by 2% to include the *Puffer*, then a more realistic 61.2 knots is calculated.

7.1.3 Avionics and Mission Computer (MC)

Both the *Aerostar* and *Dakota* provide for separate payload integration modules into the downlink data flow. For this integration effort, it is expected that the *Puffer* will provide data in a Tab delimited, RS-232 standard format. Both the *Aerostar* and *Dakota* downlink capabilities utilize data transmitted in the RS-232 format.

7.1.3.1 Avionics Changes required to integrate the *Puffer* onto the *Aerostar*

No additional software modules or hardware modifications would be required to integrate the *Puffer* onto the *Aerostar* aircraft. On the current NAVAIR configured *Aerostar* aircraft, there is a second RS-232 transmitter for the AIS information downlink from the aircraft to the Payload Commander's display.

7.1.3.2 Avionics Changes required to integrate the *Puffer* onto the *Dakota*

The Geneva Aerospace *linkTEK* datalink system offers 4 additional RS-232 ports that maybe utilized for payload interfaces. Additionally, the *linkTEK* system is optionally equipped with a JPEG 2000 video capture and compression capability for transmission of digital video. With the *linkTEK* IP based messaging system; data broadcasts are available to multiple IP addresses in the network ²².

7.2 *Puffer* data integration into Crew Station

This section will outline the changes that are required to the crew station to support the addition of the *Puffer* data stream to the Payload Commander's display and the integration of the MIDS/LVT transmitter/receiver into the GCS. This integration is required for the *Aerostar* and *Dakota* UAS systems. In those cases where system specific issues need to be addressed, a separate paragraph will be used to provide additional integration information.

7.2.1 *Puffer* Data Stream Integration

This subsection discusses the changes required to integrate the *Puffer* Data Stream into the Payload Commanders Position. This includes:

- Addition of a database that will organize the incoming data

- Software that will load the database as the data is downlinked from the aircraft
- Software that will perform the geolocation of emitters
- Software that will display the results of the geolocation calculations on the Payload Commanders Display station.

7.2.2 Puffer Data Base Structure

As stated in Section 6.1, the premise is that at least three UAVs working in concert would obtain the geolocation of an emitter. While specific data points downlinked from the *Puffer* were not referenced in Peter Bartolomeo's article ¹¹, the following information would be expected to be available from the *Puffer* system, and the aircraft:

- Aircraft Identification (ID)
- GPS Time (hh:mm:ss.msec)
- Aircraft Position (Latitude and Longitude in degrees)
- Aircraft Heading (True)
- Aircraft Speed (knots)
- Emitter Frequency
- Emitter Pulse Repetition Interval (PRI)
- Emitter Pulse Width (PW)
- Emitter Quadrant of Arrival (QRA)
- Signal Strength Antenna Q1 (P_{Q1})
- Signal Strength Antenna Q2 (P_{Q2})
- Signal Strength Antenna Q3 (P_{Q3})
- Signal Strength Antenna Q4 (P_{Q4})

Each aircraft will have its own data table. This would be the easiest way to deconflict the downlink frequency by having separate frequencies and data tables for each of the aircraft.

The following data will be added to the aircraft unique database record based on the information downlinked from the *Puffer* after additional processing:

- True Direction of Arrival (computed)

- Emitter Confidence Value (ECV) – this is a calculated value between 0 and 7 and is the sum of values for an emitter frequency (4), emitter PRI (2) and emitter PW (1) being available. An example would be at time X; the *Puffer* passes a record with a frequency value and a PW value. This would make the Emitter Confidence Value equal to “5” (Frequency = 4 and PW = 1 therefore $4 + 0$ (no PRI) $+ 1 = 5$). This value is not downlinked, but calculated when the data is stored in the data base. This value will be used to provide a higher confidence level of the ability to match a known emitter type. When computing the geolocation, all of the ECV’s will be summed to indicate the confidence of a particular emitter being at the geolocation computed.

A forth database table will be used to compute the geolocation of an emitter: Each database record will include the following information:

- GPS Time (hh:mm:ss:msec)
- Aircraft ID
- Aircraft Latitude and Longitude (in degrees)
- Computed True DOA
- ECV from the emitter hit.
- Emitter Name (From Emitter Library Database)
- Emitter Frequency
- Emitter ECV (a total of the individual aircraft ECVs)
- Emitter Location (Computed Latitude and Longitude).

These records would be stored in tables using MS Access Database manager software.

7.2.3 Geolocation Software Design

This section describes the high level software design which is required to download the data from the *Puffer*, compute the location of the emitter, and display it on the Payload Commander’s Console. Figure 7-4 shows the software modules required and the basic flow of how the data is moved from the aircraft to the Payload Commander’s Display.

The modules described will include:

- Download *Puffer* data from each aircraft, into Database

- Compute Direction of Arrival of each emitter for each Aircraft
- Combine DOAs to geolocate emitter
- Compare geolocated emitter to data base for actual emitter type
- Display on Payload Commander's Console.

Detailed flow charts for each of the modules and pseudo code may be found in Appendix F.

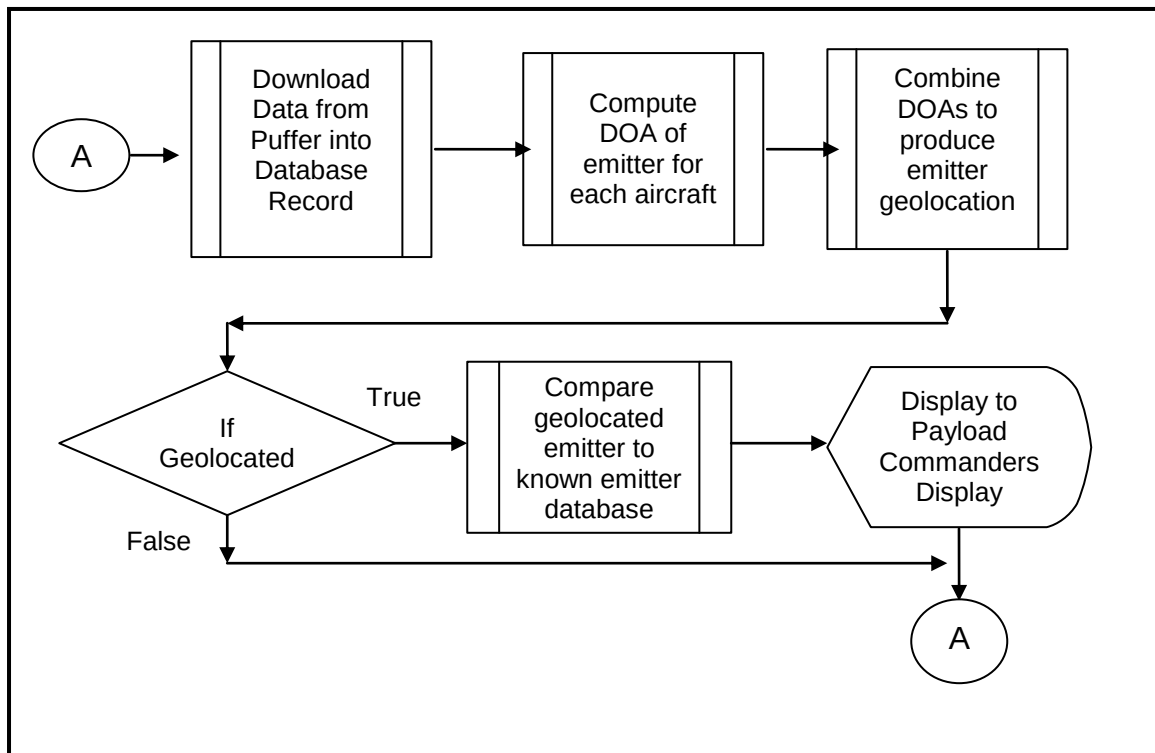


Figure 7-4. Downlinked Data and Geolocation Processing

7.2.3.1 “Download Data from Puffer into Database Record” Module Description

This module will receive the downlinked data and create a new database record. The database records will be used later by other processes to determine the geolocation of the detected emitters. The data is in a tab delimited, ASCII format. There is a table of records for each aircraft and is directly connected to the downlink frequency. A new record is generated whenever a new detection is made. Once detected, each data field

is filled in order of arrival in the data stream. This module runs continuously as long as the UAV is downlinking information on the specific payload channel.

7.2.3.2 “Compute DOA of emitter from each aircraft” Module Description

After a database record is written, the True DOA is computed. To begin, the power levels from each antenna are compared. Based on the quadrant of arrival, the power levels from the antennas that border the quadrant are compared to the power level from the center antenna of the quadrant. Figure 7-5 illustrates the Puffer quadrants and the direction of the quadrant’s antenna. The next strongest power detection will determine which two antenna power values are used to determine the DOA of the signal.

Referencing Figure 7-5, if the power level of the Quadrant 1 antenna is equal to 10 milliwatts, the power level of the antenna in Quadrant 4 is five milliwatts, and the power level of the antenna in Quadrant 2 is 1 milliwatt, then the DOA will be computed based on the ratios of the power levels of the Q1 and Q4 antennas. A quick analysis of the DOA would be that the gross direction of arrival is between 315° and 45° with a more refined guess being most likely between 0° and 45° (because the Q1 antenna has a higher power value). The first step of computing the DOA will be to further refine the angular limits. Table 11 list the limits based on the power level of the primary Quadrant of Arrival (QOA) antenna versus the values of the adjacent quadrant’s antennas.

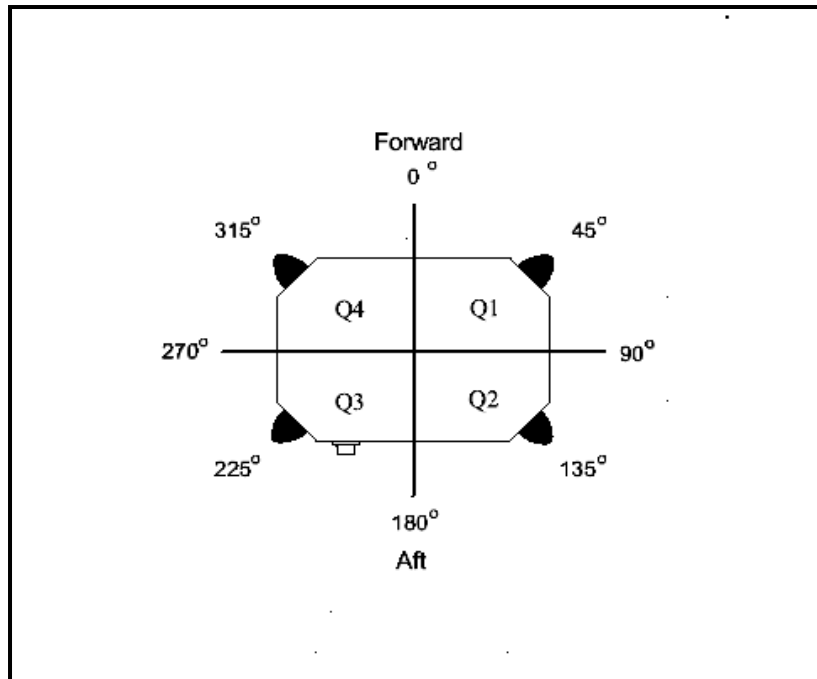


Figure 7-5. Puffer Antenna Quadrants (Top Down View)

Table 11. Rough DOA based on QOA and Antenna Power Levels

QOA	Primary Antenna	Adjacent ₁ vs. Adjacent ₂
1	Q1	$P_{Q1} = P_{Q4} = 0^\circ$
		$P_{Q4} > P_{Q2} = 0^\circ - 45^\circ$
		$P_{Q4} = P_{Q2} < P_{Q1} = 45^\circ$
		$P_{Q4} < P_{Q2} = 45^\circ - 90^\circ$
2	Q2	$P_{Q2} = P_{Q1} = 90^\circ$
		$P_{Q1} > P_{Q3} = 90^\circ - 135^\circ$
		$P_{Q1} = P_{Q3} < P_{Q2} = 135^\circ$
		$P_{Q1} < P_{Q3} = 135^\circ - 180^\circ$
3	Q3	$P_{Q3} = P_{Q2} = 180^\circ$
		$P_{Q2} > P_{Q4} = 180^\circ - 225^\circ$
		$P_{Q2} = P_{Q4} < P_{Q3} = 225^\circ$
		$P_{Q2} < P_{Q4} = 225^\circ - 270^\circ$
4	Q4	$P_{Q4} = P_{Q3} = 270^\circ$
		$P_{Q3} > P_{Q1} = 270^\circ - 315^\circ$
		$P_{Q1} = P_{Q3} < P_{Q4} = 315^\circ$
		$P_{Q1} < P_{Q3} = 315^\circ - 0^\circ$

The second step uses the limits of the rough DOA and refines the DOA by computing the DOA based on the ratio of the power level of the Primary Quadrant antenna and the adjacent antenna with the higher power level. The ratio is then used as a percentage to calculate the DOA. Using the previous example, $P_{Q1} = 10$ milliwatts, $P_{Q4} = 5$ milliwatts and $P_{Q2} = 1$ milliwatt. From table 11, the DOA limit would be between 0° and 45° . The ratio P_{Q4} to P_{Q1} would be 5 milliwatts divided by 10 milliwatts or 50%. The angle that is 50% of the high limit (45°) is 22.5° . The DOA is then computed by subtracting the angle value from the high limit (45°). The computed DOA would be 22.5° .

The third step involves taking the computed DOA and translating it to True North by adding the aircraft heading and the DOA together and then reducing it to a value between 0° and 359° if required and writing the True DOA to the database record.

Finally, the forth step involves calculating the Emitter Confidence Value (ECV) for the

signal detection based on the description in paragraph 7.2.2, and writing it to the database.

7.2.3.3 “Combine DOAs to Produce Emitter Geolocation” Module Description

This module is where the primary function of the UAS takes place. Based on the time of detection, the UAS location, and the DOA from the UAS, a geolocation for the emitter is attempted. At least two DOA's and aircraft positions are required for this calculation. If only one aircraft has a “hit”, then a geolocation will be still be attempted using two consecutive DOAs from that aircraft for the same frequency. The geolocation will be obtained using the location of the aircraft (x_i, y_i) at the time of detection and the True DOA (θ) of the emitter. A second angle (ϕ) , will be assumed that represents the error between the computed DOA and the actual DOA to the emitter (x, y) (see figure 7-6).

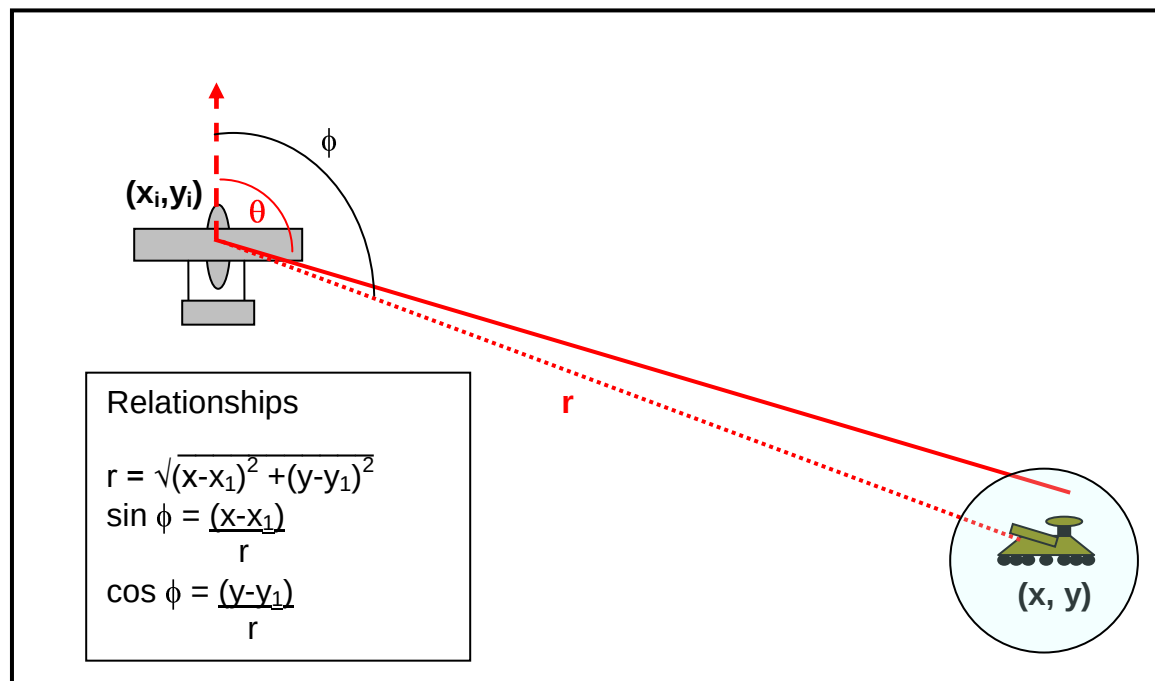


Figure 7-6. Conceptual Geolocation

With these points and angles, a routine will be invoked to compute a range (r) from the aircraft to the emitter. This routine will be an iterative process that begins by initializing a value for the error angle (ϕ) and then solving for the range based on points x_i and y_i and θ_i . When the difference between computed (x_n, y_n) and (x_{n+1}, y_{n+1}) approaches zero, then the computed x and y value is the location of the emitter and ϕ is the error of the DOA. To obtain the geolocation, a geodetic transformation is accomplished. After the emitter geolocation is obtained, the frequency, PRI, PW and geolocation will be compared to a reference library for the type of weapons system the emitter parametrics are associated with. The name and the geolocation will then be written to the database records for each aircraft. For systems where a geolocation can not be established, the location fields will be filled with zeros and the emitter name will be "unknown". Unknown emitter records may still be used for subsequent hits on the same frequencies to provide more information for a possible emitter identification and location. For subsequent hits on the same frequency a comparison check between the previously computed geolocation and the recently computed geolocation will be made. If the geolocations are the same (within some value) then the program goes on to the next emitter hit. If it is different, then a determination is made if the emitter could have moved the computed distance verse the time between detections. A distance of a few miles over 5 to 10 minutes could indicate a mobile SAM on the move and the new position should be reported (i.e. a color change on the display). If the distance is greater than 20 miles over the same 5 to 10 minutes, then the new geolocation would be flagged, but not displayed. If additional hits bring the location of the emitter back to an established location, the flagged may be discarded if the ECV value is low (less than 4). If the flagged value has a high ECV, then subsequent hits will be compared to the flagged value also as a possible additional new emitter location of the same type.

