# Point of Impact: Delivering Mission Essential Supplies to the Warfighter through the Joint Precision Airdrop System (JPADS)



by

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Bachelor of Science, International Relations and Systems Engineering
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Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of

**Master of Science in Engineering and Management**

at the
Massachusetts Institute of Technology
June 2012



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## Abstract

The Joint Precision Airdrop System (JPADS) exists to execute logistical resupply operations using fixed and rotary wing air in a safe, effective and precise manner in order to deliver supplies and equipment to intended recipients at multiple locations on a single mission in hostile or restricted terrain. In the U.S. Military's Current Operating Environment (COE) in locations all over the world, Soldiers find themselves operating in areas that are either too arduous to move to by ground or where the threat is elevated to the point where the unit must maneuver to a particular location by air in order to increase unit survivability, maintain the element of surprise and execute timely operations. Current and previous logistical resupply platforms and systems fail to meet these requirements due to inaccuracies and ineffectiveness, increased enemy capabilities to effect friendly supply lines and increased threats to low flying aircraft, which has an immediate impact on mission accomplishment. Current force structure requires a system that can operate in a dynamic and mercurial environment in order to rapidly adjust to changes on the ground, which is a necessity.

The objective of this research thesis is to provide a thorough analysis of the JPADS through a rich stakeholder analysis of the system and a complete study of the JPADS system architecture. This will allow further investigation using the Design Structure Matrix (DSM), which is a system engineering methodology and tool utilized to provide improvement recommendations to project sponsors working on the system. This research thesis will argue that there are two critical components vital to the success of the JPADS, which include an integrated Wind Data Sensor that can provide real-time wind updates to the JPADS and a Terrain Avoidance Feature to ensure success in challenging terrain such as we find our military currently operating in.

Instrumental to the success of the JPADS is developing a system that takes full advantage of tip of the spear technology through a modular system capable of adapting to both the environment and the mission. This research thesis will apply systems architecture and DSM analysis to the JPADS in order to fully analyze the system and illustrate why the incorporation of both the Wind Data Sensor and the Terrain Avoidance Feature is a necessity to ensure operational success of the system.

Thesis Supervisor: Donna H. Rhodes
Title: Senior Lecturer, Engineering Systems Division, Principal Research Scientist, Sociotechnical Systems Research Center.

## Biographical Note

Joshua Eaton is an active duty Army Special Forces Major currently working on a Masters of Science Degree in Engineering and Management as a prerequisite for subsequent assignment as an Instructor in the Department of Systems Engineering at the United States Military Academy at West Point. He is a combat veteran who served in multiple command positions in Iraq and Afghanistan.

Major Joshua Eaton was born in Columbus, Georgia. Following his graduation from the United States Military Academy in 2002, he was commissioned in the Infantry. While in the Infantry, he served as a Rifle Platoon Leader, Support Platoon Leader and Company Executive Officer while assigned to $1^{st}$ Battalion, $14^{th}$ Infantry Regiment, $2^{nd}$ Brigade, $25^{th}$ Infantry Division in Schofield Barracks, Hawaii. While assigned to 1-$14^{th}$ Infantry, he deployed to Iraq in support of Operation Iraqi Freedom (OIF). After attending the Infantry Captain's Career Course and the Special Forces Qualification Course, he served as the Detachment Commander for Operational Detachment-Alpha (ODA) 3325, $3^{rd}$ Battalion, $3^{rd}$ Special Forces Group (Airborne). During his Detachment Command, Major Eaton deployed with his Detachment in support of Operation Enduring Freedom (OEF). Following Detachment Command, Major Eaton took command of the Headquarters Support Company (HSC) for $3^{rd}$ Battalion, $3^{rd}$ Special Forces Group and again deployed to Afghanistan in support of OEF. Following his HSC command, Major Eaton proceeded to graduate school at the Massachusetts Institute of Technology.

His Awards and Decorations include: a Bronze Star Medal for Valor, Bronze Star Medal (3), Purple Heart, Meritorious Service Medal, Army Commendation Medal, Army Achievement Medal (2), National Defense Service Medal, Armed Forces Service Medal, Global War on Terrorism Expeditionary Medal, Global War on Terrorism Service Medal, Afghanistan Campaign Medal, Iraq Campaign Medal, NATO Medal, Special Forces Tab, Ranger Tab, Combat Diver Badge, Combat Infantryman's Badge, Expert Infantryman's Badge, Parachutist Badge, Air Assault Badge and Second Place in the 2006 Department of Defense Best Ranger Competition.

Major Eaton holds a Bachelor in Science Degree in Systems Engineering and International Relations from the United States Military Academy. Major Eaton is married to the former Alison Darcy and has one son, Samuel Paul Eaton.

## Acknowledgements

First, I would like to thank Dr. Donna Rhodes, my supervisor, for her invaluable insight, guidance and mentorship throughout my research thesis. Her knowledge and experience played an important role in brining together all my research and analysis in a successful manner.

I would like to acknowledge several of my colleagues within the System Design and Management (SDM) Program who participated and provided critical insight and analysis during several projects centered around the Joint Precision Airdrop System (JPADS), to include Shane Scott, Sergey Naumov, Matt Renzi and Deniz Eralp. The professionalism and knowledge of this team is truly impressive.

I am very grateful for the assistance provided by Richard Benney from Natick Labs. He and his team provided critical details to the JPADS that facilitated a rich study of this system. His cooperation, support and eagerness to assist me in this project was great.

I would also like to thank Major Nate Minami as his thesis provided a valuable blueprint and organizational architecture for my work. The SDM Program Director, Pat Hale, also provided important guidance, which allowed me to structure my course work in a manner that allowed me to focus my studies and narrow in on a topic that is critical to my line of work.

Last, but not least, I would like to thank my wife, Ali and my son, Samuel, for their love and support throughout this journey.

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# Abbreviations

| Acronym | Name |
|---|---|
| AAR | After Action Review |
| AGL | Above Ground Level |
| AGU | Airborne Guidance Unit |
| CAN | Controller Area Network |
| CARP | Computed Air Release Point |
| CDS | Container Delivery System |
| COE | Current Operating Environment |
| COIN | Counterinsurgency |
| CONOP | Concept of Operation |
| CUROPS | Current Operations |
| DOD | Department of Defense |
| DP | Design Parameter |
| DSM | Design Structure Matrix |
| DTED | Defense Terrain Elevation Data |
| DZ | Dropzone |
| FR | Functional Requirement |
| FTT | Forward Travel Time |
| GMI | Graphical Map Interface |
| GUI | Graphical User Interface |
| GN&C | Guidance, Navigation and Control |
| GPS | Global Positioning System |
| GRADS | Ground Radar System |
| HDR | Humanitarian Daily Rations |
| HMMWV | High Mobility Multipurpose Wheeled Vehicle |
| HSC | Headquarters Support Company |
| IAW | In Accordance With |
| IMC | Instrument Meteorological Conditions |
| ISAF | International Security and Assistance Force |
| ISR | Intelligence, Surveillance and Reconnaissance |
| IVI | In-Vehicle Infotainment |
| JDAMS | Joint Direct Attack Munitions |
| JPADS | Joint Precision Airdrop System |
| KIAS | Knots Indicated Airspeed |
| KPP | Key Performance Parameter |
| LCLA | Low Cost Low Altitude |
| MACV | Military Assistance Command, Vietnam |
| MP | Mission Planner |
| MRE | Meal Ready to Eat |
| MSL | Mean Sea Level |
| NSRDEC | Natick Soldier RD&E Center |
| NVA | North Vietnamese Army |

| | |
|---|---|
| ODA | Operational Detachment Alpha |
| OEF | Operation Enduring Freedom |
| OIF | Operation Iraqi Freedom |
| PADS | Precision Airdrop System |
| PAPS | Precision Airdrop Planning System |
| PEGASYS | Precision and Extended Glide Airdrop System |
| PI | Point of Impact |
| RDECOM | Research, Development, and Engineering Command |
| RP | Release Point |
| SAB | Scientific Advisory Board |
| SAF | Small Arms Fire |
| SBIR | Small Business Innovative Research |
| SDM | System Design and Management |
| SoS | System of Systems |
| SPS | System Problem Statement |
| TAS | True Airspeed |
| TFC | Time of Fall Constant |
| TOF | Time of Fall |
| TOT | Time on Target |
| TRIADS | Triwall Aerial Delivery System |
| TTF | Total Time of Fall |
| ULW | Ultra Lightweight |
| USAF | United States Air Force |
| WindPADS | Wind Profile Precision Aerial Delivery System |
| WWII | World War Two |

# Chapter 1: Introduction

***"The line between disorder and order lies in logistics..."***

**- Sun Tzu**

Soldiers know first hand the criticality of having mission essential supplies and equipment arrive at the right place, at the right time. This is of particular importance when operating in remote locations around the world where hostilities are prevalent, terrain is restrictive and mission accomplishment has strategic implications. The Joint Precision Airdrop System (JPADS) is a guided logistical resupply platform that will deliver supplies and equipment in a precise manner to Soldiers operating in restrictive or hostile terrain from a high altitude. The JPADS exists to deliver cargo to Soldiers in an effective manner when conventional means of resupply are unavailable, unrealistic or ill-advised. The motivation for this research thesis is to demonstrate why the JPADS is an operational necessity and to provide insight and analysis on how recommended changes using systems engineering methodologies and tools will increase the effectiveness of the system for the Soldiers on the ground.

## Section 1.1 - Statement of the Purpose

In our Current Operating Environment (COE) in locations all over the world, Soldiers find themselves operating in areas that are either too arduous to move to by ground or where the threat is elevated to the point where the unit must maneuver to a particular location by air in order to increase unit survivability, maintain the element of surprise and execute timely operations. Current and previous logistical resupply platforms and systems fail to meet these requirements due to inaccuracies and


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ineffectiveness, increased enemy capabilities to effect friendly supply lines and increased threats to low flying aircraft, which has an immediate impact on mission accomplishment. Our current force structure requires a system that can operate in a dynamic and mercurial environment in order to rapidly adjust to changes on the ground, which is a necessity. The purpose of this research thesis is to thoroughly analyze high altitude resupply via the JPADS from both a systems architecture and systems engineering perspective, which will facilitate evaluating potential improvements to the system in order to increase its effectiveness and provide recommendations to project sponsors working on the JPADS.

## Section 1.2 – Define the Scope and Goal

The scope of the research thesis will center around the 2K and Ultra-Light Weight (ULW) versions of the JPADS as there are numerous other variants in development and testing. The JPADS-2K is capable of delivering resupply packages up to 2,200 lbs. where the JPADS-ULW can deliver loads in the range of 250-699 lbs. This will provide focus for further analysis when the thesis examines the system from a systems architecture perspective and when utilizing the Design Structure Matrix (DSM) to provide recommended improvements to the system. The goal of the research thesis is to provide valuable insight to the project sponsors at Natick Labs and the United States military in order to continue refinement with the current system, which will have an immediate positive impact on Soldiers operating in Afghanistan and other lesser known locations around the world.


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## Section 1.3 – Project Methodology

This research thesis will integrate a number of systems engineering methodologies, tools and practices. First, the thesis will give a brief historical overview of aerial resupply from WWII to our Current Operations (CUROPS) in Afghanistan. This overview is important in order to put this challenge into perspective from a military standpoint.