7.2.4 Payload Commander Station Displays

With the emitter located and identified, the final step is displaying the emitter graphically on the Payload Commander's display. Associated with the emitter database record, will

be a display symbol representing the emitter type. This symbol may be one or two characters and or numbers that would be unique to the weapon system type. The Payload Commander's workstation will display a map of the operating area including the routes of the UAV and the symbols of the geolocated emitters. When an emitter is displayed, a display table is updated with the most recent time. If an emitter has been displayed for more than ten minutes without a subsequent update, the symbol should be removed from the display. Color coding of the symbol may be used to indicate the emitter is transmitting (having regular updates), or has not had an update for five or more minutes.

7.2.4.1 The Tactical Display Station (TDS)

In both the *Aerostar* and *Dakota* UAS, the Payload Commander's station is the heart of the information flow from the aircraft to the Human component. As a standalone system, the payload commander provides the interface to the outside world. Data is passed to other interested parties via radio or telephone communications networks. With the addition of MIDS/LVT to the equation, the Payload Commander's console becomes another node in the battlespace network, processing the data downlinked from the UAV/*Puffer* and then presenting the product to the Tactical Display Station (TDS) for display and dissemination via Link16 messaging. With the addition of this capability, the new Mission Commander's Display will have a complete view of the battlespace, being able to make tactical decisions on the *Puffer's* deployment. Figure 7-7 presents an overview of the data flow from the UAV, through the TDS/MIDS terminal, and out to the tactical units and field commanders.

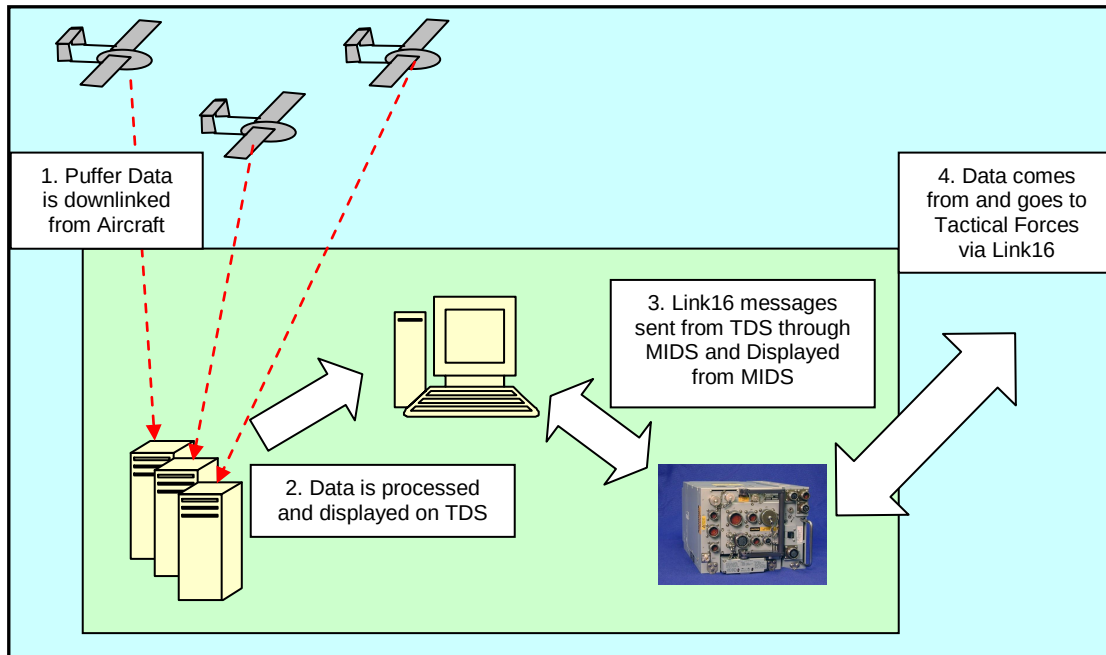


Figure 7-7. UAV – TDS/MIDS – Tactical Units Data Flow

7.2.4.2 Integrating *Puffer* Data onto the Payload/Mission Commander's Display in the S-280 (*Aerostar*) GCS

As of this writing, the *Aerostar* system requires separate Internal Pilot and Payload Commander Stations for each aircraft flying. A system to control multiple UAV's from a single control station is still under development. The *Aerostar* system the author is familiar with and used for this thesis is a single UAV to a single control station. The use of the TDS works well to integrate the separate payload downlink data streams to the emitter database and to the MIDS/LVT. This configuration provides the advantage of a single Payload display giving the Mission Commander a complete view of the surveyed area, including the situational displays from all of the UAVs and the Link16 messages displayed from other members of the network. A similar approach could be used for the Internal Pilot's displays, but this would increase the software effort substantially. A possible compromise solution may be to use commercially available switching technology that would allow the pilot to switch between UAV inputs form a single display station.

7.2.4.3 Integrating *Puffer* Data onto the Payload/Mission Commander's Display in the *Dakota* GCS

The *Dakota missionTEK*, software package is capable of controlling multiple UAV systems “out of the box”. This capability makes the integration somewhat simpler. This essentially means that the emitter database would only have a single network node inputting data, instead of multiple inputs required by the *Aerostar*. Like the *Aerostar*, a TDS would provide the interface between the *Dakota missionTEK* control system, the emitter database and the MIDS/LVT; as well as providing the *Dakota* Payload Commander with a complete situational display of the surveyed area and incoming Link16 messages from outside sources.

7.3 Integration of the MIDS/LVT into the Ground Control Station

In keeping with the philosophy to use commercially available products, Tactical Communications Group, LLC of Billerica, MA, produces a product named the “Battlefield Operations Support System (BOSS)”⁵³. This product is used by several military test organizations to provide an interface into a Link16 network. BOSS is used to interface the Advanced Weapons Laboratory's (AWL), Weapons Systems Support Activity (WSSA), the AWL's mobile MIDS support Van, and aircraft in flight, via the Link16 message system. The system readily integrates with the MIDS/LVT using the LinkPro system to provide message communications. BOSS is hosted on a standard PC platform using standard applications program interfaces (API). With the addition of an API to display the emitter and one that allows the Mission commander to select which emitters should be transmitted, BOSS is capable of forwarding messages via the MIDS/LVT using Mil-Std 1553B/Link16 protocols. With these additional API's, BOSS can become the TDS needed to interface the Puffer downlinked messages, emitter database and the Payload commander's displays.

7.3.1 Physical Placement of the MIDS/LVT into the Ground Control Station

From Table 4, The MIDS/LVT requires a space that is 7.5 inches high by 7.5 inches wide by 17.75 inches deep shelf for the actual box. The box is powered by a 115 VIC,

⁵³ TCG's Battlefield Operations Support System Sales Brochure. www.g2tcg.com

20 amp circuit with a 400 Hz power converter. Power can be supplied commercially or through a generator for off grid operations. The MIDS/LVT is configured to easily fit in a COTS computer rack. In addition to normal room air conditioning, additional cooling fans should be used to maintain proper air flow around the unit. The MIDS/LVT is an aircraft certified component and is capable of working in extreme environments. An antenna is required for MIDS/LVT network connectivity, and an Ethernet network connection is required to interface the MIDS/LVT to the computer network of the ground control station.

7.3.1.1 Placement of the MIDS/LVT into the S-280 (*Aerostar*) GCS

From 7.3.1, proper power, space, computer network connections, and HVAC is required to place the MIDS/LVT into the *Aerostar* GCS. A place to add the MIDS antenna is also required. Additionally, space and power for a PC tower and a larger (21 inch) monitor would be required for hosting the emitter database and BOSS software. As noted in section 7.2.4.2, to control multiple *Aerostar* UAVs, separate computers are required for the Internal Pilot and the Payload Commander. Space would be needed for four additional computers to control the aircraft and receive the downlink. Additional downlink interfaces would also be required to process the additional aircraft data.

7.3.1.2 Placement of the MIDS/LVT into the *Dakota* GCS

From 7.3.1, proper power, space, computer network connections, and HVAC is required to place the MIDS/LVT into the *Dakota* GCS. A place to add the MIDS antenna is also required. Additionally, space and power for a PC tower and a larger (21 inch) monitor is required for hosting the emitter database and BOSS software. As noted in section 7.2.4.3, multiple *Dakota* UAVs may be controlled by the same computer, therefore no additional computer resources would be required outside of the one required to host the TDS, BOSS and database software packages. Separate antennas for the downlink and MIDS communication will also need to be available.

7.3.2 Interfaces between the MIDS/LVT and the Mission Commanders Station

From Section 7.3, the BOSS software package hosted on a single PC will provide the common interface protocols between the UAS/Puffer downlinked information, the emitter data base, and the MIDS/LVT. From reference 54, the BOSS is capable of the following:

- Receiving and forwarding Link16 messages in the required MIL-STD 1553B format used by the MIDS/LVT.
- Displaying the battlespace based on received Link16 message traffic
- Acting as a network node using COTS computers and software which can serve as the TDS for both the *Aerostar* and *Dakota* UAS
- Through an application interface, data from the Emitter Database may be processed through the TDS and forwarded to other Link16 members.

7.4 Frequency Deconfliction

The Tier 2/Puffer UAS CONOPS is primarily an ISR asset. The UAS would be deployed to “scan” the area for potential threats and provide pre-strike intelligence of the battlespace. The possibility of opposition jamming could cause problems for uplink commands and GPS navigation. In both instances, the *Aerostar* and *Dakota* have special “return to base” routines that would be invoked in the case of loss of signal and the aircraft could not maintain its mission profile. All of the systems, UAVs, MIDS, and GPS, transmit and receive in “L” and “S” band frequencies. Table 12 contains the systems frequency and Figure 7-8 depicts the historical bands⁵⁴ and the operating frequencies of the *Aerostar*, *Dakota*, MIDS/LVT and GPS, and includes possible threat systems that operate in the same bands and could be jamming targets during the UAV operations.

Table 12. Operating Frequencies of the UAS/GPS and MIDS Systems

System Name	Frequency	Historical Band ⁵⁴
<i>Aerostar</i> Uplink	-	“S” – Band

⁵⁴ Jane's Information Group Limited, “Introduction” Jane's 2000-2001 Radar and Electronic Warfare Systems, 12th ed., pp 4

Aerostar Downlink	-	"L" – Band
Dakota Uplink	2484 – 2499 MHz ⁵⁵	"S" – Band
Dakota Downlink	1610 – 1625 MHz ⁵⁵	"L" – Band
MIDS/LVT	996 – 1624 MHz ¹⁶	"L" – Band
GPS (L1) ⁵⁶	1575.42 MHz	"L" – Band
GPS (L2)	1227.6 MHz	"L" – Band
GPS (L5)	1176.45 MHz	"L" – Band

Jamming these radars could have operational effects on the UAS, GPS and the MIDS/LVT. Another consideration is that the transmission of the uplink to, and the downlink from the UAV, may cause the Puffer to try and identify the emitter. A possible solution would be to place these frequencies into the Emitter Data Base and disregard them when encountered.

⁵⁵ Dakota linkTEK Sales Brochure. www.genaero.com

⁵⁶ Robert A. Nelson, "The Global Positioning System A National Resource", *Applied Technology Institute (ATI)*, November 1999 <http://www.dxzone.com/cgi-bin/dir/jump2.cgi?ID=9205> accessed 03/07/2009

Frequency (GHz)	.03 thru 0.3 VHF	0.3 thru 1.0 UHF	1.0 thru 2.0 “L”	2.0 thru 4.0 “S”
Band				
			MID/LVT	
				Aerostar/ Dakota Uplink
			Aerostar/Dakota Downlink	
			GPS	
Threat Systems Long Range Early Warning⁵⁷				
			GRL 600/610 (India)	
			DR Series (Germany)	
		146-1 (China)		
		HN-401R (China)		
			JLP-40 (China)	
		Model 17 C (China)		
	Type 408-C (China)			
			S743 Martello (International)	
				Long Track (Russia)
				Tinshield (Russia)
	P-12 Spoonrest (Russia)			
	P-14 TallKing (Russia)			
		P-15 Flat Face (Russia)		
				P-35/37 Barlock (Russia)
				OddGroup (HF) (Russia)
				PRV11 SideNet (HF)
			AN/TPS-44 (US)	
			AN/TPS-59 (US)	
			AN/TPS-63 (US)	
				AN/TPS-70 (US)
			Track-star (US)	

Figure 7-8 Operating Frequencies for UAS/MIDS/GPS and Selected EW Radars

⁵⁷ Jane's Information Group Limited, "Land Based Air Defense Radars" Jane's 2000-2001 Radar and Electronic Warfare Systems, 12th ed., pp 7-66

7.5 Additional Requirements

From section 7.1, the physical placement of the Puffer on either the *Aerostar* or *Dakota* is very straight forward. Both aircraft are capable of carrying the Puffer with no major modifications. Collecting the downlinked data is also within the current capabilities of each system with some minor modifications to the software that collects and stores the information. In section 7.3 the real effort becomes when integrating multiple aircraft and the MIDS/LVT into the equation.

7.5.1 Changes to the Crew Station Hardware

As noted in section 7.2.4.2, the *Aerostar* requires one computer for the Internal Pilot and one computer for the Payload Commander. To control three aircraft, four additional computers will be required for command and control of the aircraft and downlinking the information. In the case of the *Dakota*, the *missionTEK* software can control multiple UAVs; however, the downlinking of multiple data streams is not so apparent. Multiple *linkTEK* receivers would be required to collect multiple data streams. To use a single PC to control multiple aircraft and collect multiple data streams could surpass the processing power of a single PC quite quickly.

By integrating the TDS into the Crew Station, the processing of the emitter data, obtaining a geolocation, displaying the position, and sending the location out using Link16 could be accomplished by a single person. Normal operations for a single UAV require two operators, a pilot and a Payload Commander. The addition of the MIDS/LVT display with the located emitters will require a third person to maintain the situational awareness of the battlespace and make decisions on which emitters are an immediate threat to allied forces. This person would be the Mission Commander, coordinating with the pilot to place the UAVs in the optimal position for data gathering and with the Payload Commander to ensure the integrity of the data stream. An additional workstation for the TDS and the Mission Commander would be required in the Crew Station.

7.5.2 Changes to Crew Station Software

In section 7.3, the evidence overwhelmingly point to the fact that it is not the integration of the payload on the aircraft that is the challenge, but rather the processing and dissemination of the data that is collected by the aircraft. The previous sections have outlined software required to move the DOA data from each of the aircraft and performing the calculations required to obtain a geolocation of the emitter. The addition of the TDS using BOSS and LinkPro software with the appropriate APIs to display and transmit the geolocated emitters should complete the required software suite to perform the UAS/*Puffer* mission.

7.5.3 Changes to Crew Procedures

When managing a single UAV, a crew of two works well. Crew Resource Management (CRM) is minimal and is usually accomplished by leaning over and requesting the other crew member perform some action. The Internal Pilot develops an instrument scan pattern to understand the aircraft situation, and the Payload Commander reviews the downlinked data or images in real-time. Situations, both mission and emergency, are handled as they arise.

7.5.3.1 Changes to Operational Procedures

With the addition of MIDS/LVT, two aircraft, and a Mission Commander, individual responsibilities and CRM procedures require additional controls.

- **Mission Commander** – is responsible for the conduct of the On-Station portion of the mission and performs the following:
 - Coordination with the Pilot to ensure the aircrafts are flying an optimal profile to for data collection. Assist the pilot in maintaining situational awareness for the airspace surrounding the UAS platforms.
 - Coordination with the Payload Commander to ensure that the downlinked data is being processed completely, forwarded to the TDS for display, and has been properly executed
 - Coordination with the Field Commanders and other Strike assets to disseminate the geolocation data as needed.

- Coordinates the overall conduct of the Mission Portion of the flight based on the Mission Plan.
- **Payload Commander** – is now responsible for the collection and forwarding of the *Puffer* data to the TDS including:
 - Coordinating with the Pilot to ensure that aircraft function that affect downlink are within limits
 - Coordinating with the Mission Commander to ensure that data is being passed to the TDS for display and dissemination.
 - Ensuring that all downlinks and data streams are working correctly.
- **Internal Pilot** – is now responsible for the operation of multiple UAVs flying different routes, and possibly commanded by different computers:
 - Managing CAWS Display for each aircraft
 - Maintain situational awareness of the airspace
 - Communicate with ground controllers and other aircraft in the area
 - Perform route changes per Mission Commander and/or Payload Commander
 - Develop full understanding of Mission Plan and Objectives
 - Execute Emergency procedures as required.

7.5.3.2 Changes to Emergency Procedures.

Emergency procedures will center on three types of aircraft related situations, aircraft malfunctions, aircraft control malfunctions, and communication malfunctions.

- **Aircraft malfunctions** encompass situations that immediately affect the ability of the aircraft to fly or continue to fly. This would include situations like loss of power, low fuel, engine overheats, weather, aircraft fire, or crew station malfunctions. Corrective actions would require that the aircraft with the problem be isolated, removed from the mix, and flown back to base, without affecting the flight of the other aircraft or the overall mission.
- **Aircraft control malfunctions** will deal mainly with command uplink function or the aircrafts response or not, to commands. For the most part, the autopilot software in both the *Aerostar* and *Dakota* is preprogrammed to return to base in the case of uplink loss or other communications problems. If the aircraft is still able to fly, and

the problem exists within the uplink commands being transmitted, the problem may require switching to a backup uplink transmitter. If the aircraft is not responsive, then shutting down the uplink transmitter could force the UAV into an RTB mode. Whatever the case, the ability to isolate the aircraft and having it return to base without affecting the other aircraft is paramount.

- **Communications malfunctions** center around the ability of the crew station to receive and process data and to disseminate the processed information. These types of malfunctions include the downlink receivers, the MIDS/LTV, and the equipment in the ground station. This includes computers, receivers, transmitters, radios, display monitors and other interface devices. Procedures must be developed that will allow the crews to isolate the problems with minimum disruption to the mission.

7.5.4 Crew Accommodations and Human Factors

Each of the UAV systems may have the respective crew stations set up any environment where there is electrical power to energize the computers, transmitters and receivers that control the aircraft. This could be in an office, aircraft hanger, motor home, trailer, boat or airplane. The physical location is not really an issue, nor is the physical placement of the controls. Since the control systems are computer driven, the operator's positions are essentially dictated by standard office ergonomics. The Office of Occupational Health and Safety's (OHSA) web site has information concerning the placement of computer equipment in relation to the individual⁵⁸. The following is a guide to how the individual should "fit" with the computer components.

- Top of Monitor at or just below eye level
- Head and neck in line with torso
- Shoulders relaxed
- Elbows supported and close to body
- Back supported
- Wrists and hands in-line with forearms

⁵⁸ Office of Occupational Health and Safety, "Computer Workstations" www.osha.gov accessed 03/09/2009

- Adequate room for keyboard and mouse
- Feet flat on floor.

All of these positions may be improved upon by devices which allow the monitor to move up or down, forward or back; keyboard trays to adjust to elbow heights, chairs that have various position settings that allow the operator to find a workable position. Using this guideline, the following sections address some of the unique aspects of each of the crew positions. Figure 7-9 shows a conceptual design for the crew positions in the Ground Control Station and Figure 7-10 shows the floor plan. The three position station would be approximately 12 feet long with two 24 inches wide x 42 inches deep x 80 inches high cabinets at either end. The TDS and MIDS/LVT will be housed in two separate cabinets that would be 24 inches wide x 32 inches deep and 30 inches high. The crew control station for the *Puffer/UAS* would require a shelter interior volume of at least 18 feet long x 7 feet wide by 7 feet high. There are several commercially available trailers that could accommodate this configuration.

7.5.4.1 The Mission Commander's Station

The Mission Commander's station will be in the center of the work space. The pilot will be to the left of the Mission Commander and the Payload Commander will be to the right of the Mission Commander. This position allows easy communications with both members of the control team. The station will be a standard workstation configuration with a large (21 inch or larger) display. Below the desk and to the Mission Commander's right, the MIDS/LVT will be placed. Below the desk and to the left of the Mission Commander, the computer server that hosts the emitter database, the BOSS Display software and additional API's, will be placed. On the front of the desk to the left of the monitor, will be a communications switch that will include a plug for the Mission Commander's Head set and microphone, volume controls and push buttons for radio (Air Traffic Control (ATC) and Aircraft), MIDS secure voice (A and B), crew intercom and telephone selection. This switch will be close enough to the Mission Commander's chair, so that the push buttons and controls may be reached without stretching. Directly in front of

the mission commander will be an adjustable keyboard tray for the keyboard and mouse.

7.5.4.2 The Internal Pilot's Station

To the left of the Mission Commander's station is the Internal Pilot's position. This position will be a standard workstation configuration. A major difference between the Internal Pilot's position and that of the Mission Commander's and Payload Commander's positions will be the number and size of displays placed on the desktop. The display directly in front of the Pilot will be larger than the others (19 inches) and will contain the CAWS, altimeter, heading, angle of attack, air speed and fuel level displays of the aircraft that is currently being controlled by the pilot. To the left and right of the main display will be two smaller displays (12 inch) displaying the CAWS and aircraft attitude of the other two aircraft. As the pilot switches between aircraft, the controlled aircraft's CAWS and Attitude information will always be displayed on the large display. Directly above the two smaller displays, will be two more displays of the same size. The display on the left side will contain the map function with the current positions of the three aircraft and each route. This will be a moving map display that will move with the aircraft. The display on the right will have the Link16/MIDS display that is also on the Mission Commander's station. Directly above the Main Display will be a row of push button switches that will control the radio frequencies that the Pilot will need to monitor or communicate on. There will also be switches for MIDS secure voice (A and B) and an intercom for crew communication. At the far left of the pilot, will be a rack of 4 tactical radios and the uplink transmitters for control of the UAVs. Below the desk and to the left will be the computers that control the UAVs and drive the displays. Directly in front of the Pilot will be an adjustable keyboard tray that can be completely hidden when the Pilot is flying (if required). The keyboard and mouse may be replaced by an *Aerostar* control pad and control stick/Hands on Throttle and Stick (HOTAS) controller. The *Aerostar* control pad will contain altitude, speed, and heading thumbwheels that are used to control the attitude, speed, and heading of the *Aerostar*. Each thumbwheel will be at 90° to each other. The Altitude control will be above the heading control and in a vertical configuration. The Heading control will be in a horizontal position. The speed

control will be below the heading. A light over each set of thumb wheels will identify which aircraft is being controlled, green is UAV under control, red not under control. A pushbutton with the UAV number is lit when selected. Figure 7-11 illustrates the thumbwheel configurations.

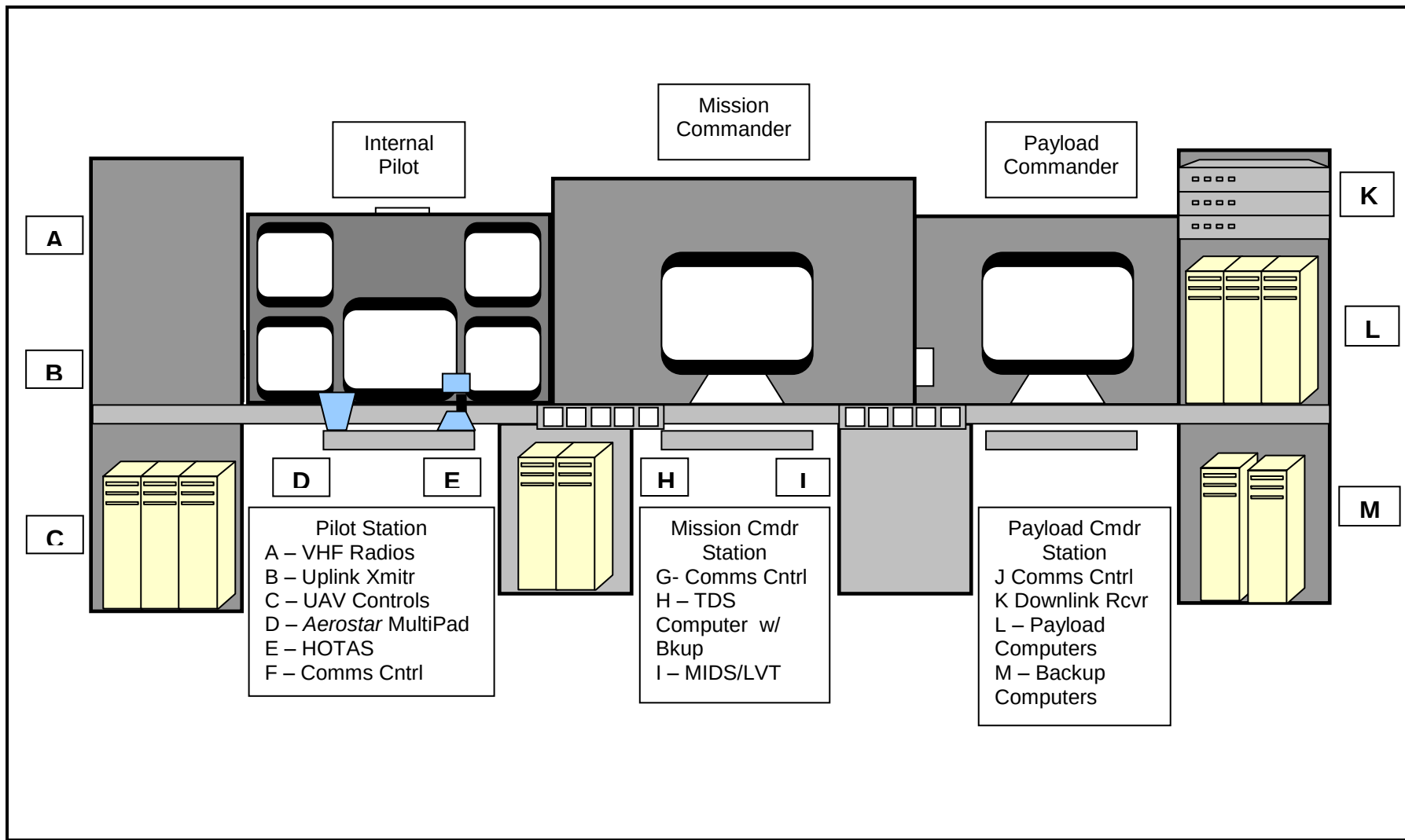


Figure 7-9. Crew Station Layout

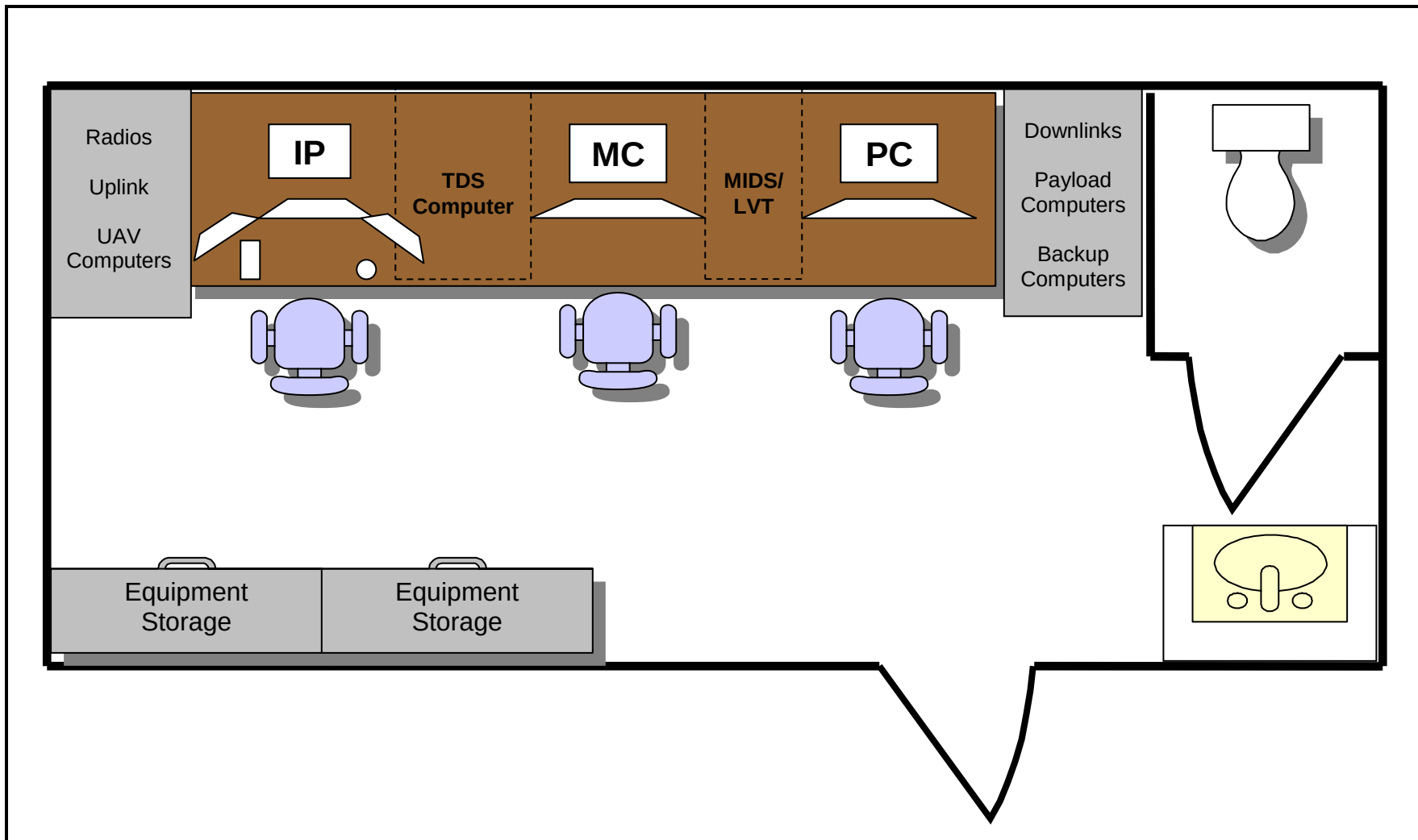


Figure 7-10. Puffer/UAS Crew Station Floorplan

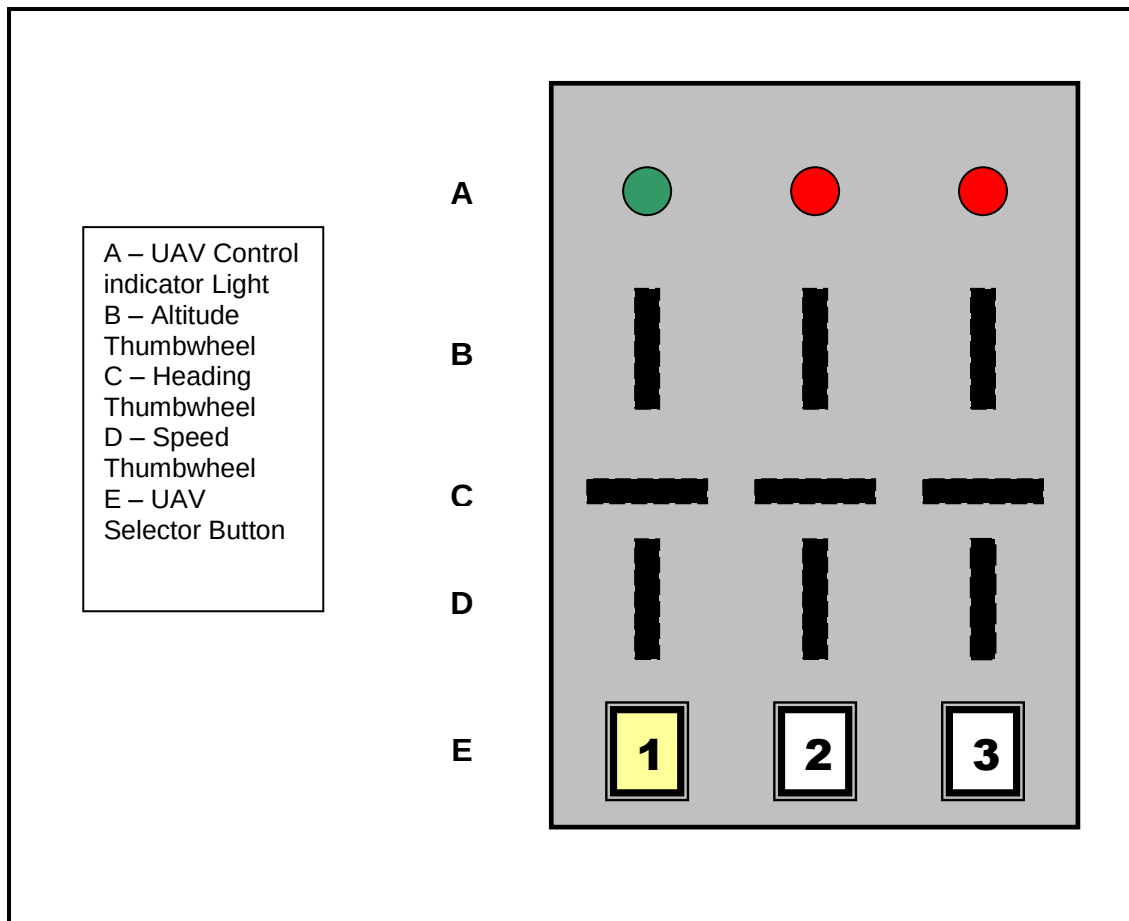


Figure 7-11. Aerostar Multi-Control Pad

7.5.4.3 The Payload Commander's Station

The Payload Commander's station is to the right of the Mission Commander. Like the others, the Payload Commander's position is a standard workstation configuration with a large 21 inch Display in the center. To the left of the display on the front of the desk above the MIDS/LVT, will be the communications controls. To the right on the top of the cabinet will be the downlink receivers, below which will be the downlink control computers. Below that will be two backup computers, one for the Payload Commander's station and one for the Internal Pilot's station. Information displayed on the Payload Commander's Station will be the constantly updating DOA's from all of the aircraft, and the aircraft positions. The Payload Commander will have different options which will filter some of the data being presented on the display.

8. Conclusions and Recommendations

In section 3, the investigation question was asked if a Tier 2 UAV carrying a *Puffer* RWR and downlinking data to a control station equipped with a MIDS/LVT would provide a real-time threat emitter geolocation and targeting capability to a field commander. In an effort to answer this question, a history was given as evidence that there was indeed a need to supply this capability due to the increased proliferation of modern, mobile, technologically advanced SAM systems. These systems are fully capable of moving, shooting and hiding without additional outside support or control. Because of this, the need to locate and eliminate the threat is paramount. Intelligence sources will not be able to provide a definitive answer as to the threat's location before aircrews are put in harms way. The development of a Concept of Operation helped to solidify that a system with the type of capabilities outlined could be an asset to commanders in the field. Besides asking if the capability would be something field commanders desired and would use, the investigation needed to show if it was feasible, (performance), could be fielded for a reasonable cost (cost) and could be done in a reasonable amount of time (schedule).

8.1 Feasibility of the UAS/Puffer/MIDS Concept

The investigation showed that it would be feasible to provide a real-time geolocation capability to field commanders using the Tier 2 UAS/*Puffer*/MIDS system, and could support the CONOPS outlined in section 6. Identification of the different systems that would be used to provide this capability showed that the parts were capable, but would require an extensive integration effort. Based on known information that was available, and interviews with users of the separate systems, the study went on to show what would be required to bring the pieces together.

8.1.1 Aircraft and Puffer Integration

Actual placement of the *Puffer* on an aircraft appears to have little impact on aircraft performance. The physical requirements to place the *Puffer* on the aircraft and connect it to the downlink transmitters is straight forward and could probably be accomplished in a day, including some kind of ground check to make sure that the system can

communicate with the payload station on the ground. Weight and power draw is not an issue for either of the aircraft. The Lift to Drag calculations showed only a minimal impact to the flight envelope. From this, it was concluded that the *Puffer* could be flown on either of the aircraft without any kind of major modification to the airframe. The advertised flight envelope would remain the same with the *Puffer* added to either aircraft.

8.1.2 Aircraft Control

After identifying the issues involved in adding the *Puffer* to the aircraft, the ability to control multiple UAVs and collect, process and disseminate the downlinked information, was investigated. The first major challenge was the control of multiple UAVs. The *Dakota's missionTEK* control software has the capability to control multiple UAVs and collect the downlinked data using a TCP/IP type protocol which essentially created a network of computers connected via a wireless local area network (LAN). The *Aerostar* on the other hand, was a single UAV to a single control station system. To fly multiple *Aerostar* UAVs would require multiple instances of the Internal Pilot and Payload Commander's stations. Also, the *Aerostar's* attitude and speed controls involve using three twist knobs for altitude, heading, and speed changes. A re-organization of the Internal Pilot's station to include some available switching technology may provide a solution to give a single pilot the ability to control multiple systems. Despite some challenges, the technology exists which will allow a single pilot to control multiple UAVs combined with good mission planning.