Following the historical overview, the research thesis will provide an in-depth stakeholder analysis illustrating the critical nature of this project for our armed forces and other possible uses of the system, which could potentially provide aid in areas devastated by natural disasters. A stakeholder is defined as a person, group, organization or system who can affect or is affected by the achievement of the firm's objective. This thesis will go into detail on the importance of clearly identifying the stakeholders along with the primary beneficiaries of the JPADS.

Following this analysis, the research will explore the JPADS from a Systems Architecture perspective in order to completely decompose the system and provide critical system details, which will aid in the DSM analysis that will follow. "The DSM is a two-dimensional matrix representation of the structural or functional relationships of objects, variables, tasks or teams." (de Wick, 152) The DSM illustrates where important interactions take place in order to identify where opportunities exist to improve the system. This could have numerous positive implications for improvements to not only the current system, but in the development of future systems, which may require a more modularized approach as technology and software constantly change and improve. This will lead into the recommendations section, which will synthesize all previous research,


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provide technical recommendations and discuss areas of continued research centered around the JPADS. The outcome of this research thesis is to not only provide recommendations to the project sponsors working on both the JPADS-ULW and JPADS-2K variants, but to illustrate the value of using Systems Engineering methodologies and tools to analyze complex systems and challenges.


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# Chapter 2: A Historical Overview of Aerial Resupply

There are numerous aspects of aerial resupply that this research thesis will cover, which will provide the audience a starting point as to why this is a critical topic of discussion for the military. To begin this discussion, it is important that the thesis provide a brief history of aerial resupply followed by an explanation as to why aerial resupply is critical from a high altitude in today's COE. This study will then elaborate on high altitude aerial resupply by going into detail on the systems architecture behind the JPADS and what improvements the designers can make to the system in order to increase it's overall effectiveness and utility. This chapter will first provide a brief historical overview of aerial resupply and will then move into why high altitude is critical in today's COE before elaborating on factors impacting current airdrop procedures. Lastly, the chapter will formally introduce the JPADS.

## Section 2.1 - History of Aerial Resupply

An important lesson known by all military professionals is that the enemy always has a vote. The enemy vote, so to speak, has led to an evolution in the way our military conducts logistical resupply operations, from ground based resupply to resupply by sea and air. This study will expound upon several historical milestones that led to airdrop usage in the

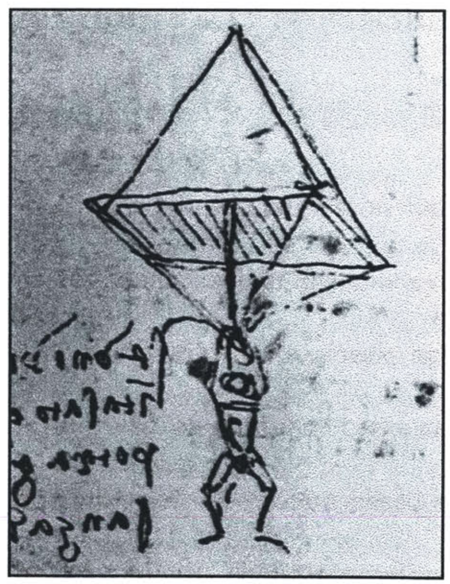

**Figure 1: Design for a parachute by Leonardo da Vinci, from the Codex Atlanticus, c. 1478–1518; in the Biblioteca Ambrosiana, Milan, Italy (Source: britannica.com)**



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military and why continued advancement in this field is critical to our ability to project military power in the interest of achieving our strategic objectives.

Leonardo da Vinci recorded one of the first parachute designs in 1495 (Parfit, 1990). In Figure 1 above, his illustration displays the first parachute design, which is taken from the Codex Atlanticus. The Montgolfier brothers, famous for their study and design of hot air balloons, developed several parachutes, which involved airdropping a sheep from a tower through the use of one of their parachute designs. Fortunately, this resulted in the safe landing of the sheep (Parfit, 1990). Andre-Jacques Garnerin, a French physicist and inventor of the first frameless parachute, demonstrated the first successful manned parachute decent in Paris, France on October 22, 1797 (Siegel, 1998). With continued advancements in parachute designs and development, it was only a matter of time before this capability presented a target of opportunity for military and humanitarian use.

World War II became the proving ground for the impact aerial resupply could have in a conflict, placing a strategic advantage to those who could master this capability. Initially, airdropping equipment and supplies was at a very primitive stage before dedicating personnel with the sole responsibility of packing and maintaining parachute equipment, which took place in 1942 and later expanded upon in 1944 at Fort Benning, GA. Originally, airdropping supplies and equipment was at first an "ad hoc experiment" when other methods of resupply were not feasible (qmfound.com, 2010). The military conducted the drops using the C-47 "Dakota" cargo plane; however, over time other bombers and fighters were modified to support airdropping supplies, equipment and


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personnel. The Allies conducted some of the first airdrops in Italy during WWII, which relied primarily on improvised packing and dropping procedures.

> "An example is the winter of 1943 when some Fifth Army units were cut off by German counterattacks in the mountains around Cassino. Because of the isolation of the positions, flooding and the quagmire roads, even pack animals were unable to reach some of the positions. Quartermaster personnel of Depot 5N60 of the Peninsular Base Section packed food and clothing into empty detachable fuel tanks normally carried by fighter planes. These "belly tanks" were flown to Naples, attached to the bomb racks of A-36 bombers and ejected over the stranded units…" (qmfound.com, 2010).

The Allies used this method as an emergency resupply means only when traditional means of resupply were unavailable.

During the D-Day Invasion in June 1944, the Allies utilized more than 900 aircraft and 400 gliders to deliver over 13,000 paratroopers and dropped approximately 69 tons of supplies to Allied elements near the coast of Normandy, France, which facilitated seizing key terrain behind enemy lines in support of follow-on operations (MAC, Office of History, 1991). Although only ten percent of the paratroopers landed on their intended drop zones due to inclement weather and a lack of Instrument Meteorological Conditions (IMC) navigation capabilities, the seizure of key terrain and follow-on logistical support illustrated the effectiveness of such operations when used appropriately.

**Figure 2: Logistical Resupply Operation During Operation JUNCTION CITY (Source: wikipedia.com)**

During the Vietnam War, the US military conducted its largest and only battalion sized airdrop during Operation Junction City, which was the largest



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airborne operation since Operation Market Garden during WWII. On February 22, 1967, the US military dispatched 13 C-130s to airdrop the 173rd Airborne Brigade over Katum near the boarder of Cambodia with the goal of easing pressure off Saigon and to disrupt the Viet Cong's stronghold in the Tay Ninh Province (MAC, Office of History, 1991). In January of 1968, the US Air Force (USAF) airdropped supplies and equipment to over 6,000 Marines at Khe Sanh who were surrounded by over 15,000 North Vietnamese Army (NVA) troops (MAC, Office of History, 1991). As a result of deadly ground fire and elevated mortar attacks, the C-130s were forced to airdrop the supplies rather than air-land. The airdrop would have been inaccurate had it not been for improved technological advances such as the airdrop Ground Radar System (GRADS) to guide the C-130s to the Computed Air Release Point (CARP) (Carrabba, 2004).

In the spring of 1972, following the withdrawal of most US ground forces, the NVA launched a significant offensive to invade South Vietnam. The NVA, supported by tanks, light and mechanized infantry, and heavy artillery, continued their advance along Highway 13 toward Saigon where they were halted after the town of An Loc went under siege (McGowan, 2000). The South Vietnamese, using only their C-123s as the United States withdrew most airlift forces in Southeast Asia, began to conduct aerial resupply operations to support the An Loc garrison; however, the South Vietnamese forces were facing mounting pressures and intractable odds in the face of increased enemy firepower. Helicopter resupply was not feasible due to the increase in Surface to Air Fire (SAF) and automatic weapons in the area, which led the Military Assistance Command, Vietnam (MACV), to begin resupply efforts using the Container Delivery System (CDS) from an much higher altitude, which fell outside the range of enemy fire while utilizing the


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GRADS for accurate positioning and precision. This became a viable solution due to the high altitude nature of the drop, which prevented the NVA from interdicting friendly aircraft with SAF. Following two months of continuous resupply via high altitude CDS operations, the MACV, in support of the South Vietnamese, finally broke the siege (McGowan, 2000). An Loc became the origin of our current high altitude resupply challenge and illustrates the criticality of this capability.

During Operation Just Cause in Panama on December 20, 1989, the 82nd Airborne Division sent a brigade task force into Torrejos-Tocumen Airport, which is east of Panama City. The operation took place at night with the Soldiers jumping from an altitude of 500 to 800 feet and their equipment dropped from between 800 and 1,200 feet. E Company, 407th Supply and Transport Battalion supported this operation by rigging CDS bundles and heavy drop platforms, which included M551 Sheridan's, howitzers, engineer equipment and multiple variations of the High Mobility Multipurpose Wheeled Vehicle (HMMWV) (qmfound.com, 2010). Over the course of Operation Just Cause, C-130s and C-141s dropped over 683 tons of equipment and supplies using the CDS delivery platform (qmfound.com, 2010).

During Operation Desert Shield and Desert Storm, the US Military's aerial delivery and support units conducted only a small number of equipment and supply drops. During Operation Provide Comfort in 1991, the 5th Quartermaster Detachment conducted a number of emergency airdrops in order to provide critical relief and support to Kurdish refugees in Northern Iraq and Turkey. This lasted from April 7th to May 1st with the unit preparing over 7,600 CDS bundles and packing over 6,700 parachutes (qmfound.com, 2010). Over the course of this support operation, the 5th used three



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methods of delivery, which included high velocity, low velocity and the free drop method. The high velocity method accounted for 76% of total airdrops and was used for those items that could best survive impact such as prepackaged food. The low velocity impact method accounted for about 22% of the drops and was suited more for medical supplies, baby food jars and water (qmfound.com, 2010). Lastly, the 5th used the free drop method when other means were not available and getting supplies to the refugees was absolutely critical even without other capabilities.

> "The arrival of the first aircraft was a dramatic and emotional scene. The noisy camp hushed when the sound of arriving airplanes was heard. At first most of the refugees rushed for cover, thinking the humming engines heralded a reappearance of Saddam's air force. However, when no bombs began falling, eyes focused upward and followed a lumbering C-130 as it slowly circled the camp. A roll of toilet paper thrown from the plane tested wind direction. Suddenly, a series of large objects dropped from the plane's tail section. The fearful Kurds were astounded when gigantic white parachutes blossomed and bundles of food floated to the earth. The hungry people mobbed the drop zone and each scrambled to capture one of the small brown plastic MRE packets. Despite the confusion on the ground, the lack of a distribution system, and poor understanding about the proper use of MRE rations, the Kurds in the camp realized that someone was helping them" (Doctor Marcel Bonnot, French Ministry of Foreign Affairs).

The quotation above illustrates the impact aerial logistical resupply can have on a population in desperate need of humanitarian support, which this research thesis will elaborate on later when discussing the potential benefit of advanced delivery systems when used to provide relief to disaster areas. The United States conducted similar humanitarian relief operations during Operation Provide Promise in Bosnia between 1993 and 1995 and Operation Unified Response in Haiti in 2010. From this brief historical overview, this research thesis will move into why high altitude is critical in our COE with ongoing operations in support of Operation Enduring Freedom (OEF).


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## Section 2.2 – Why High Altitude is Critical in our COE

Following the attacks on September 11, 2001, the United States initiated OEF in its quest to eliminate Al Qaeda and defeat the Taliban in Afghanistan. As part of OEF's strategy to demonstrate to the Afghan people that the US's fight was not aimed at the Afghan people, the US airdropped food the same night as kinetic strikes were initiated against enemy forces throughout the country (Carrabba, 2004). C-17 cargo planes, flying from Ramstein AFB in Germany, flew 175 sorties dropping over 2.4 million Humanitarian Daily Rations (HDR) between 7 October and 21 December 2001 (Carrabba, 2004). Although the goal of this humanitarian drop was aimed at providing relief to the Afghan people, the operation largely failed as the HDR packages shattered upon impact with the ground causing the food to spoil. The USAF conducted the HDR drops from above 25,000 feet using the Triwall Aerial Delivery System (TRIADS). The TRIADS is a system used to airdrop Meals Ready to Eat (MRE) and HDRs by loading them in cardboard boxes. The boxes are opened up by a static line after they are dropped without a parachute. This became an airdrop technique due to the rapid depletion of parachutes prior to its development. An additional unintended consequence of the HDR drop was that the yellow package of the HDR mirrored the yellow color of BLU-92 cluster bombs leading to several civilian casualties in the local population's attempt to find food (Neuffer, Boston Globe, 2002).

Since the beginning of OEF, the International Security and Assistance Force (ISAF) has conducted thousands upon thousands of aerial resupply operations, which have been extremely challenging and at times unsuccessful due to inaccuracy and increased complexities when dealing with challenging terrain, weather conditions and an ever increasing counterinsurgency fight. CDS drops from a high altitude are typically inaccurate and are not ideal when operating in restrictive terrain, which led to the development of an alternative means of resupply known as the Low Cost Low Altitude (LCLA) system. The LCLA is a more precise means of delivery; however, the drop must occur at lower altitudes, which places the aircraft at greater risk, and the package size is much smaller leading to an increase in sorties to deliver the resupply request. Other means include sling load operations, which require a dedicated rotary wing aircraft and also places that aircraft at increased risks. It also dedicates assets to logistical resupply when the rotary wing aircraft could be used in a more effective manner supporting Counterinsurgency (COIN) operations in other parts of the country.

As one can see, aerial logistical resupply in support of Operation Enduring Freedom has become a critical component of achieving our objectives by ensuring the forces on the ground have the supplies and equipment required to complete the mission.

**Figure 3: A C-130 Hercules drops supplies to International Security Assistance Forces assigned to Forward Operating Base Sweeney, Zabul Province, Afghanistan. (airforcetimes.com)**

During the first four months of 2011, the USAF dropped over 25 million pounds of supplies and exceeded 60.4 million pounds over the course of the year in both Iraq and Afghanistan (Larter, 2011). This discussion explains why high altitude is critical in our COE and why we must improve this capability to support our current efforts in OEF. In the next section, current airdrop procedures



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and factors impacting those efforts are discussed.

## Section 2.3 – Factors Impacting Current Airdrop Procedures

Under current procedures for CDS airdrops, air crews must use methods such as sight angle, visual reference, onboard procedures and CARP calculations in order to reach the intended Release Point (RP) (AFI 11-231, 1998, pp. 24-33). During the conduct of these operations, the CARP calculation is critical as it incorporates several key variables such as exit time, the deceleration time, the time of decent and the wind effects on the package (See Figure 4). Once the aircrew completes all the required calculations, the Mission Planner (MP) determines an estimated RP in reference to the desired Point of Impact (PI).

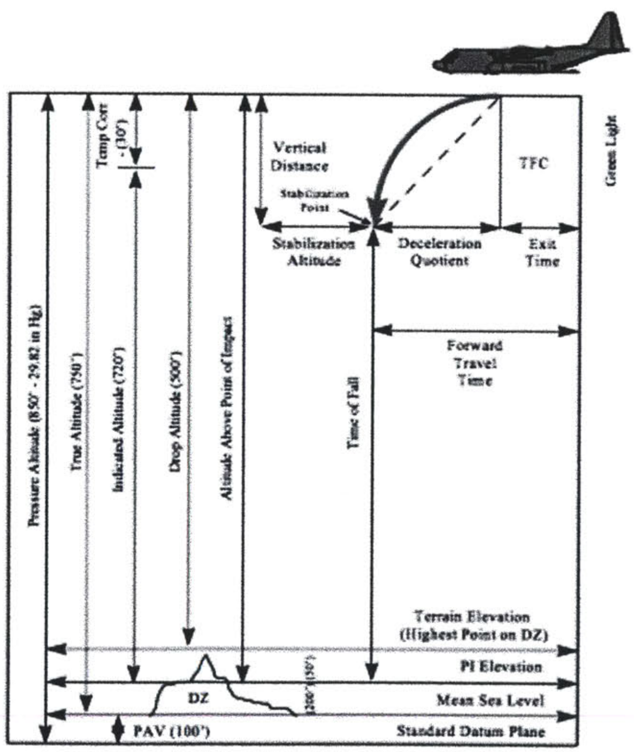


**Figure 4: CARP Diagram (AFI 11-231, 1998, pp. 13)**



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Conducting an aerial resupply mission from high altitude is much different than conducting one at a low altitude for several reasons. These differences include variations in aircraft performance, load time decent, oxygen considerations, airspeed, regulatory guidance and restrictions and air density (Carrabba, 2004). With the understanding that aircraft performance will vary with changes in altitude, it is important to note that the thinner, less dense air makes the aircraft appear heavier with a reduced performance leading to an increase in power required to maintain airspeed and altitude.

> "Because of the thinner air, the aircraft has a higher true airspeed to maintain a flying indicated or calibrated airspeed. The higher true airspeed translates to a high groundspeed so the aircraft is traveling a greater distance which will amplify exit time errors. At sea level, the aircraft is traveling 75-85 meters per second. At high altitude, the aircraft is traveling 100-140 meters per second. A 1 or 2 second delay in release time can have a large impact on the release point accuracy" (Carrabba, 2004, pp. 13-14)

The Total Time of Fall (TTF) of the airdrop package is the Time of Fall Constant (TFC) plus the Time of Fall (TOF) of the package, which changes dramatically as the altitude increases. For example, a 1,500 lb. High Velocity CDS bundle dropped from 800 feet Above Ground Level (AGL) has a TTF of 10.1 seconds and that same package dropped from 25,000 feet AGL has a TTF of 290 seconds, which is almost five minutes (Carrabba, 2004). With an increase in the TTF, there is a significantly greater wind and drift impact placed on the package, which will decrease the accuracy and increase variation on the PI. An additional challenge of TTF at a higher altitude is the desired Time on Target (TOT), which is when the aircrew calls a "Green Light" for the release of the load. This works fine when the ground forces can see the aircraft overhead; however, this becomes a much greater challenge when the ground forces cannot see the aircraft due


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to the high altitude nature of the drop. The higher the altitude, the longer ground forces will have to wait for the delivery of the package, which could have operational consequences.

Another important component in aerial resupply operations is airspeed. The aircraft will fly a specific airspeed as required by the performance manuals specific to the kind of airdrop operation the crew is conducting. As the aircraft gets higher in altitude, the True Airspeed (TAS) increases from the airspeed at sea level due to the changes in air density with the air becoming less dense at higher altitudes. TAS increases about 3 knots for every thousand-foot increase in altitude, so at 10,000 MSL, 150 Knots Indicated Airspeed (KIAS) is about 180 TAS. At 20,000 feet MSL, the TAS increases to 210 and at 30,000 feet MSL the TAS increases to 240 (Carrabba, 2004). The reason the TAS calculation is important to understand is as the TAS increases, the opening shock of the package as it exits the aircraft increases significantly and could cause the parachute system to fail if not designed to the correct specifications. A CDS drop executed at 30,000 feet MSL places an enormous amount of stress on the package and requires a specially designed parachute system to take the opening shock, or the system risks operational failure.

Lastly, the Forward Travel Time (FTT) is the time when the aircrew illuminates the green light in the aircraft to indicate the window of opportunity to release the load. This time is typically between 4.1 and 7.9 seconds for CDS drops from both C-130s and C-17s (AFI 11-231, Ch 8 and 9). The aircraft is moving between 80-120 meters per second without analyzing and incorporating the impacts of wind. When the TAS


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increases, the distance increases and is a contributing factor to accuracy challenges with CDS drops, particularly if there is a tailwind situation (Carrabba, 2004).

## Section 2.4 – Introducing the JPADS

The Joint Precision Airdrop System exists to deliver cargo to service members deployed in hostile terrain where conventional means of resupply are ineffective in a manner that is precise and accurate. Originally, the JPADS concept evolved as a result of a 1996 report from the USAF's Scientific Advisory Board (SAB) titled *New World Vistas – Air and Space Power for the 21$^{st}$ Century* (Sweetman, 2001). The SAB predicted the USAF would have the capability to deliver cargo from an altitude above 20,000 feet with an accuracy between 10-20 meters. This prediction is becoming a reality and the JPADS aims to do just this. Figure 5 above