8.1.3 Data Collection and Processing of the Emitter DOAs

With the ability to carry the payload and control the multiple aircraft required to perform the threat emitter geolocation mission established, the investigation focused on the collecting and processing the data that would be downlinked to the control station. As with commanding multiple UAVs, the *Aerostar* also requires multiple instances of the Payload Commander's interface. In the case of the *Dakota*, the *missionTEK* software can handle multiple sources of downlinked data; however, separate downlink receivers are required. In much the same way as the Pilots station, separate computer would be

used to manage each data stream. This is actually an advantage because the amount of processing required to derive the DOA of each emitter hit, from three different sources, could degrade a single processor quite quickly. With the data processing of each data stream assigned to a separate computer, each system should be able to process the emitter hits very quickly.

8.1.4 MIDS Integration and Dissemination of the Threat Geolocation

A COTS software package BOSS would be used to integrate the display of the geolocated emitters and provide the interface to transmit those locations via the MIDS/LVT using Link16. A similar application is currently in use by the AWL at NAWS China Lake to test interfaces between MIDS equipped FA-18 platforms and other MIDS equipped aircrafts, ships and ground units. With the addition of the LinkPro system and additional APIs to display and nominate (selective transmittal) of the emitters, the Mission Commander will be able to communicate via Link16 messages the emitter locations with Strike units and Field commanders.

8.2 Cost to Produce the Tier 2/Puffer UAS

The second question was that of cost. Could this UAS system be produced in such a way that the overall capability provided would be something near to, or as good as, the current AEA platforms, at a reduced cost? The current manned AEA platforms perform many missions other than that of geolocation of threat emitters, but in certain situation, these inexpensive UAS systems could be placed in situations that Field Commanders would not want to risk lives and expensive aircraft for. The estimated cost to produce this system is \$4.6 million (including a one time labor charge for the integration effort of \$2.7 million) compared to \$56M for a single EA-18G or \$18.8M for a single F-16CJ. See Appendix G for the cost breakdown.

8.3 Schedule to Produce the Tier 2/Puffer UAS

The goal of this study was to find proven systems that could be procured without the long lead time to design and manufacture a brand new system. Both UAV systems are currently available on the market. The technology used to control the aircraft is COTS computer systems. The MIDS/LVT provides all of the services to interface in the Link16

network. The BOSS, LinkPro, and MS Access systems are COTS software solutions. Materials needed to build up the control van are readily available from a variety of sources. That being said, the time and effort is focused on integrating (development of software interfaces) and testing the finished product. Table 13 identifies the major tasks in the work breakdown structure (WBS) for the Tier 2/*Puffer* UAS System Production.

Table 13. Tier 2/Puffer UAS WBS

Task Number	Task	Time	People	Link to
1.0	Interface Design Doc	20 weeks	3	
2.0	Procure UAS	24 weeks	1	
3.0	Procure <i>Puffer</i>	24 weeks	1	
4.0	Procure MIDS/LVT	16 weeks	1	
5.0	Procure Control Station components	4 weeks	1	
6.0	Procure BOSS and APIs	24 weeks	1	
7.0	PDR	Milestone		1.0
8.0	Design Control SW	12 weeks	4	7.0
9.0	CDR	Milestone		8.0
10.0	Code Control SW	12 weeks	4	1.0, 8.0, 9.0
11.0	Build Control Station	12 weeks	2	1.0, 4.0, 5.0
12.0	Develop Documents	30 weeks	2	1.0, 11.0
13.0	Control Station construction complete	Milestone		11.0
14.0	Integrate Control SW	16 weeks	6	6.0, 10.0, 13.0
15.0	Test Control Station	12 weeks	6	14.0
16.0	Integrate <i>Puffer</i> onto UAV	3 weeks	2	2.0, 3.0
17.0	Integrate UAS into Control Station	16 weeks	8	15.0, 16.0
18.0	Obtain Flight Clearance	12 weeks	2	2.0, 3.0
19.0	Ground test (Taxi)	4 weeks	6	17.0
20.0	Integrated Flight Test	25 weeks	8	17.0, 18.0, 19.0
21.0	Operational Flight Test	5 weeks	4	20.0
22.0	Deliver to Units	Milestone		12.0, 21.0

From Table 12, the estimated time from parts procurement until delivery is 119 weeks utilizing 10 people for a total of 39280 man hours or 20 man years. This timeframe may be reduced if procurement times could be decreased. It should be pointed out that this is the time to develop the initial system. Once the integration is accomplished on the first system, time to deliver could be cut to the procurement time plus software loads and basic system setup and verification, about 48 weeks. This schedule could be reduced further by procuring multiple components at once.

8.4 Recommendations

This thesis has identified how a Tier 2 UAV with a *Puffer* RWR, could downlink information to a control van equipped with a MIDS/LVT to provide a realtime geolocation capability to commanders in the field. Using available technology, this capability could be brought to the fight in 2.3 years for under \$5 million. This cost includes a one time labor charge to do the initial integration of the systems with the MIDS/LVT. Once the first system is proven, additional systems could be procured for about \$2.5 million, and about 48 weeks to procure the UAV and manufacture the control station, install software and do system checks.

The choice between UAV platforms may focus on two areas, platform endurance time and platform control. All other aspects of the issue are equal in that both systems can carry the *Puffer* with little impact to the flight envelope of the UAV. The cost to obtain the systems is the same. In the area of flight endurance the *Aerostar* stands out with an endurance of 7-9 hours (Table 1) compared to the *Dakota* endurance of 4.5 hours (Table 2). In the area of flight control, the *Dakota's missionTEK* software suite is fully capable to command multiple UAV platforms out of the box where the *Aerostar* will require an extensive integration and multiple computers to provide a capability for a single Internal Pilot to manage the controls of multiple UAVs. The multiple UAV capability of the *Dakota* could lower the cost to acquire the system because the labor involved in building the switching station to manage the *Aerostar* could be decreased. However, the *Dakota missionTEK* software package could be overwhelmed by the sizable amount of data downlinked by three different systems.

Overall, it is the author's opinion that this capability could be a battlefield asset and a viable and inexpensive alternative to placing manned platforms in harms way to provide a geolocation capability of mobile threat emitters.

Appendices

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Figure 4-6 *Aerostar* S-250 Handheld Controller – Andrew Pontzer, NAVAIR US Navy
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Figure 4-7 *Aerostar* S-280 Control Van – Andrew Pontzer, NAVAIR US Navy Archives
Figure 5-2 Russian 9M331 Tor (SA-15), SAM See Reference 45
Figure 5-3 French Roland 2 SAM, See Reference 46
Figure 5-5 Northrop Grumman EA-6B Prowler – VX-9 Archives
Figure 5-6 Boeing EA-18G Growler – VX-9 Archives
Figure 5-7 Lockheed Martin F-16CJ Viper, See Reference 48
Figure 7-1 *Puffer* Mounted on Aerolight UAV – Peter Bartolomeo, NAVAIR US Navy
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All other figures were drawn by the Author using MS Word or Turbo CAD Deluxe
version 12.

Appendix B – Acronyms and Abbreviations

Acronym	Meaning
AAA	Anti-Aircraft Artillery
AC	Aerodynamic Center
ADTS	Airborne Detection Technology Sensor
AEA	Airborne Electronic Attack
AESA	Active Electronically Scanned Aperture
AGM	Air to Ground Missile
AIS	Automatic Identification System
ALCOR	ARPA Lincoln C-band Observable Radar
AMRAAM	Advanced Medium Range Air to Air Missile
AMW	Amphibious Warfare
AOA	Angle of Attack
AP	Associate Press
ASCII	American Standard Computer Information Interface
ASTB	Airborne Seeker Test Bed
ATC	Air Traffic Control
AWL	Advanced Weapons Laboratory
BCAS	Beacon Collision Avoidance System
BDA	Bomb Damage Assessment
BMEWS	Ballistic Missile Early Warning System
C ² W	Command and Communications Warfare
C ³	Command, Control, and Communications
CA	California
CAS	Close Air Support
CAWS	Cautions, Advisories, Warnings System
CG	Center of Gravity
cm	Centimeters
COCOM	Combat Commander
CONOPS	Concept of Operations
CRM	Crew Resource Management
CSAR	Combat Search and Rescue
CSASW	Crew Station Analysis Software
CW	Continuous Wave
DARPA	Defense Advanced Research Projects Agency
dB	decibels
DEAD	Destruction of Enemy Air Defense
DOA	Direction of Arrival
DoD	Department of Defense

Acronym	Meaning
EA	Electronic Attack
ECR	Electronic Combat Range
ECMO	Electronic Countermeasures Officer
ECV	Emitter Confidence Value
EO	Electro-Optics
ES	Electronic Surveillance
EW	Electronic Warfare
EWCAS	Electronic Warfare Close Air Support
FAC-A	Forward Air Controller - Air
FEBA	Forward Edge of Battle Area
FMS	Foreign Military Sales
ft ²	Square Feet
ft ³	Cubic feet
FY	Fiscal Year
GBR	Ground Based Radar
GCS	Ground Control Station
GCI	Ground Control Intercept
GPS	Global Positioning System
GWOT	Global War on Terror
HAX	Haystack Auxiliary Radar
HF	Height Finder
HOTAS	Hands On Throttle and Stick
HTS	HARM Targeting System
Hz	Hertz
IADS	Integrated Air Defense System
ICAPIII	Improved Capability III (Three)
IFF	Identification Friend or Foe
IOC	Initial Operational Capability
IOT&E	Initial Operational Test and Evaluation
in	Inches
in ²	Square inches
ISR	Intelligence, Surveillance and Reconnaissance
IR	Infra-Red
Kgs	Kilograms
km	Kilometer
kN	Kilo Newton
kts	Knots (nautical miles per hour)

Acronym	Meaning
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ltr	Liter
MG	Missile Guidance
Mhz	Megahertz
MIDS/LVT	Multifunctional Information Display System/Low Volume Terminal
MIT	Massachusetts Institute of Technology
MSL	Mean Sea Level
MTBMF	Mean Time Between Mission Failure
NATO	North Atlantic Treaty Orgainzation
NAVAIR	Naval Air Systems Command
NAWS	Naval Air Warfare Station
NH	New Hampshire
nm	Nautical miles
NRL	Naval Research Laboratory
OSD	Office of the Secretary of Defense
OHSA	Occupational Health and Safety Agency
PRI	Pulse Repetition Interval
PW	Pulse Width
QOA	Quadrant of Arrival
RWR	Radar Warning Receiver
SAM	Surface to Air Missile
SATCOM	Satellite Communications
SEAD	Suppression of Enemy Air Defenses
SIGINT	Signals Intelligence
SOF	Safety of Flight
SRTM	Shuttle Radar Topography Mission
STANAG	Standardization Agreement (NATO)
STAP	Space-Time Adaptive Processing
STW	Strike Warfare
SUW	Surface Warfare
S _{wet}	Wetted Surface Area
TACAN	Tactical Air Navigation System
TCAS	Traffic Collision Avoidance System
TCG	Tactical Communications Group Limited
TDS	Tactical Display Station
THAAD	Theater High Altitude Air Defense system
TA	Target Acquisition

Acronym	Meaning
TI	Target Illuminator
TJS	Tactical Jamming System (ALQ-99)
TRADEX	Target Resolution and Discrimination Experiment
TT	Target Tracking
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
USAF	United States Air Force
USN	United States Navy
USNS	United States Naval Ship
VAC	Volts Alternating Current
VDC	Volts Direct Current
WBS	Work Breakdown Structure
WSO	Weapons System Officer
WSSA	Weapon's System Support Activity

Appendix C – List of Fielded Mobile Surface to Air Missile Systems

Table 14. Mobile Surface to Air Missile Systems ^a

Country of Manufacture	Name of System	Type (AAA, AD, MR, LR, ST, ABM)^b	Country Fielding System (Jane's) ³⁵	Country Fielding System (Wikipedia) ³⁶
Brazil				
Canada	ADATS	AD		Canada
Peoples Republic of China (PRC)	HQ-9	LR		PRC
	Kai Shan -1 (KS-1)	MR		PRC
France	Croteale	MR	Bahrain, Egypt, France, Libya, Pakistan, Saudi Arabia, South Africa, United Arab Emirates	
	Roland	AD	Finland, 10 other countries	Argentina, Brazil, France, Iraq, Nigeria, Qatar, Slovenia, Spain, US, Venezuela
	Shahine		Saudi Arabia	
Germany		AAA		
Germany/Italy/US	MEADS	MR		Development
India	Akash	MR		India
	PAD	ABM		Development
Italy	Aspide 2000	MR		Italy, Egypt
Netherlands		AAA		
Norway	NASAMS	MR		Norway

Table 14. Mobile Surface to Air Missile Systems ^a

Country of Manufacture	Name of System	Type (AAA, AD, MR, LR, ST, ABM)^b	Country Fielding System (Jane's) ³⁵	Country Fielding System (Wikipedia) ³⁶
Russian Federation	SA-3 Goa ^c	MR		Algeria, Angola, Armenia, Bulgaria, Cuba, Egypt, Ethiopia, Georgia, India, Libya, Moldova, Mozambique, North Korea, Peru, Poland, Russia, Serbia, Syria, Ukraine, Tanzania, Vietnam, Yemen, Zambia
	SA-4 Ganef	MR High Altitude		Armenia, Azerbaijan, Bulgaria, Poland, Russia, Turkmenistan, Kyrgyzstan
	SA-6 Gainful	MR	Algeria, Angola, Azerbaijan, Belarus, Bulgaria, Cuba, Czech Republic, Egypt, Georgia, Germany, Guinea, Guinea-Bissau, Hungary, India, Iran, Iraq, Kazastan, Libya, Mozambique, Poland, Romania, Slovakia, Somalia, Syria, Tanzania, Ukraine, Viet Nam, Yemen, Yugoslavia	Armenia, Algeria, Bosnia and Herzegovina, Cuba, Czech Republic, Egypt, Hungary, India, Iran, Libya, Mozambique, Poland, Romania, Slovakia, Serbia, Syria, Vietnam
	SA-8 Gecko	AD	RFAS, Algeria, Angola, Armenia, Azerbaijan, Belarus, Croatia, Czech Republic, Greece, India, Iraq, Jordan, Libya, Poland, Syria, Tajikistan, Ukraine, Yugoslavia	Algeria, Armenia, Azerbaijan, Belarus, Bulgaria, Cuba, Ecuador, Georgia, Greece, India, Jordan, Kuwait, Libya, Poland, Romania, Russia, Syria, Turkmenistan, Ukraine
	SA-10 Grumble (S-300P)	LR, ST	Belarus, Bulgaria, Croatia, Cyprus, Hungary, Iran, PRC, RFAS, Slovakia, Syria, Ukraine	Armenia, Belarus, Bulgaria, PRC, Cyprus, Greece, Slovakia, India, Iran, Kazakhstan, Syria, Russia, Ukraine, US, Vietnam

Table 14. Mobile Surface to Air Missile Systems ^a

Country of Manufacture	Name of System	Type (AAA, AD, MR, LR, ST, ABM)^b	Country Fielding System (Jane's) ³⁵	Country Fielding System (Wikipedia) ³⁶
Russian Federation	SA-11 Gadfly	LR	Belarus, Finland RFAS, Syria, Ukraine, Yugoslavia	Abkhazia, Belarus, Cyprus, Egypt, Finland, Georgia, Russia, Ukraine, Indonesia
	SA-12 Giant/Gladiator (S-300V)	LR, ST		Belarus, PRC, Russia, Ukraine, US,
	SA-13 Gopher	AD	Afghanistan, Algeria, Angola, Bulgaria, Croatia, Cuba, Czech Republic, Germany, Hungary, Iraq, Jordan, Libya, Poland, Slovakia, Syria	Armenia, Azerbaijan, Belarus, Bulgaria, Czech Republic, Croatia, Cuba, Hungary, Jordan, Macedonia, Poland, Russia, Serbia, Slovakia, Ukraine
	SA-15 Gauntlet	AD	Belarus, PRC, India, Peru, RFAS, Ukraine	Belarus, PRC, Cyprus, Egypt, Georgia, Greece, India, Iran, Libya, Myanmar, Peru, Russia, Ukraine, Venezuela, Yemen
	SA-17 Grizzly	MR		Abkhazia, Belarus, Cyprus, Egypt, Finland, Georgia, Russia, Ukraine, Indonesia
	SA-19 Grison	AD, AAA	Russia	Belarus, India, Iran, Morocco, Burma, Russia, Ukraine
	SA-20 Gargoyle (S-300PMU)	LR, ST		PRC, Cyprus, India, Iran, Russia, Ukraine, Vietnam
	SA-21 Growler	LR, ST, ABM		Russia
	SA-22 Greyhound	AD, AAA		Russia, United Arab Emirates, Algeria, Syria, India, Iran
South Africa	ZA-HVM	AD, AAA		
Sweden	Skygard			

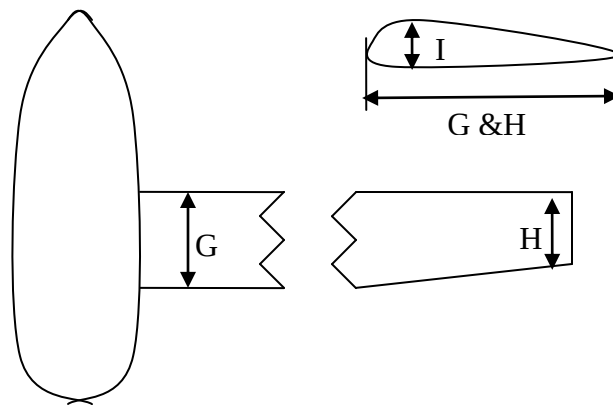
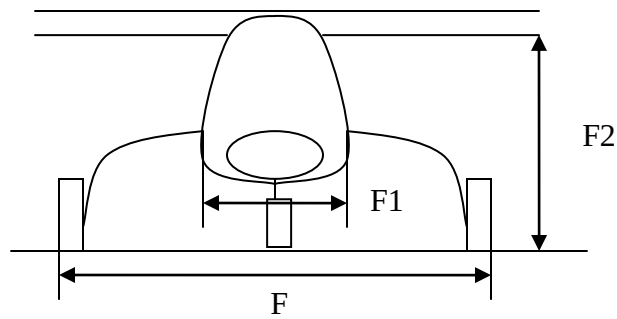
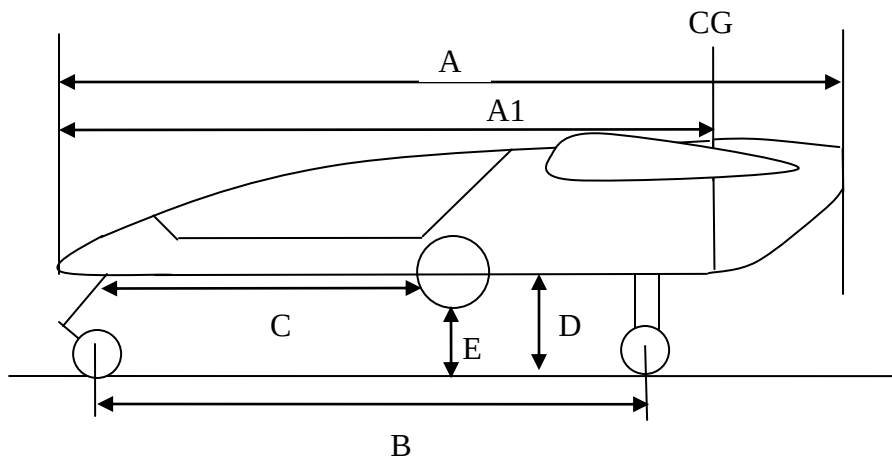
Table 14. Mobile Surface to Air Missile Systems ^a