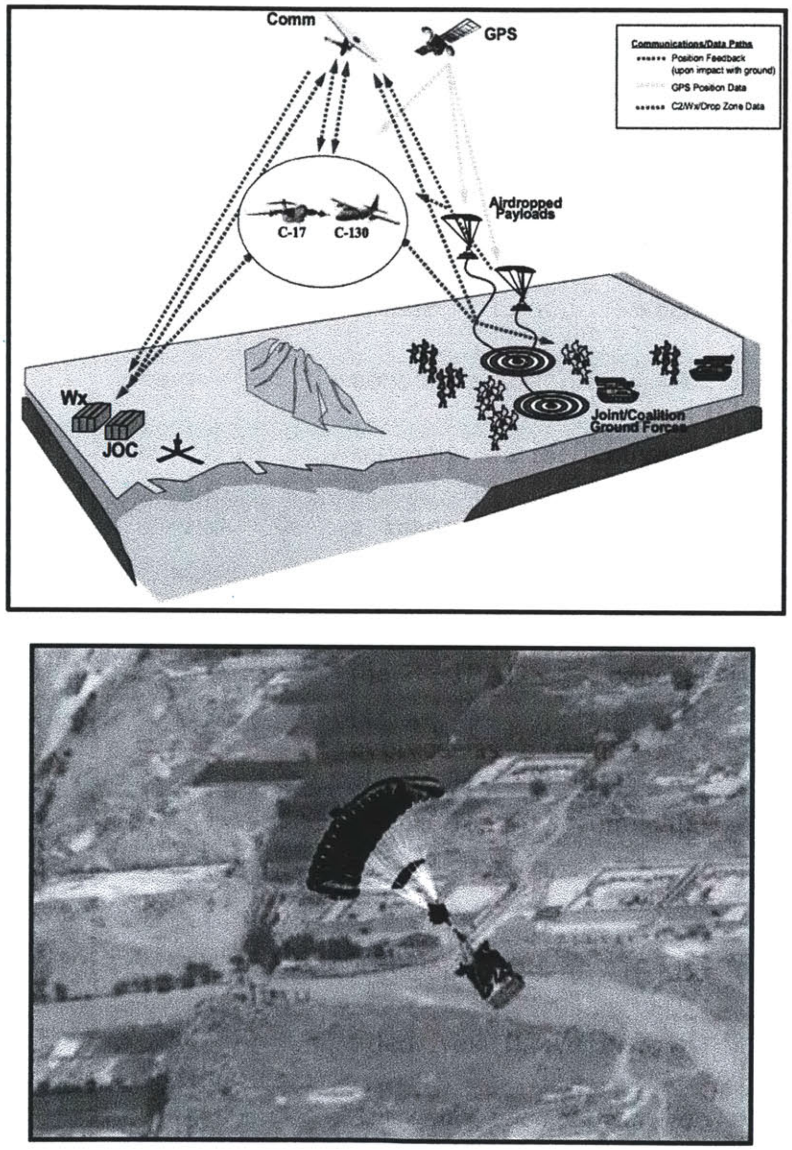


**Figure 5: The JPADS Concept of Operations Diagram and Visual of JPADS in Flight (Benney, et al., 2005)**


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illustrates the JPADS Concept of Operation (CONOP) and will give a good frame of reference on what this system intends to do. From the CONOP, the mission of the JPADS is to execute logistical resupply operations using fixed and rotary wing air in a safe, effective and precise manner in order to deliver supplies and equipment to intended recipients at multiple locations on a single mission in hostile or restricted terrain. In the ensuing chapters, the research thesis will move into the JPADS stakeholder analysis and system decomposition in order to begin a rich analysis of the system.



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# Chapter 3: JPADS Stakeholder Analysis

## Section 3.1 – Stakeholder Analysis Overview

In this chapter, the research thesis will cover an in-depth stakeholder analysis beginning with the identification of the primary beneficiary and stakeholders for the JPADS. Following this discussion, the thesis will move into a discussion on the stakeholders and their needs, which will elaborate on whether the stated needs are beneficial or charitable needs. In the sections following, the paper will cover stratification of stakeholder needs, value flow within the JPADS enterprise and prioritizing the needs of the individual stakeholders. A thorough stakeholder analysis will prepare the audience for further examination when the research thesis moves into Chapter 4, which will cover the systems architecture of the JPADS.

## Section 3.2 – Identification of Primary Beneficiary and Stakeholders

As we know, the JPADS exists to deliver cargo to service members deployed in hostile and restrictive terrain where conventional means of resupply are ineffective. A beneficiary can be generalized as anyone with a stake in a venture, which leads to the stakeholders of the system. Figure 6 below shows the stakeholders for the JPADS 2K variant. Beneficiaries have needs, which are project attributes defined as a necessity. It is an overall desire, want or wish for something that is lacking (Crawley, 2011).

"Benefit is driven by function externally delivered across the interface (Crawley, 2011)." Benefits are directly related to costs and a good architecture delivers benefits at a



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competitive cost, which the JPADS aims to do. The JPADS problem statement is as follows: how to execute logistical resupply operations using fixed and rotary wing air in a safe, effective and precise manner in order to deliver supplies and equipment to intended recipients at multiple locations on a single mission in hostile or restricted terrain. The direct beneficiaries are the soldiers on the ground (labeled "blue forces" in Figure 7) that receives the bundles containing mission critical supplies and equipment, as they are the fundamental stakeholders of the system. The primary benefit that flows to them are the

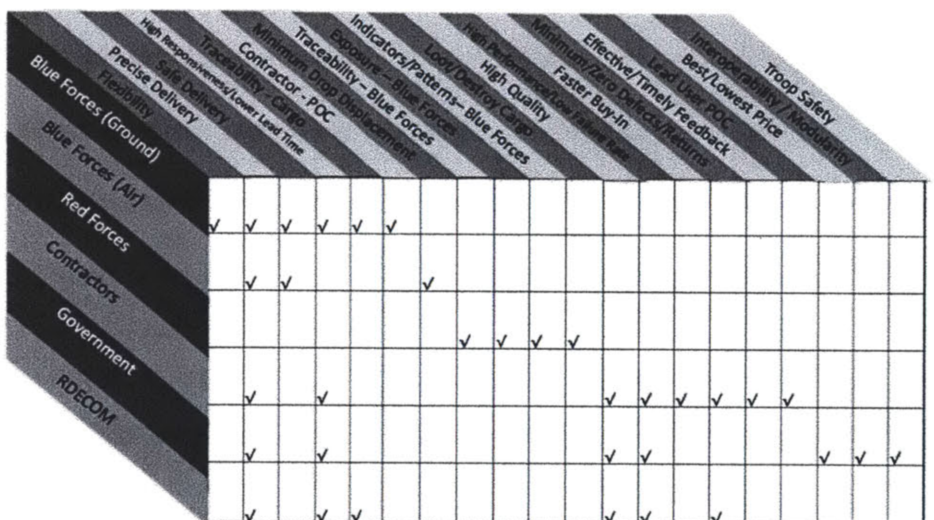

**Figure 6. JPADS Stakeholders**

supplies and equipment that allow the unit to complete the mission. Indirectly, and possibly directly, the resupply through the JPADS facilitates the completion of the mission. Below is a graphical articulation of the JPADS Concept of Operations (CONOP), which shows the key stakeholders of the system within the boundary established.


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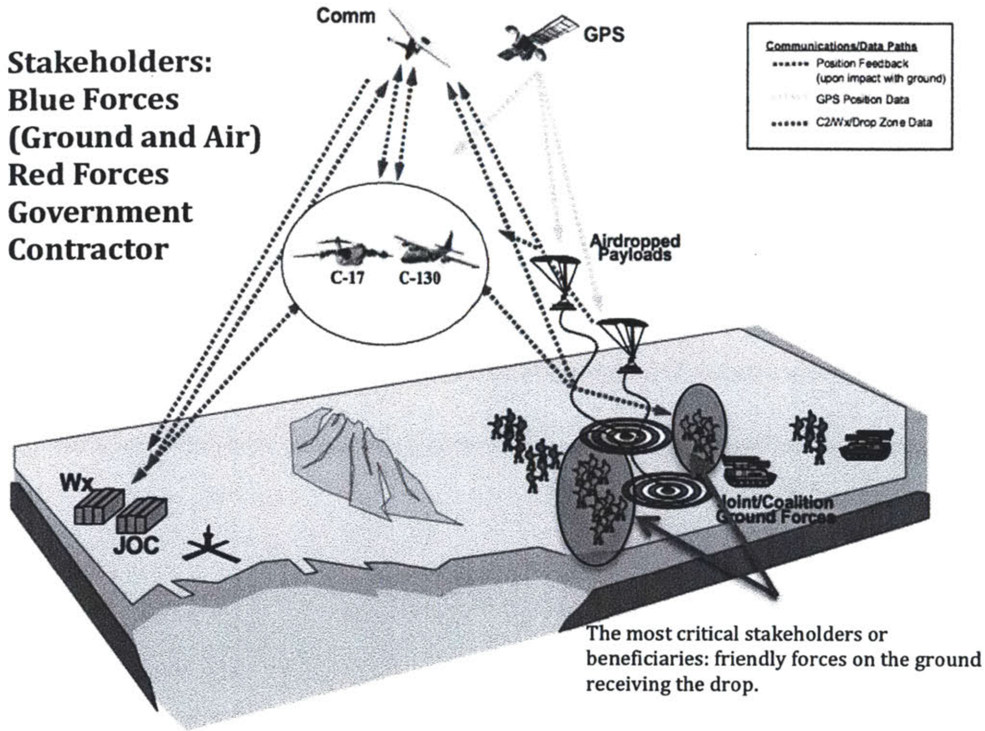


**Figure 7. Stakeholders within the Concept of Operations, (U.S. Army Natick Soldier Research, Development and Engineering Center, Aerial Delivery Overview, 2010)**

Other non-primary benefits are shown above in Figure 6 along with the other stakeholders of the system, encompassing the indirect beneficiaries with the benefits that flow to them. These benefits include, but are not limited to, financial gain, name recognition, future contracts awarded and mission accomplishment.

In March 2011, Boeing subsidiary Argon ST in Fairfax, VA won a $45 million contract to lead the procurement, testing, delivery, training, and logistical support of the JPADS-Ultra Light-Weight variant (ULW) (JPADS, 2011). Although Argon ST is not the direct beneficiary, the company is a vital stakeholder for the JPADS. The JPADS is a small subsystem within the larger military context. Guided systems and aerial resupply have a long development history. The publically familiar Joint Direct Attack Munitions (JDAMS) for guided munitions was a precursor to the JPADS system, and the Low-Cost,



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Low-Altitude (LCLA) system has been used for close-to-ground parachute drop resupply. The overall system description, to safely and accurately deliver a package from the air to the stakeholders on the ground in support of current operations, drives the key needs, goals, function, and form, which this thesis will address in detail in subsequent chapters. Existing military systems provide boundaries for the model of the JPADS system.

The driving model for the JPADS system is the top-level specification, providing a list of stakeholder needs, goals of the system and boundary description of forms and function. This is an incomplete model. For example, although the requirement does not specify form directly, boundaries of form are inferred by aircraft interoperability and cargo harness configurations. Most documents in the public domain for JPADS contain further descriptions of form, using sketches and block diagrams used to illustrate the critical interfaces of the existing, larger package delivery system. Sketches, providing an overview of system expectations, generally represent function. Again, a discussion on function and form with regards to the JPADS system architecture will be elaborated on in detail in the next chapter; however, it is important that we briefly address the model here during our stakeholder analysis.

With respect to models used, the key system descriptor is "safely." Military planes at high altitude are considered safe, at this time, from low-intensity asymmetric threats. A program description model will provide estimates of safe ranges. The key interactions of

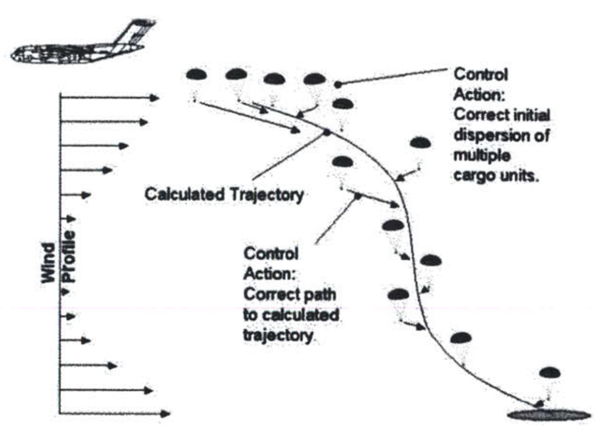

**Figure 8. A sample sketch to describe the function of the system (U.S. Army Natick Soldier Research, Development and Engineering Center, Aerial Delivery Overview, 2010).**


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the technical system are shown via this model. A program description model is used for the sociotechnical interaction, that of the stakeholder in the air and the stakeholder on the ground, connected by the JPADS technical system.