Country of Manufacture	Name of System	Type (AAA, AD, MR, LR, ST, ABM)^b	Country Fielding System (Jane's) ³⁵	Country Fielding System (Wikipedia) ³⁶
United Kingdom	Rapier	MR	Venezuela	Abu Dhabi, Brunei, Indonesia, Iran, Libya, Malaysia, Oman, Singapore, Turkey, Switzerland, UK, Zambia
United States	Patriot	MR, LR	Germany, Israel, Japan, Kuwait, Netherlands, Saudia Arabia	Egypt, Germany, Greece, Israel, Japan, Jordan, Kuwait, Netherlands, Taiwan, Saudi Arabia, South Korea, Spain, US
	HAWK	MR		Bahrain, Belgium, Denmark, Egypt, France, Germany, Greece, Indonesia, Iran, Israel, Italy, Japan, Jordan, South Korea, Kuwait, Netherlands, Saudi Arabia, Singapore, Spain, Sweden, Taiwan, Turkey, UAE
	Chaparral	AD		Ecuador, Egypt, Israel, Morocco, Portugal, Taiwan, Tunisia, USA
Notes: a. Only mobile systems which use radar to acquire, track and/or target are listed. Does not include MPADs, or fixed base systems. b. AAA – Anti-Aircraft Artillery, AD – Area Defense (Short Range < 10nm), MR – Medium Range (10-25nm), LR – Long Range (25-100nm), ST – Strategic (> 100nm), ABM – Anti Ballistic Missile c. The SA-3 Goa was originally a fixed base system. As the Russian Air Defense Forces (PVO Strany) replaced the systems with SA-10 and SA-12 systems, many SA-3 systems were re-furbished and retrofitted to fit a mobile launcher. ⁵⁹				

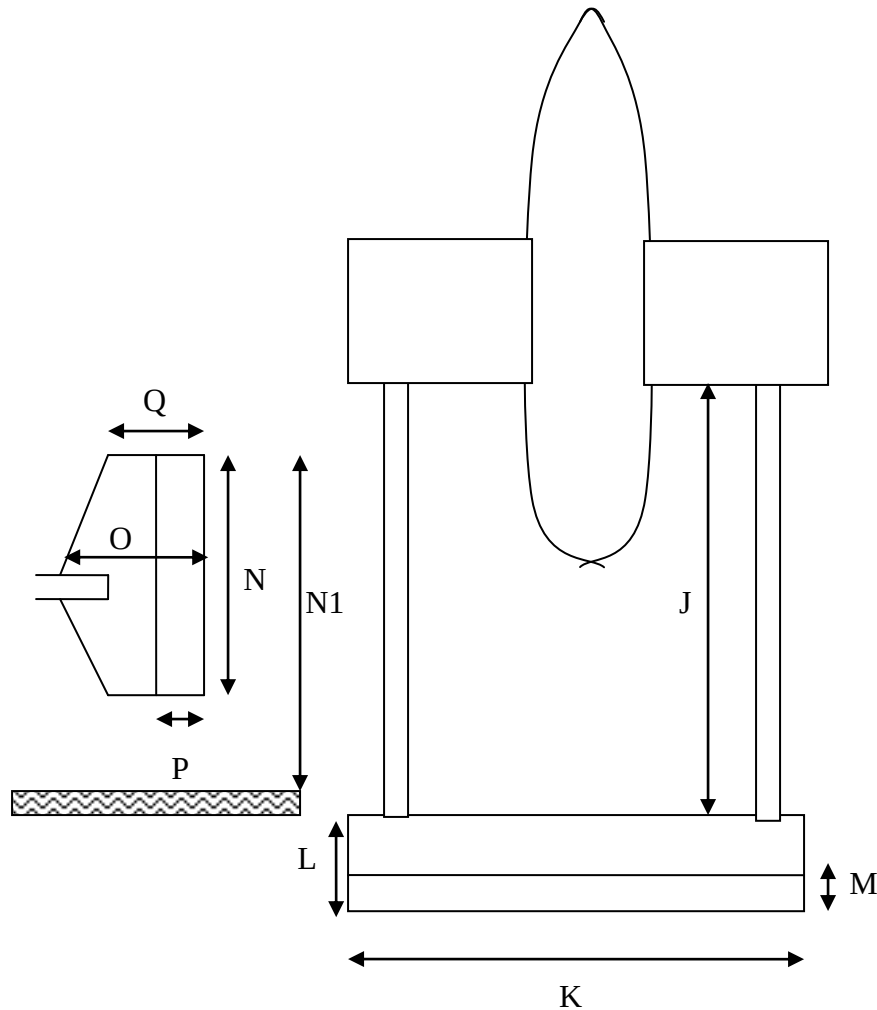
⁵⁹ Wikipedia, "SA-3 History"

Appendix D – Additional *Aerostar* Measurements and Calculations.

The following measurements were taken by Mr. Andrew Pontzer from an *Aerostar* UAV at NAS Patuxent River, MD. These measurements were needed to do additional aerodynamic calculations and fit checks for integration of the *Puffer* on the *Aerostar*. Drawings are by the author and approximate the shape of the *Aerostar*. A combination of these measurements and the measurements listed in Table 1 were used to calculate the wetted surface area of the aircraft.



I = Thickest part of wing at root and tip. (I1 & I2)



A = Length of Fuselage (in) 111
 A1 = Distance from nose to CG of Aircraft (in) 92.13
 B = Distance from center of nose wheel to line connecting center of Main Landing Gear (in) 61
 C = Distance from Nose Wheel landing gear assembly to front of POP turret (in) 30.19
 D = Distance from bottom of Fuselage to ground (in) 14
 E = Distance from bottom of POP Turret to ground (in) 6.88
 F = Wheel Base (in) 42.13
 F1 = Width (widest part) of Bottom plane of Fuselage between the nose and the POP Turret (in) 16
 F2 = Distance from wing to ground (in) 31.5
 G = Width (cord) of Wing at Wing root (in) 24.81
 H = Width (cord) of Wing at Wing Tip (in) 18
 I1 = Thickness of wing at Wing root (in) 4.31
 I2 = Thickness of wing at Wing Tip (in) 1.06

(If you know the NACA wing form of the wing that would be very helpful too.)

J = Distance from trailing edge of wing to leading edge of Horizontal Stabilizer (in)
75.13

K = Length of Horizontal Stabilizer (in) 63.25

L = Width of Horizontal Stabilizer (in) 12.63

M = Width of Horizontal Stabilizer control surface (in) 4.75

N = Length of Vertical Stabilizer (in) 24.63

N1 = Distance from top of Vertical Stabilizer (in) 51.13

O = Width (Widest part) of Vertical Stabilizer (in) 15.75

P = Width of Vertical Stabilizer control surface (in) 5.25

Q = Width of Vertical Stabilizer (Narrowest/Tip) (in) 12.75

Additional Calculations Formulas were taken from Daniel P. Raymer's book *Aircraft Design: A Conceptual Approach, Fourth Edition* (See Reference 8)

Taper ratio (λ) = C_{tip}/C_{root} = 18.0in/24.8in = **0.73**

Mean Wing Cord = $\bar{c} = ((2/3) (C_{root})(1+\lambda+\lambda^2))/(1+\lambda)$

$$= ((2/3)(24.8in)(1+0.73+(0.73)^2))/(1+0.73)$$

$$= ((16.5)(1.73+0.53))/1.73$$

$$= ((16.5)(2.26))/1.73$$

$$= 37.3/1.73$$

$$\bar{c} = \mathbf{21.6 \text{ inches}}$$

Wing Surface Area

$$(S_{ref}) = b * c = 21 \text{ ft} * 24.8 \text{ in}$$

$$= 21(12) * 24.8$$

$$= 624.6 \text{ in}^2$$

$$S_{ref} = \mathbf{43.4 \text{ ft}^2}$$

Aspect Ratio = b^2/S_{ref} = $(21)^2/43.4$

$$= 441/43.4 = \mathbf{10.2}$$

$$\text{Wing Loading} = W_0/S_{\text{ref}}$$

$$= 440 \text{ lbs}/43.4 \text{ ft}^2 = \mathbf{10.1 \text{ lbs/ft}^2}$$

$$\text{Stall Speed Calculations } V_{\text{TO}} = 1.1 (V_s) \quad V_s = V_{\text{TO}}/1.1$$

$$= V_{\text{TO}}/1.1 = 60/1.1 = 54.5 \text{ knt} = 92.1 \text{ ft/sec}$$

However, the landing speed for the Aerostar is 50 knts. The Aerostar has a flapped wing that would reduce the stall speed. I did not receive the flap area measurements, and will guess the stall speed to be 49 knts or 82.8 ft/sec.

$$\text{Reynolds Number Calculation } Re_{\text{min}} = (V_s c)/\nu_0$$

$$= ((82.8 \text{ ft/sec})(24.8 \text{ in}/12))/0.1572 \times 10^{-3}$$

$$= (82.8)(2.1)/0.1572 \times 10^{-3}$$

$$\mathbf{Re_{\text{min}} = 1.1 \times 10^6}$$

$$\text{Maximum Coefficient of Lift } (C_{L\text{max}}) = 2W/\rho V_s^2 S$$

$$= 2(440)/(.002376 \text{ slugs/ft}^3)(82.8^2 \text{ ft/sec})(43.4 \text{ ft}^2)$$

$$= 880/((.103)(6856))$$

$$\mathbf{C_{L\text{max}} = 880/706.2 = 1.25}$$

$$\text{Maximum Section Lift Coefficient } (C_{l\text{max}})$$

$$\mathbf{C_{L\text{max}} = 0.9 C_{l\text{max}}}$$

$$\mathbf{C_{l\text{max}} = C_{L\text{max}}/0.9 = 1.25/0.9 = 1.39}$$

Power to Weight Ratio = P/W (From Raymer's book, ref 8. Used as a rule of thumb)

$$= 38 \text{ hp}/440 \text{ lbs}$$

$$\mathbf{P/W = 0.09 \text{ hp/lb}}$$

$$\text{Lift to Drag (preliminary) = } 1/(P/W)$$

$$\mathbf{L/D = 1/0.09 = 11.1}$$

Thrust to Weight_(cruise) = T/W = (η_p/V) (P/W) Propeller efficiency (η_p) computed using propeller efficiency program supplied by Dr. U. P. Solies. Inputs are altitude = 10,000 ft ($\rho=.001756$), propeller diameter = 29 inches and cruise speed = 62 knots.

$$T/W = (550(.56)/62 \text{ knts})(38\text{hp}/(.956)440\text{lbs})$$

$$= (550(.56)/104.8\text{ft/sec})(38\text{hp}/(.956)440\text{lbs})$$

$$= 550(.56)(38)/104.7(.956)(440)$$

$$T/W = 11704/44041$$

$$T/W_{(cruise)} = 0.27$$

$$L/D = 1/(T/W) = 3.70 \text{ (Calculated)}$$

Thrust to Weight calculation based on Wetted Aspect Ratio L/D calculation

$$T/W = 1/(L/D) = 1/2.7 = 0.37$$

Cruise Speed Calculation based on Thrust to Weight with Puffer Added

$$T/W = 0.38 = (\eta_p/V) (P/W)$$

$$0.38 = ((550(.56))/V)(38/ (.956(440)))$$

$$0.38V = (550(.56)(38))/ (.956(440))$$

$$0.38V = 11704/420.6$$

$$V = 27.8/.38$$

$$V = 73.2 \text{ ft/sec} = 43.3 \text{ knts}$$

Cruise Speed Calculation based on calculated Thrust to Weight plus 1%

$$T/W = 0.273 = (\eta_p/V) (P/W)$$

$$0.273 = ((550(.56))/V)(38/ (.956(440)))$$

$$0.273V = (550(.56)(38))/ (.956(440))$$

$$0.273V = 111704/420.6$$

$$V = 27.8/.273$$

$$V = 101.83 \text{ ft/sec} = 60.3 \text{ knts}$$

$$\text{Lift to Drag (wetted Aspect ratio)} = b^2/S_{\text{wetAerostar}}$$

$$(21)^2/S_{\text{wetAerostar}} = 441/165.5 = 2.7$$

Calculations of the Wetted surface Area of the Aerostar. Calculations are for geometric blocks approximating the shape of actual components.

Table 15. Total Wetted Area for Aerostar aircraft

Component	Area (ft ²)
Wings	88.2
Vertical Stabilizer (2)	10.8
Horizontal Stabilizer	11.1
Booms (2)	13.4
Fuselage	37.7
Landing Gear (wheels and struts)	3.9
Pop Group Camera Pod	0.4
Total Wetted Area of Aerostar (S_{wetAerostar})	165.5

Wings

$$21\text{ft} \times 24.8\text{in} = 21\text{ft} \times 2.1\text{ft} = 44.1\text{ft}^2 \text{ (top)} + 44.1\text{ft}^2 \text{ (bottom)} = \mathbf{88.2 \text{ ft}^2}$$

Vertical Stabilizer

$$24.6\text{in} \times 15.8\text{in} = 388.7\text{in}^2 \times 4(2 \text{ sides for } 2 \text{ VS}) = 1554.8\text{in}^2$$

$$\text{Divide to get ft}^2 = 1554.8\text{in}^2/144\text{in}^2/\text{ft}^2 = \mathbf{10.8\text{ft}^2}$$

Horizontal Stabilizer

$$63.3\text{in} \times 12.6\text{in} = 797.6\text{in}^2 \text{ (top)} + 797.6\text{in}^2 \text{ (bottom)} = 1595.2\text{in}^2$$

$$\text{Divide to get ft}^2 = 1595.2\text{in}^2/144\text{in}^2/\text{ft}^2 = \mathbf{11.1\text{ft}^2}$$

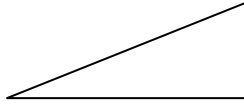
Two Booms (tubes = $2\pi r^2 + 2\pi rh$)

$$(2 \times 3.14 \times (2\text{in})^2) + (2 \times 3.14 \times 2\text{in} \times 75.1\text{in}) = 25.1\text{in}^2 + 943.3\text{in}^2 = 968.4\text{in}^2$$

Divide to get $\text{ft}^2 = 968.4\text{in}^2/144\text{in}^2/\text{ft}^2 = \mathbf{6.7\text{ft}^2} \times \mathbf{2} = \mathbf{13.4\text{ft}^2}$

Fuselage

Sides (Forward nose area)



$$12\text{in} \times 45\text{in} = 540\text{in}^2 \text{ (2 nose area sides)}$$

$$\text{Divide to get ft}^2 = 540\text{in}^2 / 144\text{in}^2/\text{ft}^2 = \mathbf{3.8\text{ft}^2}$$

Sides (Aft engine area)



$$12\text{in} \times 66\text{in} = 792\text{in}^2 \times 2 \text{ (sides)} = 1584\text{in}^2$$

$$\text{Divide to get ft}^2 = 1584\text{in}^2 / 144\text{in}^2/\text{ft}^2 = \mathbf{11.0\text{ft}^2}$$

Bottom Fuselage

$$14\text{in} \times 111\text{in} = 1554\text{in}^2$$

$$\text{Divide to get ft}^2 = 1554\text{in}^2 / 144\text{in}^2/\text{ft}^2 = \mathbf{10.8\text{ft}^2}$$

Top (Forward nose area)

$$14\text{in} \times 46.6\text{in} = 652.4\text{in}^2$$

$$\text{Divide to get ft}^2 = 652.4\text{in}^2 / 144\text{in}^2/\text{ft}^2 = \mathbf{4.5\text{ft}^2}$$

Top (Aft engine area)

$$14\text{in} \times 66\text{in} = 924\text{in}^2$$

$$\text{Divide to get ft}^2 = 924\text{in}^2 / 144\text{in}^2/\text{ft}^2 = \mathbf{6.4\text{ft}^2}$$

Aft Fuselage

$$12\text{in} \times 14\text{in} = 168\text{in}^2$$

$$\text{Divide to get ft}^2 = 168\text{in}^2 / 144\text{in}^2/\text{ft}^2 = \mathbf{1.2\text{ft}^2}$$

$$\text{Total Fuselage Wetted Area} = \mathbf{37.7\text{ft}^2}$$

Landing Gear Struts (Main)

1 Strut = 3in wide x 14 in long x .5 in thick

$$3\text{in} \times 14\text{in} = 42\text{in}^2 \times 2 \text{ (top and bottom)} \times 2 \text{ (struts)} = 168.0\text{in}^2$$

$$.5\text{in} \times 14\text{in} = 7.0\text{in}^2 \times 2 \text{ (front and back)} \times 2 \text{ (struts)} = 28.0\text{in}^2$$

$$.5\text{in} \times 3\text{in} = 1.5\text{in}^2 \times 2 \text{ (strut bottom ends)} = 3.0\text{in}^2$$

$$\text{Total Main Landing Gear Struts} = 199.0\text{in}^2$$

$$\text{Divide to get ft}^2 = 199.0\text{in}^2 / 144\text{in}^2/\text{ft}^2 = \mathbf{1.4\text{ft}^2}$$

Landing Gear Nose Strut (Bowed Strut 2in wide x 12in high x .5 thick)

$$2\text{in} \times 15\text{in} = 30\text{in}^2 \times 2 \text{ (front and back)} = 60\text{in}^2$$

$$.5\text{in} \times 15\text{in} = 7.5\text{in}^2 \times 2 \text{ (2 sides)} = 15\text{in}^2$$

$$\text{Total nose landing gear strut} = 75\text{in}^2$$

$$\text{Divide to get ft}^2 = 75\text{in}^2 / 144\text{in}^2/\text{ft}^2 = \mathbf{0.5\text{ft}^2}$$

$$\text{Total Landing Gear Struts} = \mathbf{1.9\text{ft}^2}$$

Wheels (3 x 6in tall x 2in wide cylinders $2\pi r^2 + 2\pi rh$)

$$(2 \times 3.14 \times (3\text{in})^2) + (2 \times 3.14 \times 3\text{in} \times 2\text{in}) = 56.5\text{in}^2 + 37.7\text{in}^2 = 94.2\text{in}^2$$

$$3 \text{ wheels} \times 94.2\text{in}^2 = 282.6\text{in}^2$$

$$\text{Divide to get ft}^2 = 282.6\text{in}^2 / 144\text{in}^2/\text{ft}^2 = \mathbf{2.0\text{ft}^2}$$

$$\text{Total Landing Gear (wheels and struts)} = \mathbf{3.9\text{ft}^2}$$

POP Group Camera Turret

Half a cylinder of radius 6in. and height 6in =

$$2\pi r^2 + 2\pi rh = (2 \times 3.14 \times (6)^2) + (2 \times 3.14 \times 6\text{in} \times 6\text{in})$$

$$\text{Divide to get ft}^2 = 113.0\text{in}^2 / 144\text{in}^2/\text{ft}^2 = \mathbf{.8\text{ft}^2}$$

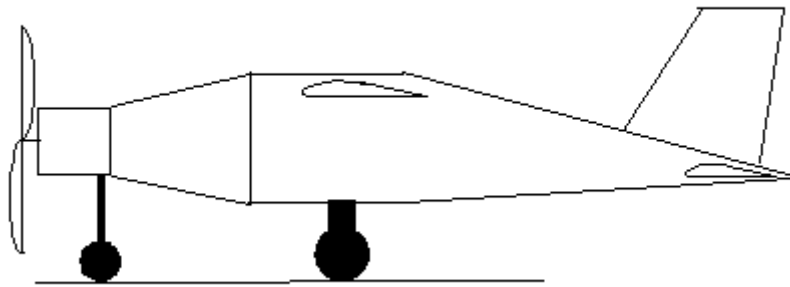
Divide area by 2 for half of the cylinder that is exposed to air.



$$.8\text{ft}^2/2 = .4\text{ft}^2$$

Appendix E – Additional Dakota Measurements and Calculations.

The following measurements were taken by the Author from a *Dakota* UAV at NAWS China Lake, CA. The *Dakota* that was available was not fully assembled, some of the measurements are approximated based on the size of the parts. These measurements were needed to do additional aerodynamic calculations and fit checks for integration of the *Puffer* on the *Dakota*. Drawings are by the author and approximate the shape of the *Dakota*. A combination of these measurements and the measurements listed in Table 2 were used to calculate the wetted surface area of the aircraft.



Distance from center of nose wheel to line connecting center of Main Landing Gear (in) 29.5

Distance from bottom of Fuselage to ground (in) 12

Length of Horizontal Stabilizer (in) 30.5 (single)

Width of Horizontal Stabilizer (in) 13.5

Width of Horizontal Stabilizer control surface (in) entire surface

Length of Vertical Stabilizer (in) 22

Width (Widest part) of Vertical Stabilizer (in) 23

Width of Vertical Stabilizer control surface (in) 6.5

Length of Vertical Stabilizer control surface (in) 19.5

Width of Vertical Stabilizer (Narrowest/Tip) (in) 13

Additional Calculations Formulas were taken from Daniel P. Raymer's book *Aircraft Design: A Conceptual Approach, Fourth Edition* (See Reference 8)

Wing Surface Area

$$(S_{\text{ref}}) = b * c = 15.6 \text{ ft} \times 1.6 \text{ ft}$$

$$S_{\text{ref}} = 25.0 \text{ ft}^2$$

$$\text{Aspect Ratio} = b^2/S_{\text{ref}} = (15.6)^2/25.0$$

$$= 243.4/25.0 = 9.7$$

$$\text{Wing Loading} = W_0/S_{\text{ref}}$$

$$= 240\text{lbs}/25.0 \text{ ft}^2 = 9.6 \text{ lbs/ft}^2$$

$$\text{Stall Speed Given in Table 2} = 40 \text{ kts} = 64.5 \text{ ft/sec}$$

$$\text{Reynolds Number Calculation } Re_{\text{min}} = (V_s c)/\nu_0$$

$$= ((64.5 \text{ ft/sec}) \times (1.6))/0.1572 \times 10^{-3}$$

$$= 102.9/0.1572 \times 10^{-3}$$

$$Re_{\text{min}} = 6.6 \times 10^5$$

$$\text{Maximum Coefficient of Lift } (C_{L\text{max}}) = 2W/\rho V_s^2 S$$

$$= 2(240)/(.002376 \text{ slugs/ft}^3)(64.5^2 \text{ ft/sec})(25 \text{ ft}^2)$$

$$= 480/((.06)(4160.3))$$

$$C_{Lmax} = 480/249.6 = 1.92$$

Maximum Section Lift Coefficient (C_{lmax})

$$C_{Lmax} = 0.9C_{lmax}$$

$$C_{lmax} = C_{Lmax}/0.9 = 1.92/.9 = 2.13$$

Power to Weight Ratio = P/W (From Raymer's book, reference 8)

$$= 22hp/240lbs$$

$$P/W = 0.09 \text{ hp/lb}$$

Lift to Drag (preliminary) = 1/(P/W)

$$L/D = 1/0.09 = 11.1$$

Thrust to Weight_(cruise) = T/W = (η_p/V) (P/W) Propeller efficiency (η_p) computed using propeller efficiency program supplied by Dr. U. P. Solies. Inputs are altitude = 10,000 ft ($\rho=.001756$), propeller diameter = 31 inches and cruise speed = 62 knots.

$$= (550(.62)/62knts)(22hp/ (.956)240lbs)$$

$$= (550(.62)/104.8ft/sec)(22hp/ (.956)240lbs)$$

$$= 550(.62)(22)/104.7(.956)(240)$$

$$T/W = 7502/24022.4$$

$$T/W_{(cruise)} = 0.31$$

$$L/D = 1/(T/W) = 3.23 \text{ (Calculated)}$$

Thrust to Weight calculation based on Wetted Aspect Ratio L/D calculation

$$T/W = 1/(L/D) = 1/2.2 = 0.45$$

Cruise Speed Calculation based on Thrust to Weight with Puffer Added

$$T/W = 0.458 = (\eta_p/V) (P/W)$$

$$0.458 = ((550(.62))/V)(22/ (.956(240)))$$

$$0.458V = (550(.62)(22))/(.956(240))$$

$$0.458V = 7502/229.4$$

$$V = 32.7/.458$$

$$V = 71.4 \text{ ft/sec} = 42.2 \text{ knts}$$

Cruise Speed Calculation based on calculated Thrust to Weight plus 2%

$$T/W = 0.316 = (\eta_p/V) (P/W)$$

$$0.316 = ((550(.62))/V)(22/ (.956(240)))$$

$$0.316V = (550(.62)(22))/(.956(240))$$

$$0.316V = 7502/229.4$$

$$V = 32.7/.316$$

$$V = 103.5 \text{ ft/sec} = 61.2 \text{ knts}$$

Lift to Drag (wetted Aspect ratio) = $b^2/S_{\text{wetDakota}}$

$$(15.6)^2/S_{\text{wetDakota}} = 243.4/109.7 = 2.2$$

Calculations of the Wetted surface Area of the *Dakota*. Calculations are for geometric blocks approximating the shape of actual components.

Table 16. Total Wetted Area for *Dakota* aircraft

Component	Area (ft ²)
Wings	50.0
Vertical Stabilizer	6.9
Horizontal Stabilizer	11.4
Fuselage	36.4
Landing Gear (wheels and struts)	5.0
Total Wetted Area of <i>Dakota</i> ($S_{\text{wetDakota}}$)	109.7

Wings

$$15.6 \text{ ft} \times 1.6 \text{ ft} = 25.0 \text{ ft}^2 \text{ (top)} + 25.0 \text{ ft}^2 \text{ (bottom)} = 50.0 \text{ ft}^2$$

Vertical Stabilizer (rectangle 13 in x 22 in) + right triangle (10 in x 22 in)

$$13 \text{ in} \times 22 \text{ in} = 286 \text{ in}^2 + \frac{1}{2}(22 \text{ in} \times 10 \text{ in}) = 220 \text{ in}^2/2 = 110 \text{ in}^2$$

$$286 \text{ in}^2 + 110 \text{ in}^2 = 496 \text{ in}^2 \times 2 \text{ sides} = 992 \text{ in}^2$$

$$\text{Divide to get ft}^2 = 992 \text{ in}^2/144 \text{ in}^2/\text{ft}^2 = \mathbf{6.9 \text{ ft}^2}$$

Horizontal Stabilizer

$$61.0 \text{ in} \times 13.5 \text{ in} = 823.5 \text{ in}^2 \text{ (top)} + 823.5 \text{ in}^2 \text{ (bottom)} = 1647 \text{ in}^2$$

$$\text{Divide to get ft}^2 = 1647 \text{ in}^2/144 \text{ in}^2/\text{ft}^2 = \mathbf{11.4 \text{ ft}^2}$$

Fuselage**Engine Cowling (Forward nose area elliptical cylinder⁶⁰)**

$$a = 13.4 \text{ in}/2; b = 10 \text{ in}/2; L = 11 \text{ in} \text{ area} = 2L\pi(1/2(a^2 + b^2))^{-1/2} + 2\pi ab$$

$$= 2 \times 11 \text{ in} \times 3.14 \times (1/2((6.7 \text{ in})^2 + (5 \text{ in})^2))^{-1/2} + (2 \times 3.14 \times 6.7 \text{ in} \times 10 \text{ in})/2 \text{ (only front face is needed for wetted area)}$$

$$= 69.1 \text{ in} \times (1/2(44.9 \text{ in}^2 + 25 \text{ in}^2))^{-1/2} + 420.8 \text{ in}^2/2$$

$$= (69.1 \text{ in} \times 5.9 \text{ in}) + 210.4 \text{ in}^2$$

$$= 407.7 \text{ in}^2 + 210.4 \text{ in}^2 = 618.1 \text{ in}^2$$

$$\text{Divide to get ft}^2 = 618.1 \text{ in}^2/144 \text{ in}^2/\text{ft}^2 = \mathbf{4.3 \text{ ft}^2}$$

Sides forward of wing box (Trapezoid ((a+b)h)/2)

$$a = 10 \text{ in}; b = 20.1 \text{ in}; h = 20.9 \text{ in}$$

$$((10 \text{ in} + 20.1 \text{ in}) \times 20.9 \text{ in})/2 = (30.1 \text{ in} \times 20.9 \text{ in})/2 = 629.1 \text{ in}^2/2 = 314.6 \text{ in}^2$$

$$\text{Times 2 sides} = 629.2 \text{ in}^2$$

$$\text{Divide to get ft}^2 = 629.2 \text{ in}^2/144 \text{ in}^2/\text{ft}^2 = \mathbf{4.4 \text{ ft}^2}$$

Top and Bottom forward of wing box (Trapezoid ((a+b)h)/2)

⁶⁰ www.efunda.com engineering fundamentals

a=11 in; b = 13.4 in; h = 20.9 in

$$((11 \text{ in} + 13.4 \text{ in}) \times 20.9 \text{ in})/2 = (24.4 \text{ in} \times 20.9 \text{ in})/2 = 510 \text{ in}^2/2 = 255 \text{ in}^2$$

Times top and bottom = 510 in^2

$$\text{Divide to get } \text{ft}^2 = 510 \text{ in}^2/144 \text{ in}^2/\text{ft}^2 = \mathbf{3.5 \text{ ft}^2}$$

Wing Box sides (Rectangle = a x b)

$$a = 20.1 \text{ in; } b = 23.0 \text{ in} = 20.1 \text{ in} \times 23.0 \text{ in} = 462.3 \text{ in}^2$$

Times 2 sides = 924.6 in^2

$$\text{Divide to get } \text{ft}^2 = 924.6 \text{ in}^2/144 \text{ in}^2/\text{ft}^2 = \mathbf{6.4 \text{ ft}^2}$$

Wing Box top and bottom

$$a = 13.4 \text{ in } b = 23.0 = 13.4 \text{ in} \times 23 \text{ in} = 308.2 \text{ in}^2$$

Times top and bottom = $2 \times 308.2 \text{ in}^2 = 616.4 \text{ in}^2$

$$\text{Divide to get } \text{ft}^2 = 616.4 \text{ in}^2/144 \text{ in}^2/\text{ft}^2 = \mathbf{4.3 \text{ ft}^2}$$

Aft Fuselage Side (Triangle $\frac{1}{2} bh$)

$$b = 20.1 \text{ in } h = 58.0 \text{ in} = \frac{1}{2}(20.1 \times 58.0) = 1165.8 \text{ in}^2/2 = 582.9 \text{ in}^2$$

Times 2 sides = 1165.8 in^2

$$\text{Divide to get } \text{ft}^2 = 1165.8 \text{ in}^2/144 \text{ in}^2/\text{ft}^2 = \mathbf{8.1 \text{ ft}^2}$$

Aft Fuselage top and bottom (Triangle $\frac{1}{2} bh$)

$$b = 13.4 \text{ in; } h = 58.0 \text{ in} = \frac{1}{2}(13.4 \times 58.0) = 777.2 \text{ in}^2/2 = 388.6 \text{ in}^2$$

Times top and bottom = 777.2 in^2

$$\text{Divide to get } \text{ft}^2 = 777.2 \text{ in}^2/144 \text{ in}^2/\text{ft}^2 = \mathbf{5.4 \text{ ft}^2}$$

Total Fuselage Wetted Area = 36.4 ft^2

Landing Gear Struts (Main)

1 Strut = 4 in wide x 14.8 in long x .5 in thick

$$4 \text{ in} \times 14.8 \text{ in} = 59.2 \text{ in}^2 \times 2 \text{ (top and bottom)} \times 2 \text{ (struts)} = 236.8 \text{ in}^2$$

$$.5 \text{ in} \times 14.8 \text{ in} = 7.4 \text{ in}^2 \times 2 \text{ (front and back)} \times 2 \text{ (struts)} = 29.6 \text{ in}^2$$

$$.5 \text{ in} \times 4 \text{ in} = 2.0 \text{ in}^2 \times 2 \text{ (strut bottom ends)} = 4 \text{ in}^2$$

$$\text{Total Main Landing Gear Struts} = 270.4 \text{ in}^2$$

$$\text{Divide to get ft}^2 = 270.4 \text{ in}^2 / 144 \text{ in}^2/\text{ft}^2 = \mathbf{1.9 \text{ ft}^2}$$

$$\text{Landing Gear Nose Strut (Single 15 in x 1 in tube } 2\pi r^2 + 2\pi rh)$$

$$(2 \times 3.14 \times (0.5 \text{ in})^2) + (2 \times 3.14 \times 0.5 \text{ in} \times 15 \text{ in}) = 1.5 \text{ in}^2 + 47.1 \text{ in}^2 = 48.6 \text{ in}^2$$

$$\text{Divide to get ft}^2 = 48.6 \text{ in}^2 / 144 \text{ in}^2/\text{ft}^2 = \mathbf{0.3 \text{ ft}^2}$$

$$\text{Total Landing Gear Struts} = \mathbf{2.2 \text{ ft}^2}$$

$$\text{Main Wheels (2 x 8 in tall x 2 in wide cylinders } 2\pi r^2 + 2\pi rh)$$

$$(2 \times 3.14 \times (4 \text{ in})^2) + (2 \times 3.14 \times 4 \text{ in} \times 2 \text{ in}) = 100.5 \text{ in}^2 + 50.2 \text{ in}^2 = 150.7 \text{ in}^2$$

$$2 \text{ wheels} \times 150.7 \text{ in}^2 = 301.4 \text{ in}^2$$

$$\text{Divide to get ft}^2 = 301.4 \text{ in}^2 / 144 \text{ in}^2/\text{ft}^2 = \mathbf{2.1 \text{ ft}^2}$$

$$\text{Nose Wheel (1 x 6 in tall x 1.5 in wide cylinder } 2\pi r^2 + 2\pi rh)$$

$$(2 \times 3.14 \times (3 \text{ in})^2) + (2 \times 3.14 \times 3 \text{ in} \times 1.5 \text{ in}) = 56.5 \text{ in}^2 + 42.4 \text{ in}^2 = 98.9 \text{ in}^2$$

$$\text{Divide to get ft}^2 = 98.9 \text{ in}^2 / 144 \text{ in}^2/\text{ft}^2 = \mathbf{0.7 \text{ ft}^2}$$

$$\text{Total Wheel Area} = \mathbf{2.8 \text{ ft}^2}$$

$$\text{Total Landing Gear (wheels and struts)} = \mathbf{5.0 \text{ ft}^2}$$

Appendix F – Flowcharts and pseudo code for Downlink Data Processing and Emitter Geolocation

The following flow charts are expansions of the modules presented in top level design for loading the *Puffer* downlinked information into a database on the Payload Commander's console (Figure 7-1) and the subsequent module description paragraphs.

F-1 Download Data from Puffer into Database record

The following is the Program flow for the “Download Data from the *Puffer* into the Database record” module. The module is essentially an “infinite loop” and will continue processing until there is no downlink data, or the process is terminated by the Payload Commander.