## Section 3.3 –Stakeholders and their Needs

The primary stakeholder or beneficiary for the JPADS is the ground-based Soldier who depends on the system for mission-essential equipment and supplies and life-supporting cargo. Other stakeholders in the enterprise are the US Air Force, Defense

| Stakeholder | Needs | Beneficial / Charitable? |
|---|---|---|
| Ground Soldiers / Marines **(Primary Beneficiary)** | Cargo, Precise Delivery | Beneficial |
| US Air Force **(Beneficiary)** | Safety (defined as distance from enemy forces), Reduced number of sorties, JPADS Components Recovered, System standardization. | Beneficial |
| Combatant Commanders **(High Leverage Stakeholder)** | Troop Safety, Tactical military objectives met, funds, system interoperability | Beneficial |
| US Army Research Development and Engineering Command | Clear statements of needs from the services, system components built to specifications, system components, funds | Beneficial |
| Defense Contractor **(High Leverage Stakeholder)** | Clear articulation of specifications, funds, user feedback, technology for component integration | Beneficial |
| Other Military Airspace Users | Airspace deconfliction | Charitable |
| US Government **(High Leverage Stakeholder)** | Strategic Military Objectives met, High Quality / Lowest possible cost equipment, Troop safety, Public Support (votes) | Beneficial |
| Enemy Forces **(Potential Loser)** | Location of Ground Soldiers and Marines, Reduced effectiveness of soldiers and marines. | Charitable |
| Indigenous Population / *Society* | Non-destructive cargo delivery, humanitarian-type cargo | Situationally dependent: Charitable/ Beneficial |
| Coalition Partners | Technology / Capability Sharing, Interoperability | Beneficial |
| American Public (taxpayers) *Society* | Security | Subjective: Problem/ Beneficial |

**Table 1: Stakeholders and their Needs.**

Contractors, the US Government, and the US Army's Research, Development, and


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Engineering Command (RDECOM), which acts as the program's manager and lead integrator. The specific needs of the stakeholders are detailed in Table 1, above.

***Needs of the Enterprise: As a Stakeholder:***

For the JPADS enterprise, the value proposition or need is to integrate the capabilities of the enterprise's stakeholders to accurately deliver materiel required by the intended recipient at the point of need in a manner that minimizes the hazards associated with delivering and receiving the cargo.

***Stakeholder Segmentation:***

The most practical method of segmentation for this set of stakeholders is to create groups of stakeholders with similar interests. The stakeholders identified in Table 1 may be grouped as follows:

• ***Segment 1***: The American government and the American public. These stakeholders, for the purpose of JPADS, are the bill payers. Through taxation, the government collects revenue from the people for the provision of the national defense, from which it allots funds annually for the military to operate and purchase equipment. In exchange for revenue, the public expects security from the government; and the military, as a tool of the government, provides that security.

• ***Segment 2***: The Military. The Combatant Commanders, the ground forces and the Air Force are linked by the common purpose of achieving the government's strategic objectives. Each stakeholder has a very specific role in this endeavor, and they must exchange value in order to achieve their goals (vice acting as independent entities who


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are not mutually supporting). This segment requires the support of Segment 3, the Material Developers, to provide the equipment necessary for military success and the fulfillment of the government's strategic goals.

• ***Segment 3***: Material Developers. The Research, Development, and Engineering Command (RDECOM) works with contractors, such as Argon ST and Atair Aerospace, to develop, test and deliver sustainable equipment to the military in accordance with the military's needs. The RDECOM develops new technologies and works with the contractors to evolve the technology into producible and usable platforms. These efforts are undertaken often with the nation's coalition partners for the purpose of technology/capability exchange and battlefield interoperability. The government regulates this process because it is in this exchange where taxpayer money is spent.

It is important to understand that although the RDECOM is a part of the military, they are placed in this segment according to the role that they play in the process. They are not a part of the warfighting effort directly, but instead provide material support to the warfighter.

• ***Segment 4***: Battlefield Partners. The Coalition Partners and other users of the military airspace make up the fourth segment of our stakeholders. These groups are also located on the battlefield, but during combat operations they do not provide any benefit to the rest of the enterprise as it applies to JPADS. Airspace users benefit from the reduced number of cargo planes in the airspace and more so from the reduced number of parachutes in the air during combat operations. Because of its precision, JPADS reduces air traffic, which directly benefits everyone in the airspace. It is for this reason that this group is a charitable stakeholder. The coalition partners assist in technology



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development, and may use JPADS in their own operations, but for the purposes of resupplying American ground forces, they do not play a direct role.

• ***Segment 5***: Other potential beneficiaries. Both the indigenous population of the area where combat operations are occurring and the enemy forces may be charitable beneficiaries of the JPADS. Neither group assists in the development or deployment of JPADS, but each may gain some particular benefit. For the indigenous population, JPADS may be used to deliver humanitarian aid to the point of need when access to their location is not possible or practical by ground vehicle. The enemy forces may intercept cargo delivered by the JPADS if the system deviates from its course, but more likely, the benefit gained by enemy forces is a precise location for ground forces executing resupply operations, which will facilitate deliberate operations against friendly forces. Since the JPADS delivers the cargo exactly where it is needed, the enemy can simply watch where the parachute goes and follow it to the ground forces.

## Section 3.4 –Stratification of Stakeholder Needs

In a military enterprise, particularly during the conduct of combat operations, the characterization of needs is most often conducted according to the intensity of the need; generally weighting the needs of the ground forces highest, as prioritized by the Combatant Commander. A close second is the US Air Force's needs, again prioritized by the Combatant Commander.

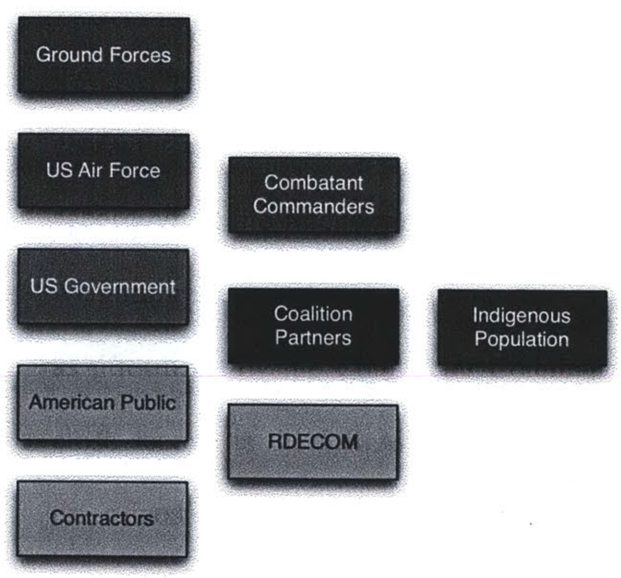


**Figure 9. Stratification of Stakeholder Needs.**



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Following the needs of the warfighters, the intensity of needs flows down from within the power of the checkbook.

Because of this stratification of needs it would be incorrect to consider all the stakeholders on the basis of needs that must be considered and/or met when serving the needs of the warfighter. Instead, it is preferable to consider the needs of other stakeholders in their relative importance to that of the warfighter and budgeting power as shown in Figure 9 above. The US ground forces' needs rank highest because of their proximity to danger on behalf of the US Government and its citizens.

The needs of the US government, the coalition partners and the indigenous population are remarkable because they represent the will of sovereign nations that must defer to the needs of others, whether by choice or by default. In most cases, the US government defers to the needs of the ground forces due to its relationship with the American public and need for public support. This contract with the military is not absolute, but is the rule rather than the exception, so we place the needs of the government below the US military.

The needs of the coalition partners and indigenous population are placed in Figure 9 just below that of the US Government because each group represents a relationship that must be maintained for various reasons. In short, the US government and its proxy, the military, are best served in the short and long term by giving careful consideration to the needs of other states and their citizens.

The lower tiers are positioned according to the budgetary power. Contractors fall at the bottom of the list because where there is money and a need, there will be a business that seeks to fill that need. It is here that we see the effect of competition among


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suppliers affect the enterprise. Because of competition for government contracts and the typical size of government contractors, the winner of the contract generally maintains its position for years in both the manufacturing and sustainment of various systems. Once the flow of information, money and materiel to a contractor is established, they are seldom changed during the life of the system. Figure 10 below illustrates the flow of materials, technology, information and money for the JPADS system and shows the interconnectedness of multiple stakeholders within the JPADS enterprise.

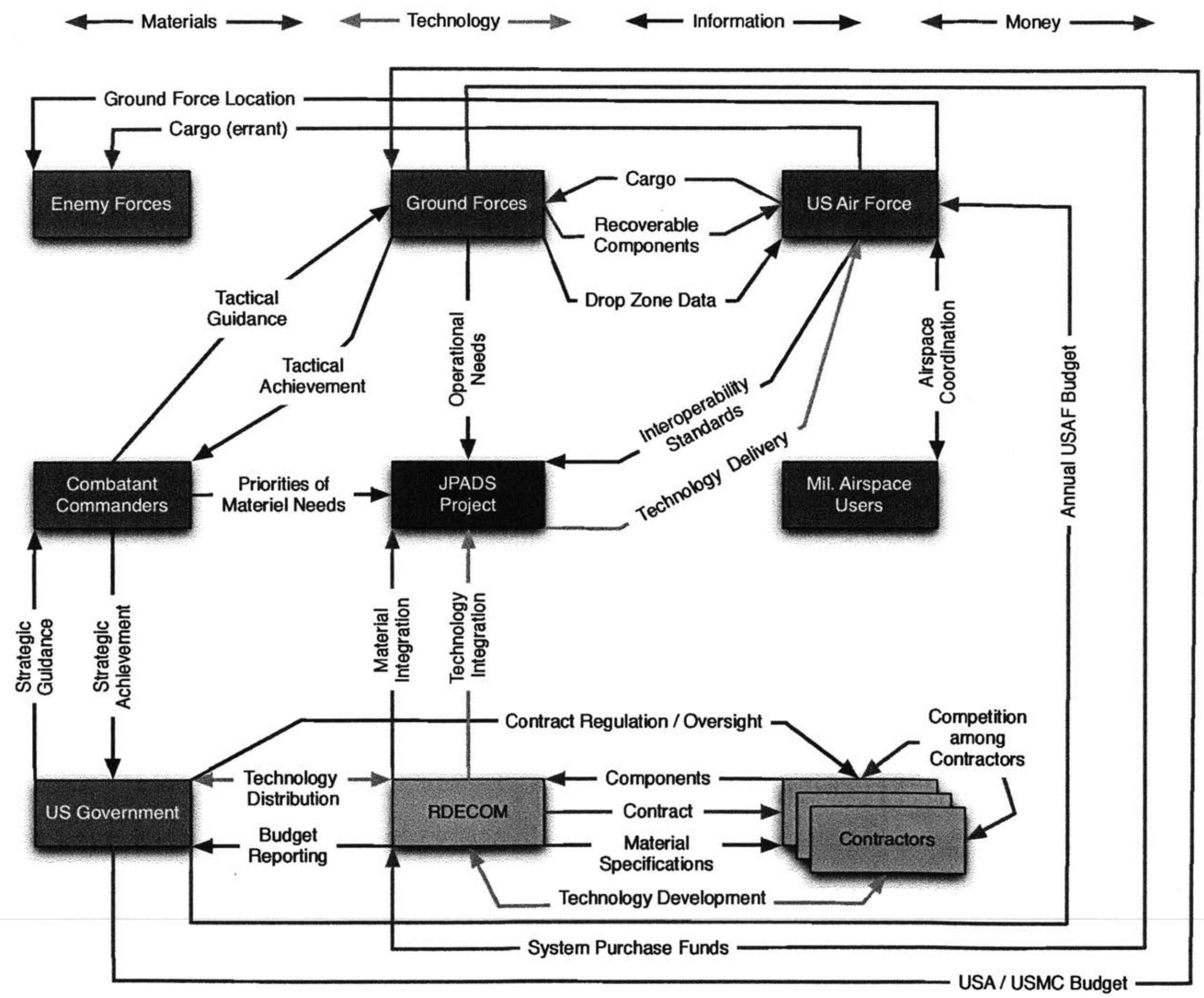


**Figure 10. Stakeholder Value Exchange Map: Value Flow within the JPADS Enterprise (JPADS Architectural Analysis Project)**