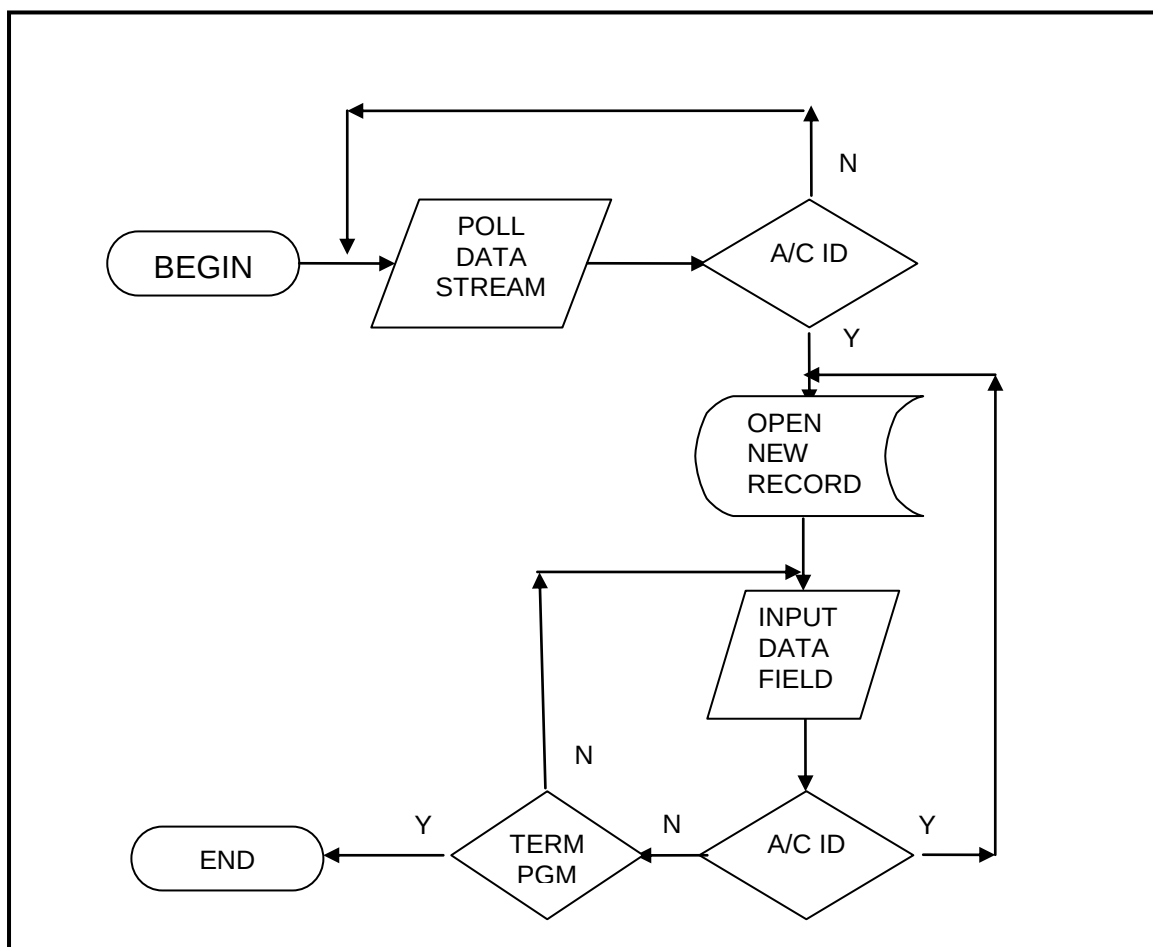


Figure F-1. Download Puffer Data into Database

F-1.1 Pseudo Code for “Download Puffer Data into Database”

```
Begin;  
Poll the data stream;  
    If ACID = 1,2,or 3    /* New aircraft record?*/  
    Then  
        Do Until “Terminate”  
            Create New Record;  
            Do Until input record = 1, 2. or 3  
                Input Data into data field;  
            end do;  
        end do;  
    Else  
        Goto Poll the data steam;  
    End if;  
End;
```

F-2 Compute DOA of Emitter

This routine will examine each record in the aircraft table and compute the true DOA of the emitter. This is a separate process from the download data module and continues as long as there is data to process, or the Payload Commander terminates the process. A separate process runs for each aircraft table.

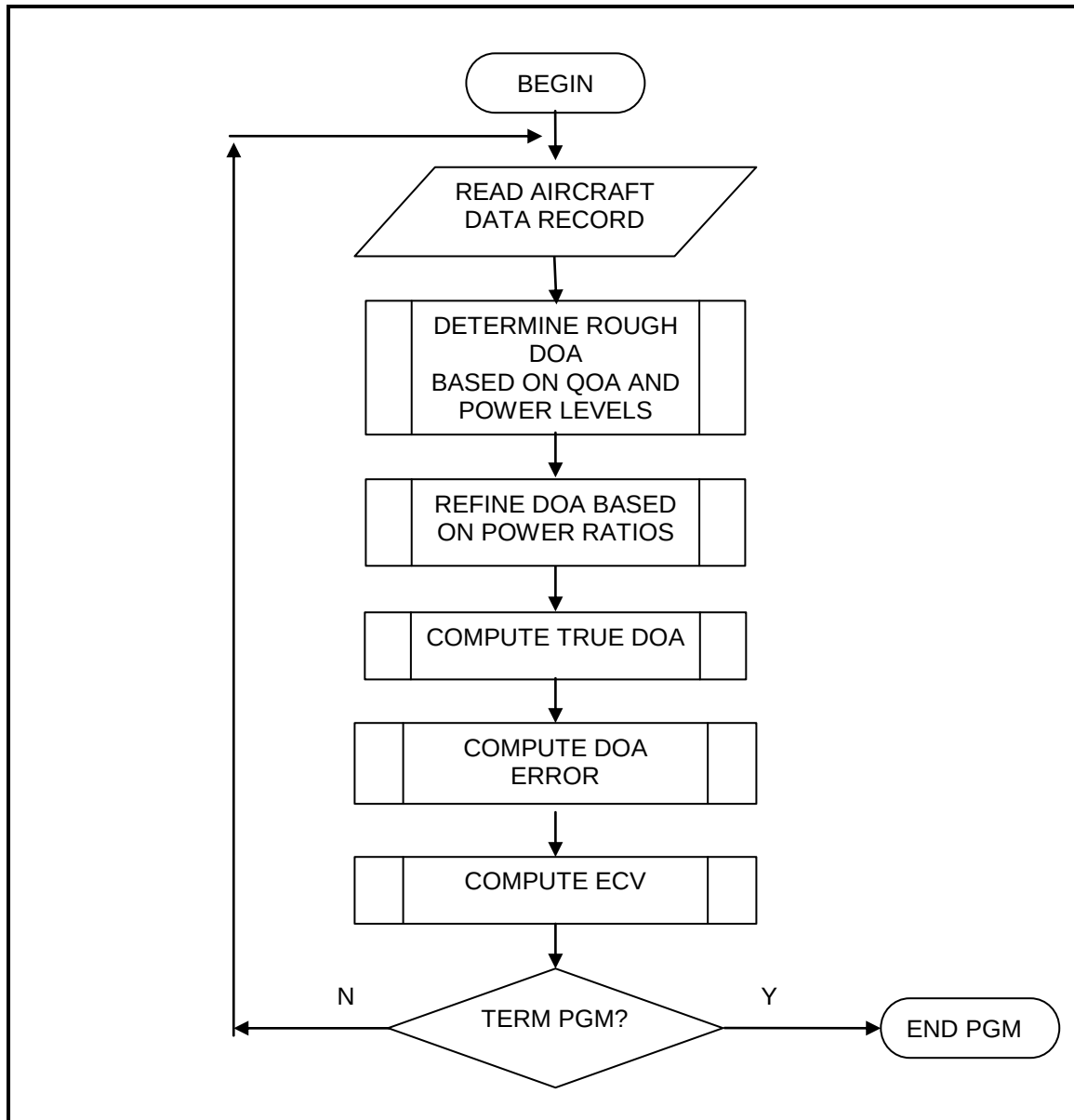


Figure F-2. Compute DOA of Emitter

F-2.1 Pseudo Code for “Compute DOA of Emitter” Module

```
Begin
    Do Until Terminate Program or EOF
        Read Aircraft Data Record;
        Perform Compute Rough DOA from QOA;
        Perform Compute Refine DOA;
        Perform Compute True DOA;
        Perform Compute ECV;
    End do;
End;
```

F-3 Subroutines for “Compute DOA of Emitter” Module

Each of the subroutines for the “Compute DOA of Emitter” module is flowcharted in this section. In those cases when a subroutine is referenced, the routine will be explained, but not flowcharted or coded.

F-3.1 “Compute Rough DOA from QOA” Module

This module will give a rough DOA (45° limits) based on the power levels of the adjacent quadrant antennas to the downlinked QOA.

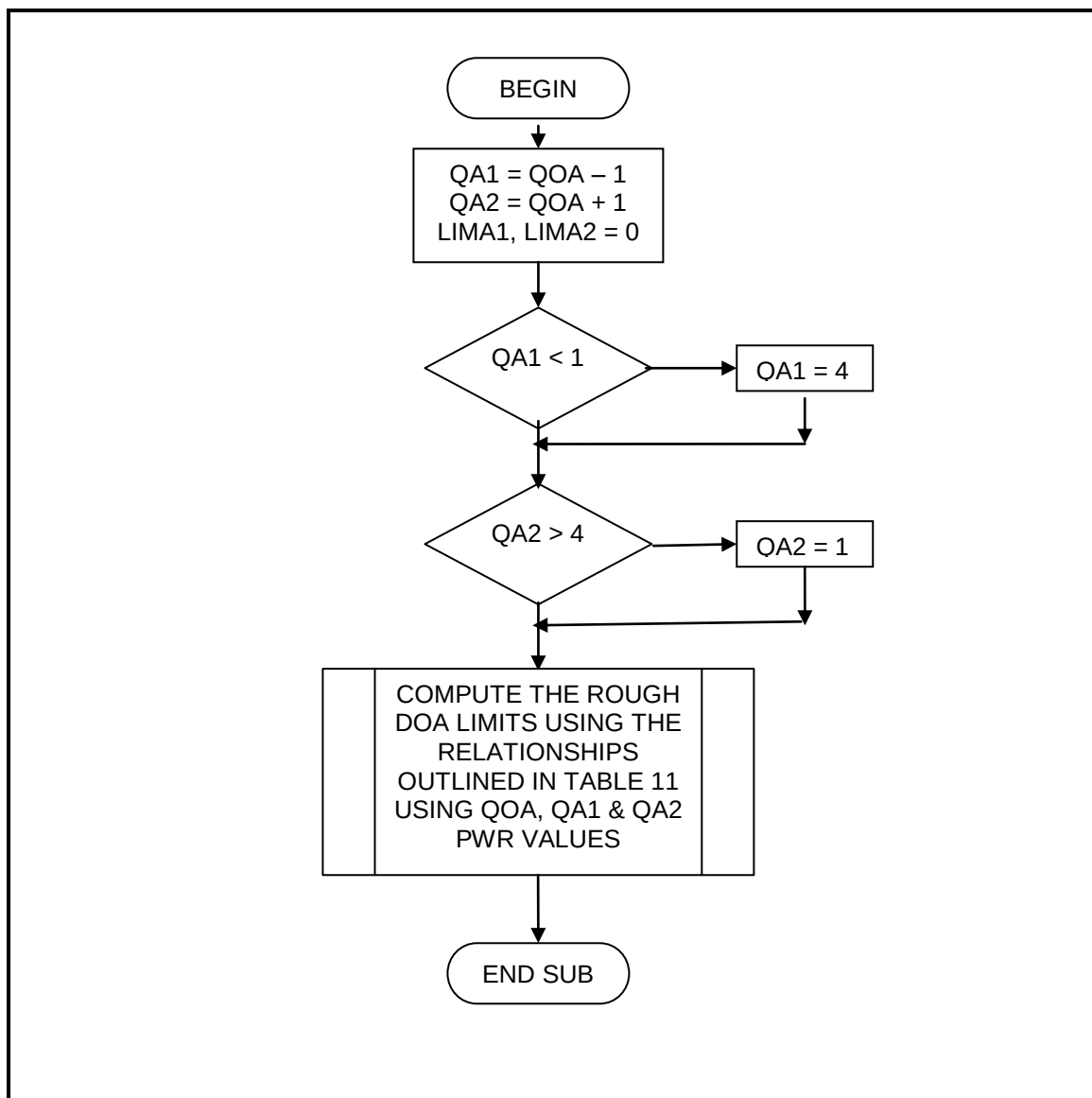


Figure F-3. “Compute Rough DOA from QOA” Flowchart

F-3.1.1 Pseudo Code for “Compute Rough DOA from QOA”

Begin Subroutine Compute Rough DOA from QOA

QA1 = QOA – 1;

QA2 = QOA + 1;

LIMA1 = 0

LIMA2 = 0

If QA1 < 1

Then QA1 = 4;

endif;

If QA2 > 4

Then QA2 = 1;

endif;

```
/* The Perform Rough DOA from QA Power routine will produce */
/* a rough DOA by using the power limits found in Table 11. */
/* The power levels of the adjacent antenna will either provide a */
/* direction value directly (i.e. PQ1 = PQ2) or limits that the ratio of */
/* the power levels will be used to compute the refined DOA. */
```

Perform Rough DOA from QA Power;

End;

F-3.2 Compute Refined DOA

This Routine uses the rough DOA and computes a refined DOA. The results from this module will be the DOA with respect to the Aircraft.

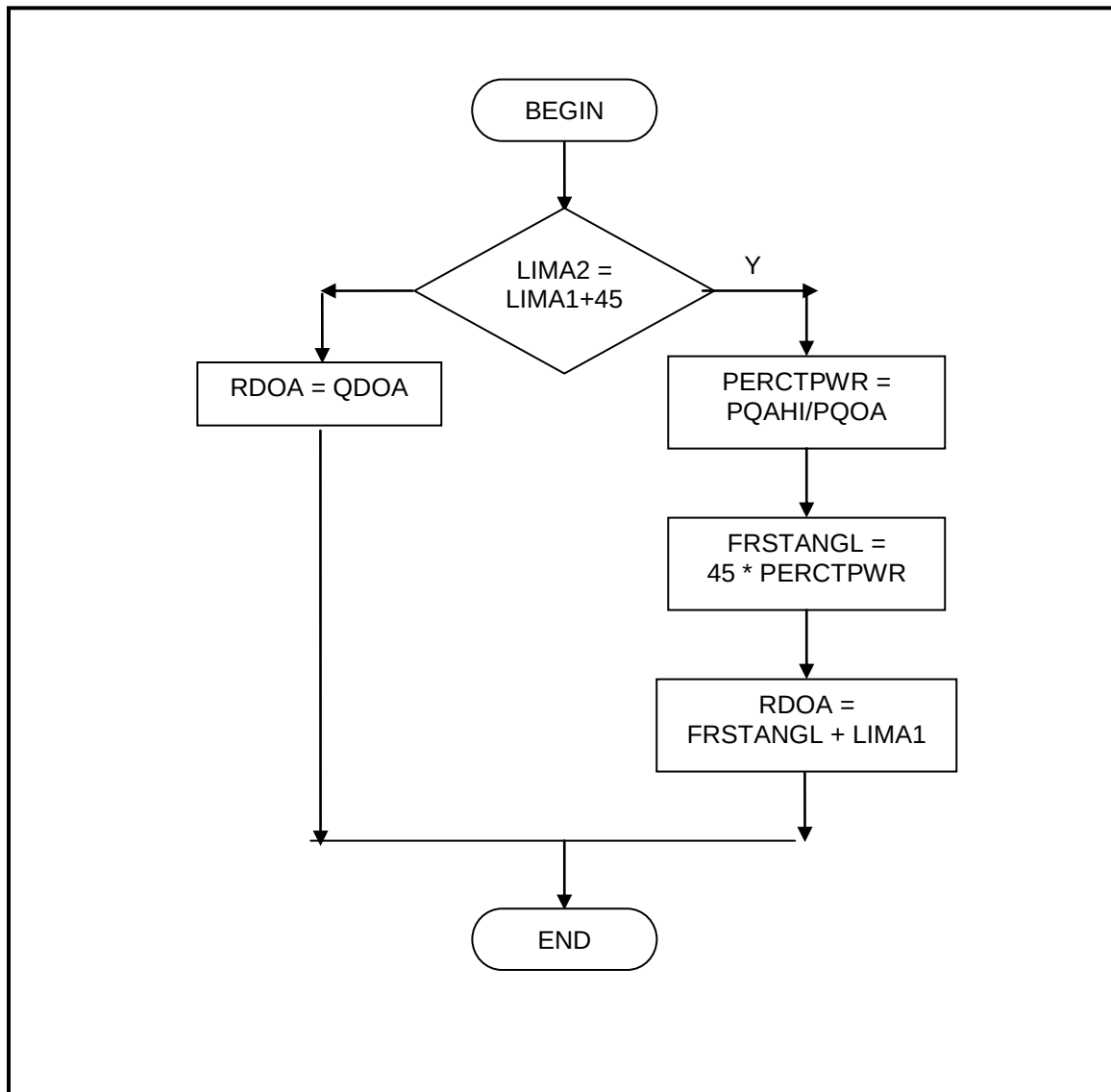


Figure F-4. “Compute Refine DOA” Flowchart

F-3.2.1 Pseudo Code for “Compute Refine DOA” Module

Begin Subroutine Compute Refine DOA;

```
    If (LIMA2 = LIMA1+45)
        Then
            PERCTPWR = PQAHI/PQOA;
            FRSTANGL = 45 * PERCTPWR;
            RDOA = FRSTANGL + LIMA1;
        Else
            RDOA = QDOA;
    endif;
End;
```

F-3.3 “Compute True DOA” Module

This Module will compute the True DOA using the refined DOA and the Aircraft’s heading

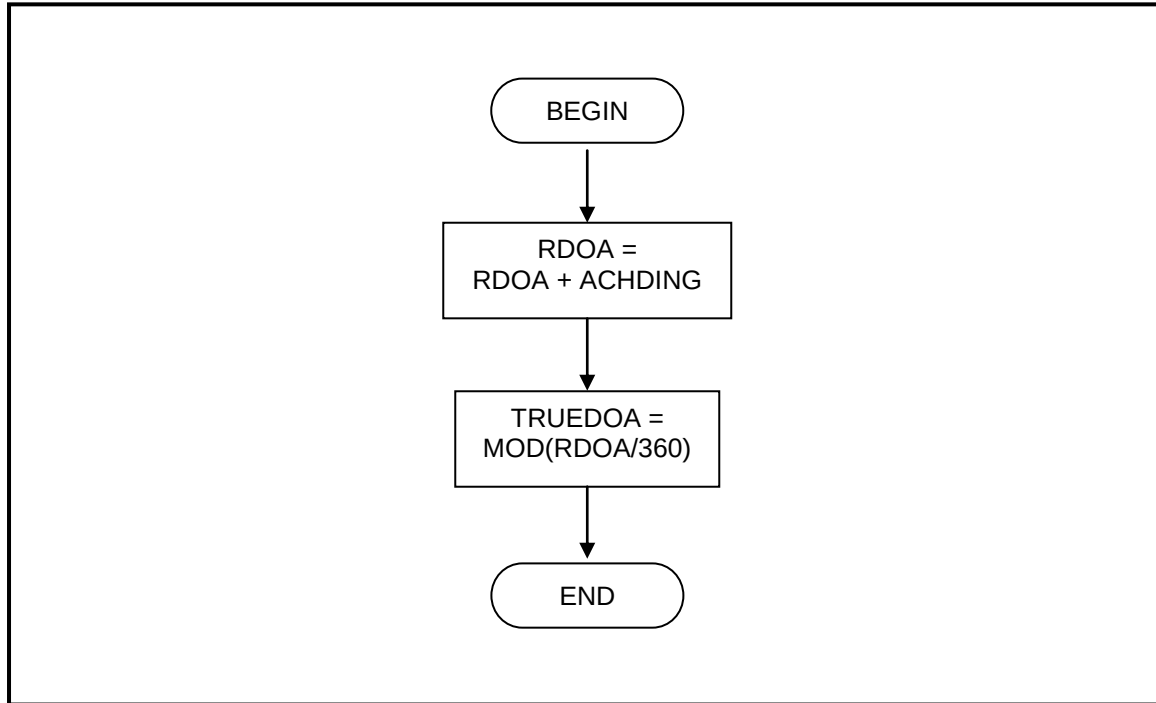


Figure F-5. “Compute True DOA” Module Flowchart

F-3.3.1 Pseudo Code for “Compute True DOA” Module

Begin Subroutine Compute True DOA;

/* Add Refine DOA to AC Heading */

RDOA = RDOA + ACHDNG;

/* Find True DOA by taking Modulus of the Refine DOA/360 */

TRUEDOA = Mod(RDOA/360);

End;

F-3.4 “Compute ECV” Module

This module will compute the Emitter Confidence Value (ECV) of the received emitter using the Values for each of the Emitter Parameters found in Section 7.2.2.