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## Section 3.5 –Prioritizing Needs of Individual Stakeholders

| JPADS Need | |
|---|---|
| **Stakeholder** | **Need Intensity** |
| Ground Soldiers/Marines | 3 |
| US Air Force | 3 |
| Combatant Commanders | 2 |
| Contractors | 2 |
| RDECOM | 1 |
| US Government | 1 |
| Coalition Partners | 1 |
| American Public | 0 |

**Table 2: Need for the JPADS System**

As stated above, the needs of all stakeholders in this enterprise are secondary to the needs of the ground Soldier. Because of this, we will put greatest emphasis on the "Intensity of Need" in our analysis, ranking each of the warfighting elements as a *three* (of a possible three) on our Need Intensity Table (Table 2), which ranks the stakeholders' relative needs for the value delivered by the system as a whole. As an example, the contractors need the JPADS system because they will derive value for themselves through creating value for the enterprise. Their lives do not depend on the existence of the system, so they cannot have as high of a Need Intensity as the Soldier. The American public ranks 0 in Need Intensity, since they are ambivalent to the means of resupplying the ground forces, so long as the job is done and the Soldiers receive what they need to complete the mission.

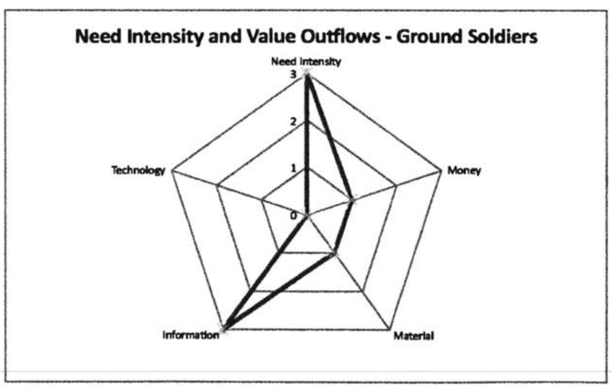


**Figure 11. Need Intensity and Value Outflows of Ground Soldiers to the JPADS Enterprise (JPADS Architectural Analysis Project)**

Using Need Intensity as a starting point for comparing the relative importance of the stakeholders' needs within the JPADS enterprise, we next determine the overall worth of the stakeholders to the enterprise. We do this by measuring how much stakeholder value for exchange is



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generated by each. It is reasonable to infer the worth of a stakeholder relative to the others this way, because if a stakeholder is generating value for the others, then there must be a need within the enterprise that the stakeholder is filling. This is done by comparing the outflows (Refer to Figure 10) and plotting the raw number of flows from each stakeholder as shown in Figure 11.

When we compare Figures 10 and 11 and Table 2, we can see that the ground Soldier has the highest level of Need Intensity; they have one outflow of money, one outflow of material and three outflows of information to the rest of the Enterprise. The outflow of money is to RDECOM to allow RDECOM to acquire the system, and the outflow of material is to the Air Force in the form of reusable components. The ground Soldier provides information to the enterprise by providing the Air Force with system

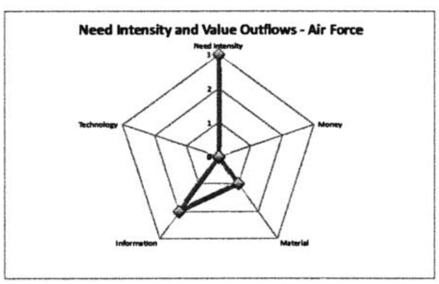


**Figure 12. Air Force Need Intensity and Value Outflows. Value outflows to Enemy Forces have been removed, as they are not constructive for the enterprise.**

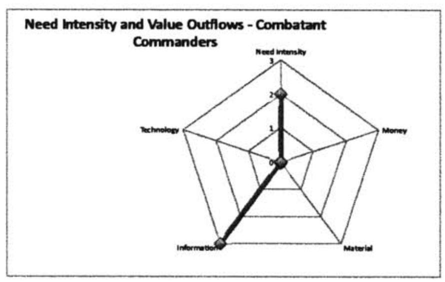


**Figure 13. Combatant Commanders' Need Intensity and Value Outflows.**

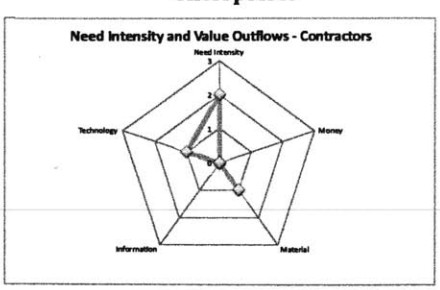


**Figure 14. Contractors' Need Intensity and Value Outflows.**

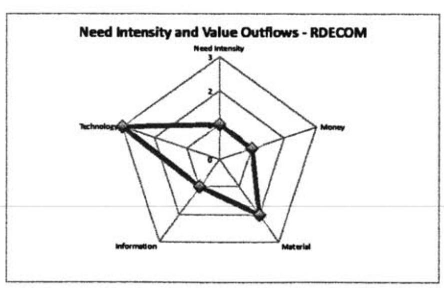


**Figure 15. RDECOM Need Intensity and Value Outflows.**



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deployment data, the JPADS project with operational needs data and the Combatant Commander with tactical achievements.

Using this technique we can compare the graphical representation of the overall stakeholder worth to the enterprise. We will make this comparison in Figures 12 through 16.

We can see in the comparison of Figures 11 through 16, RDECOM and ground Soldiers provide the most value to the enterprise's other stakeholders. Although RDECOM has the lowest need for the system among those compared, its needs must be met so that it can provide the required value for the rest of the enterprise. This comparative analysis, carried through to the rest of the stakeholders, yields the ranking of stakeholders by needs importance, which is relative to the enterprise shown in Table 3.

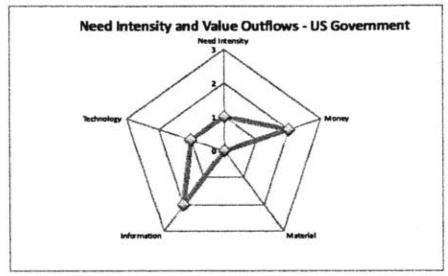


**Figure 16. US Government Need Intensity and Value Outflows (JPADS Architectural Analysis Project)**

**Needs Importance**

| | |
|---|---|
| 1 | Ground Soldiers |
| 2 | RDECOM |
| 3 | US Air Force |
| 4 | US Government |
| 5 | Combatant Commanders |
| 6 | Coalition Partners |
| 7 | Contractors |
| 8 | American Public |

**Table 3. Needs Importance Among Stakeholders.**

If we assume that a stakeholder cannot generate the value required for the enterprise without the enterprise providing the requisite value for that specific stakeholder, then it follows that the inflows of value to the most important stakeholder are the most important to the enterprise. Conversely, needy stakeholders, defined as those whose value inflow:outflow ratio are high, are those whose needs are least important, relative to the other stakeholders.


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***Prioritizing Needs of Individual Stakeholders:***

Regarding the prioritization of needs within individual stakeholders, we must consider the impact of each need on stakeholder value generation for the enterprise's delivery on its overall value proposition. Likewise, we must consider the fulfillment of individual stakeholders' needs by the importance of that need for fulfilling the individual stakeholders' needs and that of their shareholders. The prioritized list follows in Table 4 below. The validation of needs ranking within the individual stakeholder organizations can only be accomplished by the stakeholders themselves in accordance with their corporate strategy and expectations of the shareholders.

**Table 4. Importance of Needs by Stakeholder**

| Stakeholder Rank (by Importance of Needs) | Stakeholder | Needs (Ranked Internally per Stakeholder) |
|---|---|---|
| 1 | Ground Soldiers / Marines<br>**(Primary Beneficiary)** | 1. Cargo<br>2. Precise Delivery |
| 2 | RDECOM/JPADS Project | 1. Operational Needs Statement<br>2. Money for the Project<br>3. Components built to spec<br>4. Interoperability Standards<br>5. Technology Development |
| 3 | US Air Force<br>**(Beneficiary)** | 1. Drop Zone Data<br>2. Annual Budget (for Operations)<br>3. Interoperability.<br>4. JPADS Components Recovered for re-use<br>5. Technology Delivery |
| 4 | US Government<br>**(High Leverage Stakeholder)** | 1. Strategic Achievement<br>2. Budget Reporting<br>3. Technology Distribution |
| 5 | Combatant Commanders<br>**(High Leverage Stakeholder)** | 1. Tactical military objectives met<br>2. Strategic Guidance |
| 6 | Defense Contractor<br>**(High Leverage Stakeholder)** | 1. Material Specifications<br>2. Funds for production<br>3. Technology Sharing<br>4. Contract Oversight |



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## Section 3.6 –Stakeholder Analysis: Final Thoughts

The JPADS is a vital system designed at ensuring Soldiers operating in an austere and mercurial environment receive mission critical supplies and equipment in a precise and timely manner to complete their mission. Important to fully understand the JPADS is a clear analysis of the stakeholders of the system, which drive decision making within the enterprise. This investigation aimed to provide a rich and thorough stakeholders analysis as a basis for an in-depth systems architecture study, which will follow in Chapter 4.


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# Chapter 4: JPADS System Architecture Analysis

A good architecture is one that meets the needs of the stakeholders in a satisfactory manner and one that doesn't violate the accepted principles of systems architecture. A suitable architecture is also one that abides by the respective "ilities" that apply to the architectural design, such as maintainability, interoperability, customizability, understandability, to name a few. These apply directly to the architecture's maintenance, evolution, further development, refinement and improvement, as the stakeholders require (System Architecture, 2011). In this and subsequent chapters, the research thesis will provide a detailed systems architecture analysis of the JPADS beginning with the JPADS top level function, the formal decomposition and the JPADS System Problem Statement (SPS). Following this, the thesis will cover the JPADS subsidiary and expanded goals, Level 1 analysis, the high-level concept tree for the JPADS, Level 2 analysis and multiple functional decompositions.

## Section 4.1 – JPADS Top Level Function

The JPADS exists to deliver cargo to service members deployed in hostile terrain where conventional means of resupply are ineffective. When one breaks down the nature of an engineered system, included in this is the Operand and Processing Element of the system, which makes up the system's function while the Instrument Object makes up the system's form, which is termed

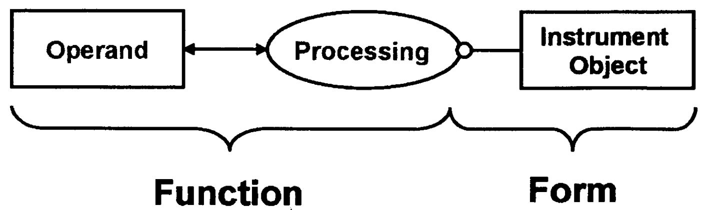


**Figure 17: Process Nature of an Engineered System Illustration (Crawley, 2011)**



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the Instrument Object. Function can be defined as "the activities, operations and transformations that cause, create or contribute to performance" or "the actions for which a thing exists or is employed" (Crawley, 2011). The action that takes place is the process and the object that is acted upon is referred to as the operand. The instrument object is the form and also makes up the elements and structure of the system (Crawley, 2011). An illustration of the process nature of an engineered system is shown above in Figure 17. With regards to the JPADS, the cargo is the system operand while the processing function is "delivers." The instrument object is the JPADS itself, which is illustrated in Figure 18. This shows the JPADS top-level function and will be the basis for further analysis of the system from a systems architectural standpoint.

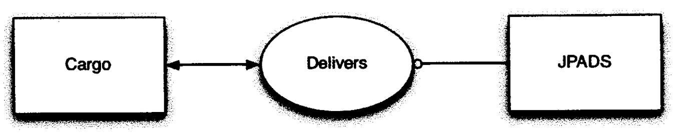


**Figure 18. JPADS Top Level Function**



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## Section 4.2 – JPADS Formal Decomposition

In this section, the thesis will move into the JPADS formal decomposition, which will identify the disparate elements of form that make up the system. These include the aircraft by which the JPADS is released during an operation, the USAF Precision Airdrop System (PADS) computer, which is combined with the Army's Precision and Extended Glide Airdrop System (PEGASYS) program to meet joint requirements in order to conduct a precision airdrop and several other elements in the JPADS formal decomposition, which is illustrated below in Figure 19. The dropsonde is a device

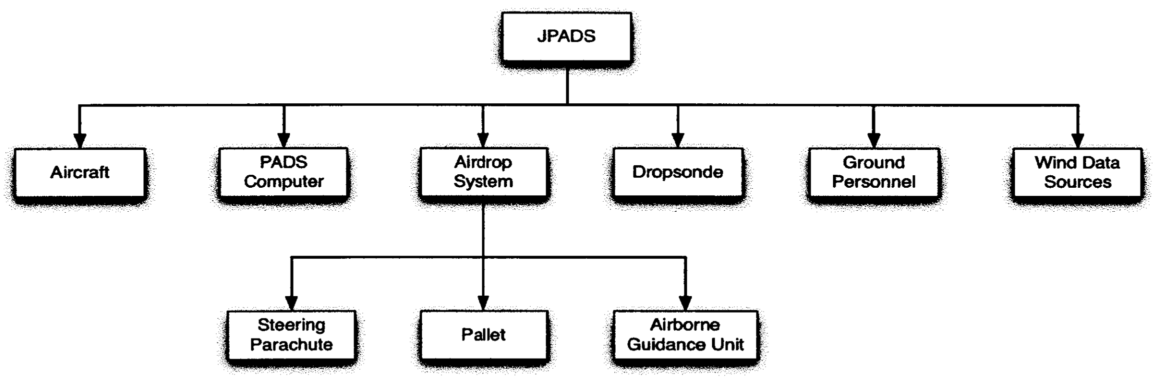


**Figure 19. JPADS Formal Decomposition**

utilized by the JPADS to collect critical wind data and other atmospherics prior to the operation, which assists the MP in planning the route for the JPADS package. The Airborne Guidance Unit (AGU) includes the battery power pack, the Global Positioning System (GPS) receiver, the Guidance, Navigation and Control (GN&C) package and the hardware critical to operate the steering lines in the JPADS to keep the system on course.

The AGU, which uses preplanned data from the MP, data from the PADS component and the GPS retransmission system, acquires its location or position before exiting the aircraft. Once the JPADS acquires its position, the AGU steers the resupply bundle according to the preplanned trajectory to a specific point on the ground, while



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simultaneously making correction in flight through the actuator system on board, which controls the steering lines. As one can see, the JPADS is a System of Systems (SoS) and this research thesis will focus on the top-level decomposition of the elements of form shown in Figure 19. In the next section, the research will move into the JPADS System Problem Statement (SPS) in order to clearly identify the challenge the system aims to overcome.



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## Section 4.3 – The JPADS System Problem Statement

The primary beneficiary and need for the System Problem Statement diagram below are the ground forces or Soldiers operating in restricted and hostile terrain. The reason ground forces are the primary beneficiary is due to the prioritization of the need and the fact that the military's sole purpose to develop a system to meet this need is to fulfill critical requirements of the ground forces. There are several other beneficiaries discussed earlier; however, the ground force is the primary beneficiary. Their stated need is to have critical supplies and equipment transported and delivered to them in a safe, accurate and precise manner without damage. The operand and value related solution neutral transformation is annotated in Figure 20 to the right and identifies the intent, function and form.

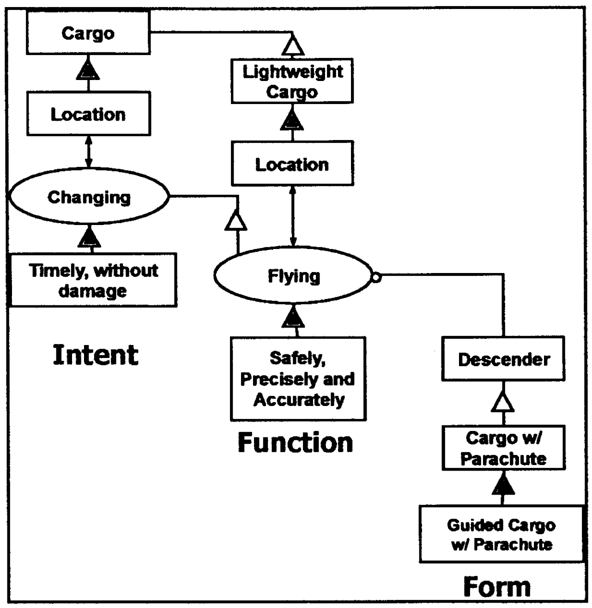

**Figure 20: System Problem Statement: Guided Cargo Parachute System**

The original and existing SPS is to design, manufacture and sell a safe, precise and effective air delivery system to resupply security minded ground forces. The function of this statement is to change the location of the lightweight cargo in a timely manner, without damage, by flying in a safe, precise and accurate manner using cargo with a parachute, which will have the means to be a guided system.

**Our revised SPS is to provide our ground forces a product that will transport their supplies and equipment in a timely manner without damage. They will do so**



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**by flying their lightweight cargo in a safe, precise and accurate manner. This will occur utilizing a guided cargo parachute system.**



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## Section 4.4 – JPADS Subsidiary and Expanded Goals

The system problem statement can be developed, from the prior analysis, into a completed statement, to provide our ground forces a product that will transport their supplies and equipment in a timely manner without damage. They will do so by flying their lightweight cargo in a safe, precise and accurate manner. This will occur utilizing a guided cargo parachute system, which we will call a "descender."

The subsidiary goals apply to all stakeholders within the system, including the primary beneficiary. In this case, the primary beneficiary has needs that could be considered subsidiary, for example, traceability of the supply delivery for the ground forces. This attribute is not specific to the JPADS architecture and could be considered a general attribute for all resupply. One critical goal, which the system must be able to control, is its speed and position while descending. This is more specific to the JPADS architecture. The problem statement becomes more detailed as goals are expanded below, as mapping goals to the system increases the required functions.

The rigidity of the goals is high. The primary function of the JPADS system is precision and accuracy; the goals that map to this function will be measurable and inflexible. The military recognizes variation and typically creates threshold levels of performance. This threshold level can be thought of as the rigid goal. The JPADS goals map to the system as they map to the form and function. Goals of form (compatibility with existing delivery infrastructure) and function (able to control speed and position) provide system boundaries for the architect.


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# **Expanded goals:**

*Criticaly:*

- Must be compatible with existing cargo delivery infrastructure (interoperability)
- Must engage suppliers and contractors in long term stable relationships with good revenue streams to them (mildly constraining, contractor relationship)
- Must accommodate required supplies (constraining, physical dimensions, carrying capacity of the descender)
- Must be able to control its speed and position while descending (constraining, limits to speed and offset)
- Must be traceable by ground forces (constraining, must be able to provide location information)
- Must minimize drop displacement (constraining, distance, accuracy and steering ability of the descender)
- Must be NOT traceable by enemy forces (constraining, secure channels of information exchange)

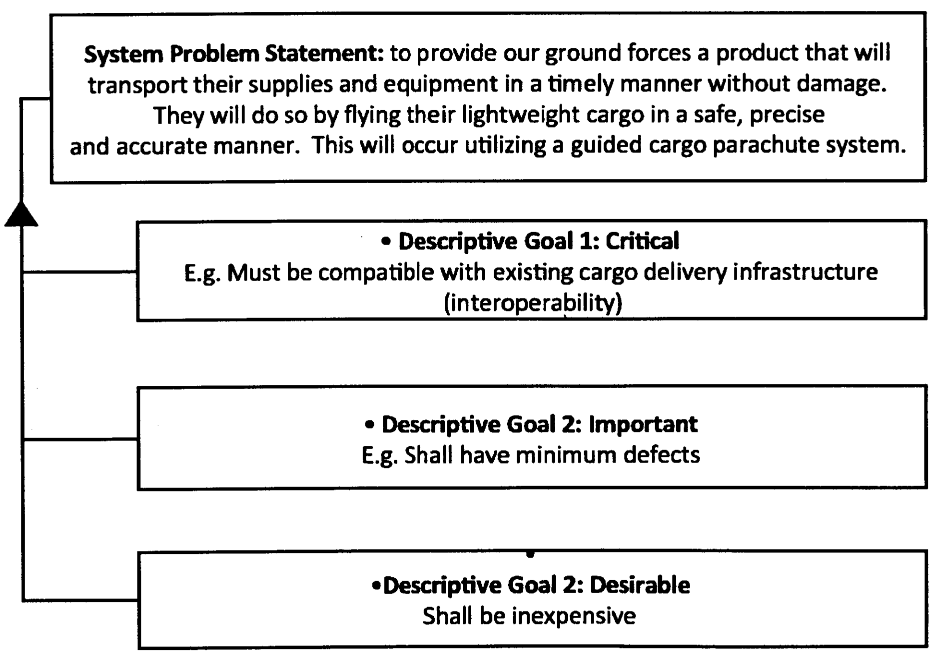


**Figure 21: System Problem Statement with Goals**



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***Importantly:***

- Shall reduce the risk of supply destruction
- Shall have minimum defects
- Shall enhance air force safety (above threshold height for enemy fire)
- Shall reduce exposure of ground forces (drop to safer locations to minimize exposure to enemy forces)
- Shall be easily detachable from cargo (constraining, reuse)
- Shall be recoverable (constraining, reuse)
- Shall have active steering elements to increase precision, accuracy and safety

***Desirably:***

- Shall steer varying weights of cargo (200 lbs. to 20,000 lbs.)
- Shall provide high benefit at a reasonable cost[1]
- Shall be flexible and modular
- Shall provide stable and rewarding employment to contractors and suppliers

Our refined version of goals statements is much more structured and allows for better prioritization. The original set of goals didn't include all the stakeholders listed in the table below. We cannot conclude that our version of goals is better, however, we believe it provides a better way of looking at the needs of the different stakeholders. The table below shows the needs goals and corresponding goals to address those needs.