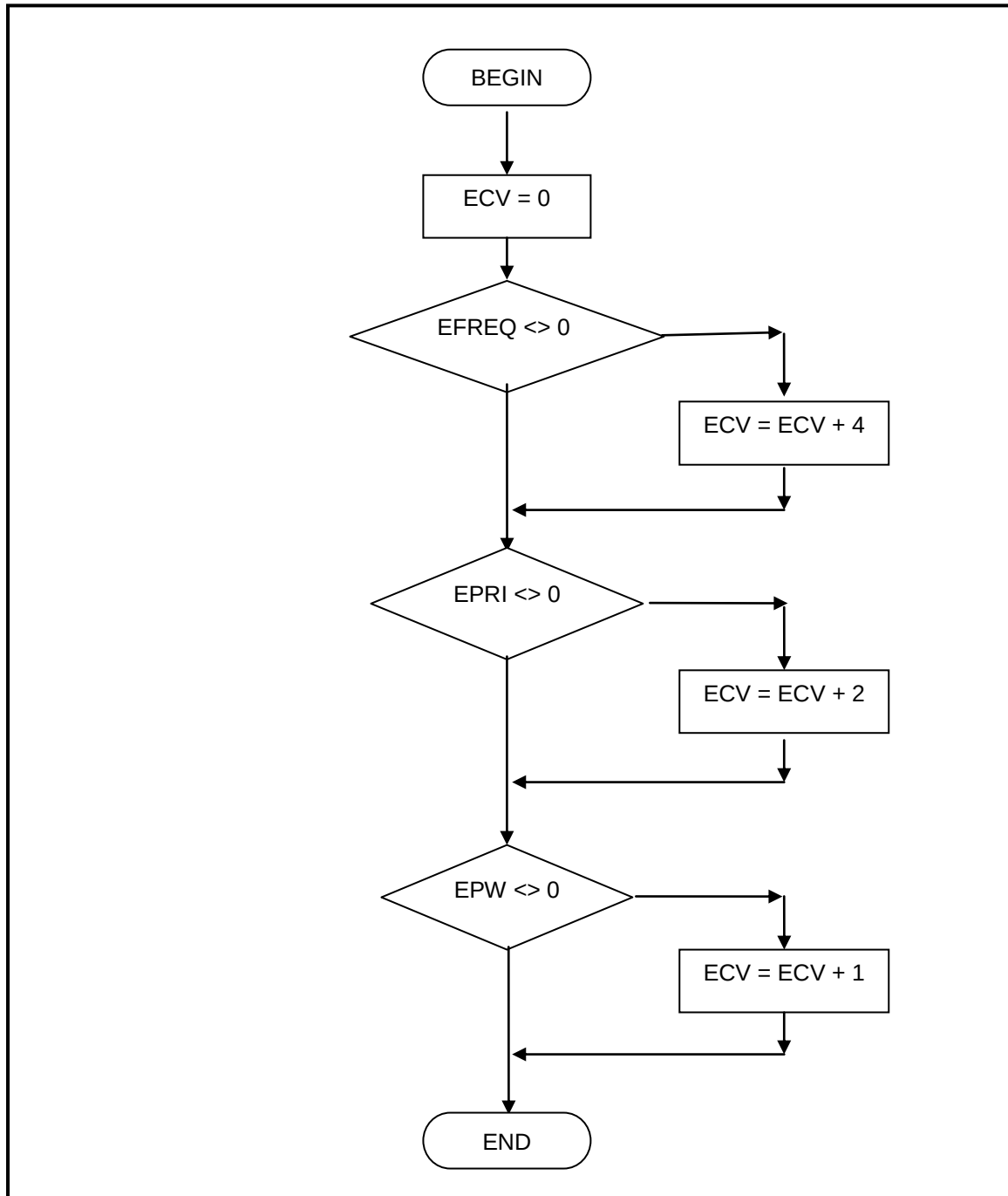


Figure F-6. “Compute ECV” Flowchart

F-3.4.1 Pseudo Code for “Compute ECV”

```
Begin Subroutine Compute ECV;  
    ECV = 0;  
    If EFREQ <> 0  
        Then ECV = ECV + 4;  
    endif;  
    If EPRI <> 0  
        Then ECV = ECV +2;  
    endif;  
    If EPW <> 0  
        Then ECV = ECV + 1;  
    endif;  
End;
```

F-4 “Compute Geolocation of Emitter” Module

This module will compute the geolocation of the Emitter based on the location and True DOA of each aircraft. To begin, position and True DOA information for each aircraft are placed into a single record for the same frequency correlated by time. The routine computes a geolocation of the emitter for each DOA placed in the database by each UAV. If there are multiple hits on a single emitter from multiple UAVs at a common time, the routine goes on to refine the geolocation based on simultaneous DOA from the multiple UAV.

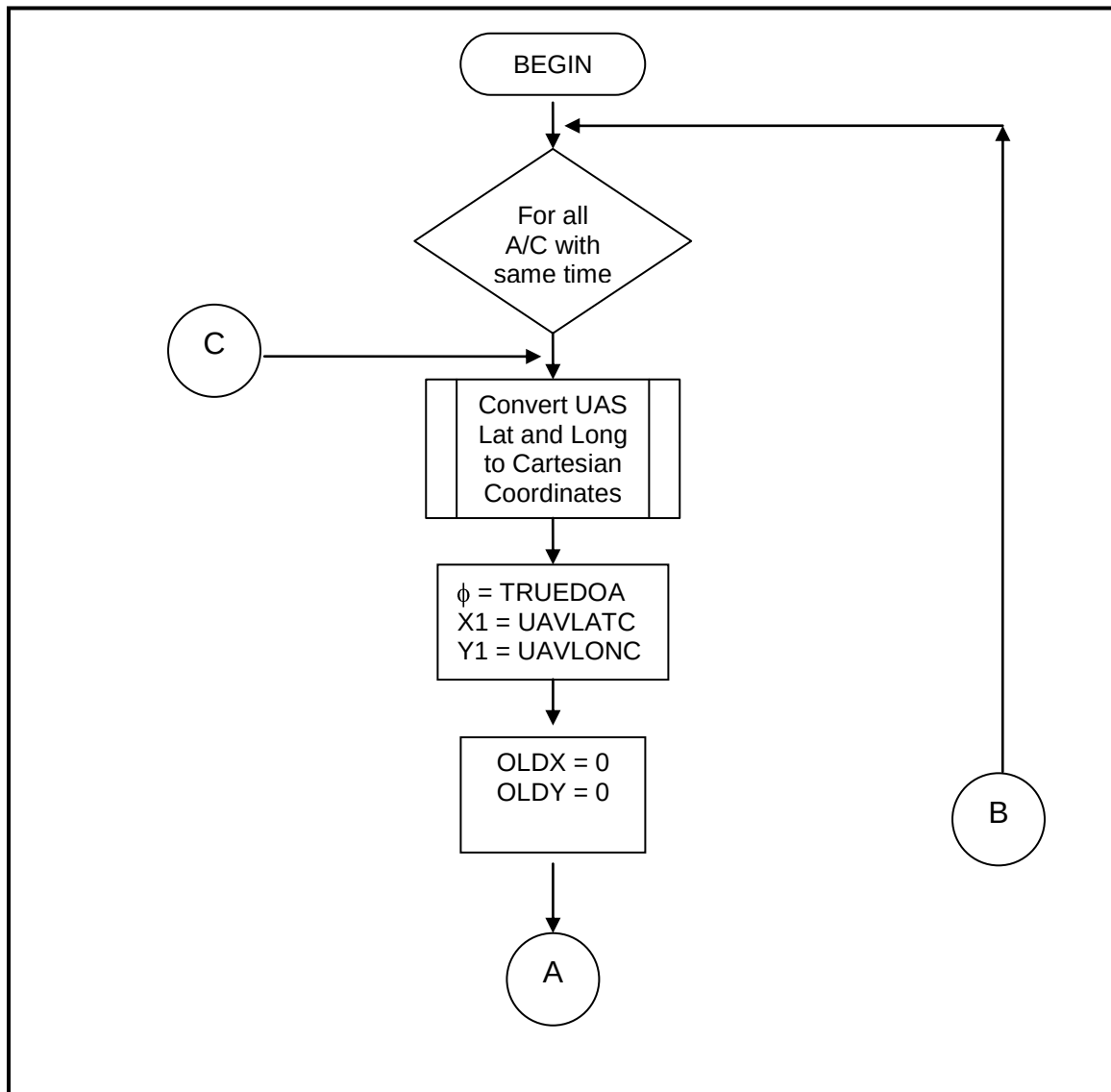


Figure F-7. "Compute Geolocation of Emitter" Module Flowchart

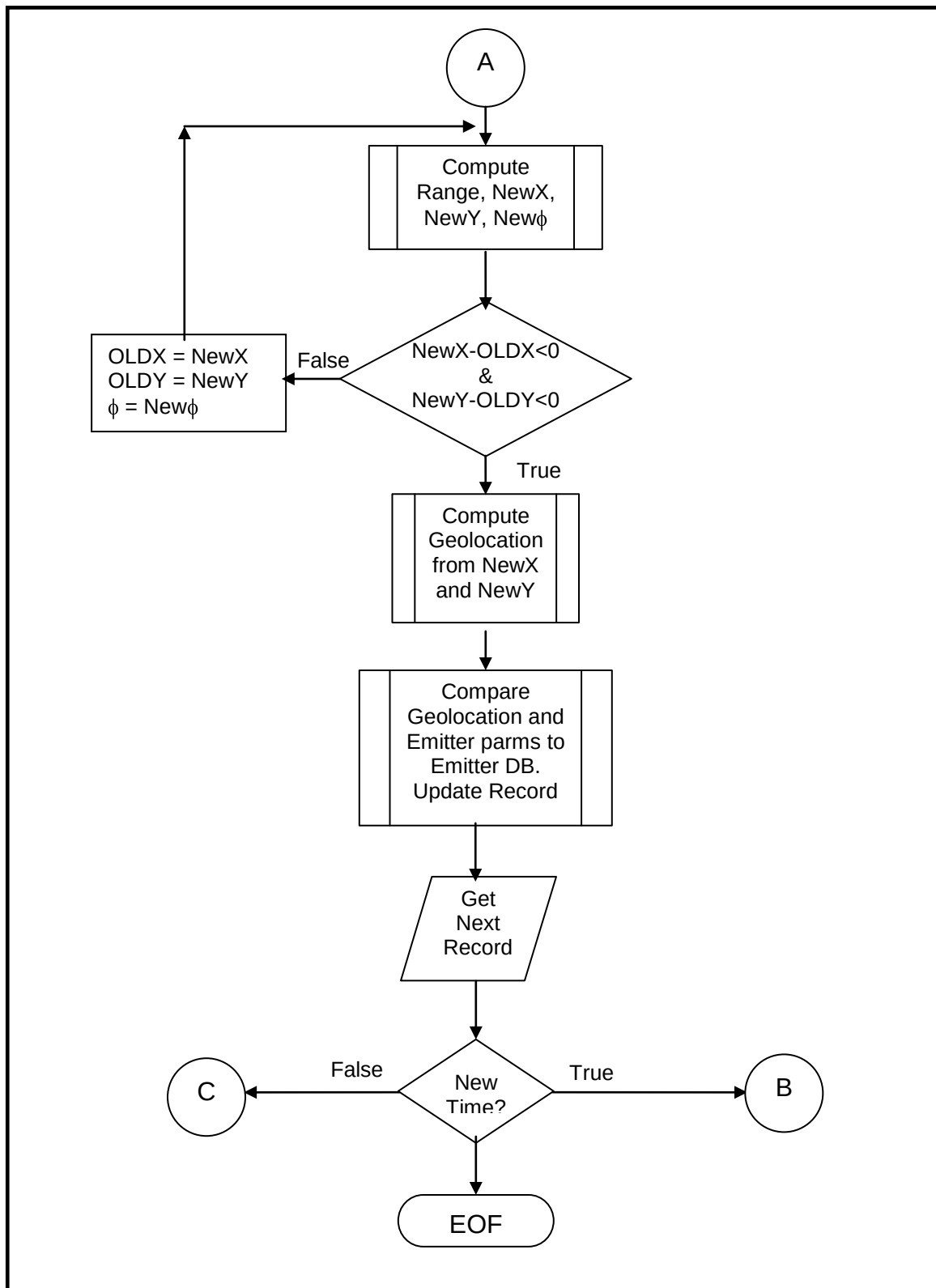


Figure F-8. “Compute Geolocation of Emitter” Module Flowchart (cont.)

F-4.1 Computer Geolocation of Emitter Pseudo Code

```
Begin;  
  Get Record;  
  Do Until EOF  
    Do While New Time = Current Time  
      Perform Convert UAS Position;  
       $\phi$  = TRUE DOA;  
      X1 = UAVLATC;  
      Y1 = UAVLONC;  
      OLDX = 0;  
      OLDY = 0;  
      Do Until (NewX – OLDX < 0) and (NewY – OLDY < 0)  
        Perform Compute Range, NewX, NewY, New $\phi$ ;  
        If (NewX-OLDX>0) and (NewY-OLDY>0)  
          Then  
            OLDX = NewX;  
            OLDY = NewY;  
             $\phi$  = New $\phi$ ;  
          endif;  
        enddo;  
        Perform Compute Geolocation with NewX and NewY;  
        Perform Compare New Geolocation to Emitter DB and  
          Update Record;  
        Get New Record;  
      enddo;  
    enddo;  
  End;
```

Appendix G – Cost Estimate Table

The Cost Estimate is made based on the list of items discussed throughout this document that would make up the *Puffer* UAS. For UAV, MIDS/LVT, Personal Computers, Computer Equipment Racks, Tables in this document, or prices from the internet were used. Prices are not guaranteed because no order has been placed. Labor rates were based on the average of 4 labor categories hourly rate, Subject Matter Expert (SME) – \$92.00/hr, Senior Engineer – \$74.00/hr, Intermediate Engineer – \$68.00/hr, and Junior Engineer – \$42.00/hr for an hourly average of \$69.00/hr. Total hours were based on the schedule outlined in section 8.3.

Table 17. Cost Estimate For Puffer/UAS

Item Description	Qty	Cost per Unit (\$)	Total Cost (\$)
UAV Aircraft (<i>Aerostar</i> or <i>Dakota</i>)	3	250,000	750,000
MIDS/LVT	1	250,000	250,000
<i>Puffer</i> RWR ^(note 1)	3	100,000	300,000
BOSS w/LinkPro and APIs	1	500,000	500,000
Computers w/ MS Office	10	2,000	20,000
Displays (21") MC and PC	2	500	1,000
Displays IP (17")	4	300	1,200
Display IP (19")	1	400	400
UHF/VHF Radios	4	1,000	4,000
UHF/VHF Antennas	2	1,100	2,200
Antenna Mast	1	750	750
Computer Cabinets (Tall)	2	1,350	2,700
Computer Cabinets (Small)	2	550	1,100
Shelter Trailer	1	15,000	15,000
14kWGenerator (Propane)	1	3,800	3,800
Misc Cables and Wiring	1	5,000	5,000
Misc Building Materials	1	5,000	5,000
Labor (SW and HW)	20	135,240	2,704,800
Total			4,566,950

Vita

Ward Huffine was born November 28, 1951 in Hollywood, CA. He grew up in the San Fernando Valley and attended Haskell Ave. Elementary School, George K. Porter Jr. High School and Granada Hills High School. Moving to the Santa Clarita Valley during his sophomore year, he graduated from William S. Hart High School in 1969 and obtained his AA Degree from College of the Canyons in 1971.

In 1972, he joined the U.S. Air Force and served as a Radio Communications and Electronic Warfare Analyst until being Honorably Discharged in 1978. He received his B.S. Degree in Computer Science from Chapman University in 1986.

During the course of his career in computers, he has worked in various capacities on many high visibility programs including NASA's Space Shuttle (both at the Vandenberg Launch Site and Kennedy Space Center), the Navy's EA-6B and EA-18G test and evaluation, the Marine's AV-8B aircrew trainers, and the Army's Theater High Altitude Area Defense missile system. He is employed by the Department of the Navy assigned to Test and Evaluation Squadron Nine (VX-9), China Lake, CA, as the Lead EW Branch Analyst, currently completing the Initial Operational Test and Evaluation of the EA-18G aircraft. Ward has completed the US Navy's Test Pilot School's UAV Test and Evaluation course, the HARM Subject Matter Expert course, and the Operational Test Director's course.

Ward is married to the former Joy Lynn Werle of Melbourne Beach, FL, has three daughters, Chyrrl, Julie, and Courtney, and one grandson, Ethan.