[1] Stated in Figure 21 as "Shall be inexpensive," which is relative to other more expensive projects in the military. For example, one Excalibur round, which is a munition for the M982 Excalibur Artillery Piece, costs over $85,000. The JPADS runs about $13,000 for the 2K system and there is work to develop a one time use JPADS 2k system for a cost of $5,800 (Palumbo, 2011).



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**Table 5: Stakeholders, Needs and Goals to Address the Needs**

| Stakeholder | Needs | Goals to address the needs |
|---|---|---|
| Ground Soldiers / Marines **(Primary Beneficiary)** | Cargo, Precise Delivery | **Critical:** Must accommodate required supplies, Must be traceable by ground forces, Must minimize drop displacement **Important:** Shall reduce the risk of supply destruction |
| US Air Force **(Beneficiary)** | Safety (defined as distance from enemy forces), Reduced number of sorties, JPADS Components Recovered, System standardization. | **Critical:** Must be compatible with existing cargo delivery infrastructure, Must be able to control its speed and position while descending **Important:** Shall have minimum defects , Shall be recoverable |
| Combatant Commanders **(High Leverage Stakeholder)** | Troop Safety, Tactical military objectives met, funds, system interoperability | **Critical:** Must be NOT traceable by enemy forces **Important:** Shall provide troop safety, Shall be easily detachable from cargo, Shall reduce exposure of blue forces |
| US Army Research Development and Engineering Command | Clear statements of needs from the services, system components built to specifications, system components, funds | **Critical:** Must engage suppliers in long term stable relationships with good revenue streams to them **Important:** Shall have minimum defects **Desirable:** Shall be inexpensive |
| Defense Contractor **(High Leverage Stakeholder)** | Clear articulation of specifications, funds, user feedback, technology for component integration | **Critical:** Shall provide good financial return to contractors |
| US Government **(High Leverage Stakeholder)** | Strategic Military Objectives met, High Quality / Lowest possible cost equipment, Troop safety, Public Support (votes) | **Critical:** Must be traceable by ground forces, Must minimize drop displacement, Must be NOT traceable by enemy forces **Important:** Shall have minimum defects **Desirable:** Shall be inexpensive, Shall provide stable and rewarding employment to contractors and suppliers |
| Enemy Forces **(Potential Loser)** | Location of Ground Soldiers and Marines, Reduced effectiveness of soldiers and marines. | Not addressed here, as our goals are opposite of their needs, and any occurrences when their goals are met shall be considered as failure of our goals. |

The developed goals may or may not be directly testable. In a scientific test, under controlled conditions, multiple airdrops can be performed to establish precision/accuracy, or drop displacement. Supply destruction upon impact can be monitored during the testing. These tests are conducted at the Yuma, AZ proving



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grounds and other locations to establish a repeatable set of data. The controlled conditions can provide insight into accuracy/precision, but there are limits due to the varying specifics of military missions, including the local topography of valleys and mountains in non-similar regions. For example, desert weather changes differently from arctic weather and can significantly affect the aerial drop conditions.

Due to military specifications, interoperability can be tested. Resupply aircraft are somewhat standardized with detailed requirements documents. Once the required aircrafts are defined, interoperability is simple to measure.

Other goals are more complicated for measurement. Reducing exposure of blue forces (friendly ground forces) can be measured through After-Action Reviews (AAR) with ground forces. The military has a system in place for collecting responses from the troops on new technology and its efficacy. Again, the difficulty is comparison of situations. During a crucial situation in the field, the military will be less interested in varying conditions for testing of goals.

***Goal***: Must be compatible with existing cargo delivery infrastructure (interoperability)

***For aircraft***: The JPADS-ULW will be dropped from various aircraft depending on the mission being performed. The JPADS-ULW shall be capable of being airdropped from the aircraft listed below at their respective airdrop speeds per FM 3-21.220 Table 20-1 and A1-V22AB-NFM-000, page I-4-10A (Military Specification Document).

a. C-130 [ULW-044]
b. V-22 [ULW-046]
c. CH-53 [ULW-047]


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It is desired that the JPADS-ULW be capable of being airdropped from the following aircraft:

a. C-17
b. CH-46
c. C-7A Caribou
d. C-23B Sherpa
e. C-27A
f. DC-3
g. CASA-212

This goal is easily testable, as sample flights could validate compatibility and interoperability with both critical/important (shall be capable) and important/desirable (it is desired) goals. All the goals are consistent, attainable and humanly solvable. There are no conflicting goals, except for the pressure to have inexpensive, but profitable to defense contractors, delivery systems.

Critical goals are validated by the military when the system is being developed and then delivered through a number of tests and checkpoints throughout the whole project. Important goals are sources of negotiation during the project and are generally attainable by iterative testing and field-testing. Desirable features are used as an important input for the next generation systems and are mostly controlled by contractors to ensure they continue to supply the military and block competition.

Since our breakdown of goals into sub goals was made on the basis of stakeholders' needs, we can conclude that if we meet the goals, the needs of the stakeholders will be addressed, at the level of verification of goals. The feedback loop providing validation of the delivered function, and the value of that function, must be closed through an iterative process with the stakeholder, both during development, and after system deployment. Validation of form and function delivery can not be neglected


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by the systems architect, as satisfaction of stakeholder needs can only be complete if needs have been translated to goals properly, goals have been met and stakeholders are satisfied. If the metric is that JPADS delivers 90% of cargo, not all stakeholders will be satisfied, as some ground troops will not receive their supplies, but validation would be completed in aggregate, as the majority of troops would be satisfied and delivery rates could potentially be higher and safer than the alternatives.

As an additional reference, the following chart from a JPADS test document has been included to illustrate the testability of goals within the system. This does not provide the validation loop, which would most likely be supplied by after-action reports with the troops:

| **Criteria** | **Threshold for DT Exit**[a] | **Rationale** |
|---|---|---|
| Altitude | 14 drops w/zero SA at 24,500 ft MSL | IAW KPP 3, with 85% reliability/90% confidence |
| Rigged Weight | Conduct airdrop at minimum, optimal, and maximum[b] values for rigged weight | IAW KPP 6, with matrix of test weights TBD |
| Accuracy | 30 drops with 80% of actual PIs being within 150m of planned PI | IAW KPP 5, with statistically significant number of data points |
| Offset | 14 drops from 8 km offset (zero wind post processed) | IAW KPP 4, with 85% reliability/90% confidence |
| Aircraft Type | 14 drops w/zero SA from C-17[c]<br>14 drops w/zero SA from C-130 | IAW AA 1, with 85% reliability/90% confidence for interface with each aircraft |
| Reuse | 10 drops each on 3 (or more) AGUs and decelerators | IAW AA 15, with statistically significant number of data points |
| Reliability | 28 drops w/zero SA | IAW KPP 2, with 92% reliability/90% confidence |

**Table 6: DT Exit Thresholds (Source: www.jisc.ac.uk/uploaded.../EPICS_ProjectPlan-final_1.0.doc, Accessed on June 15, 2011)**

[a] Test scenarios must use stable design configuration of JPADS
[b] Weight values and test matrix to be determined prior to DT (after technology down select) and documented in DTP
[c] Zero SA with respect to aircraft interface/safety issues
**Specified number of drops assumes no failures.



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In the next chapter, the research thesis will move into the JPADS Level 1 analysis in order to further analyze the architectural development of the system through process mapping.



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# Chapter 5: JPADS System Architecture Level 1 Analysis

## Section 5.1 – JPADS Level 1 Process Mapping

By revisiting the original intent for the system problem statement, the entire intent for Level 0 is determined, shown in Table 7 below. The formulation of the system problem statement from the prioritized stakeholder needs ensures that the goals for the system are consistent with and representative of what is needed most by the stakeholders. Finally, the solution neutral concept for fulfilling the intent is complete, again, in accordance with the prioritized stakeholder needs discussed in Chapters 3 and 4.

| | Level 0 | |
|---|---|---|
| | Intent | Concept |
| Documentation and knowledge capture | The current goal of the system is to deliver cargo to beneficiaries in remote, hostile, and/or restricted terrain. | The concepts that are embodied in the field of possible solutions are those that are existent in part or in whole within the enterprise's current array of solutions for flying people or material from an origin to a point of need. The following options were considered, but abandoned:<br>• Flying in an unmanned, fixed-wing cargo aircraft.<br>• Flying in a cargo helicopter<br>• Flying in an unmanned utility helicopter<br>• Descending via a customer-guided parachute system<br>• Descending via a radio homing parachute system<br>• High Altitude unguided parachute system.<br>• Flying in a precision (and non-precision), rocket-propelled projectile<br>• Flying in a ballistic projectile<br>• Flying in a manned, armed utility helicopter.<br>• Flying in a manned, short field takeoff/landing capable fixed-wing cargo aircraft.<br>• |
| Analysis | Write the current goals as origin goals:<br>The beneficiary of the system is the cargo, which has the need of "location" associated with that of the system beneficiary. The system will change (solution neutral transforming) the location of the cargo by flying it to the desired location in a manner that is timely and does not cause it damage. The "flying" shall be conducted in a manner that is safe, precise, and accurate. The system shall be compatible with the existing cargo delivery infrastructure; it should have minimal defects, and should be inexpensive. | Concepts that were retained for further evaluation:<br>• Descending in a high-altitude released, guided parachute system. |
| Critique | Reflect on goals:<br>Representative? Yes<br>Complete? Yes<br>Consistent? Yes<br>Solution neutral? Yes | The concepts retained for evaluation fulfill the requirements detailed in the system problem statement as well as the descriptive goals. |

**Table 7:. Level 0 Analysis of System Intent and Concepts (JPADS Architectural Analysis Project)**


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Moving from intent to concept in Level 0, this research developed an array of concepts that could satisfy the solution neutral intent described in the system problem statement as well as the system descriptive goals. From the original array of concepts, an additional concept was selected for further evaluation, as it was deemed the best concept according to the characterizations of the needs in the SPS as well as comparative superiority according to the descriptive goals. The concept, "Descending in a high-altitude released, guided parachute system," became the intent for the Level 1 analysis.


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In Table 8 we can see this translation from Level 0 Concept to Level 1 intent. The system intent is expanded in Table 8 below covering the Level 1 Analysis to

| | Level 1 | | |
|---|---|---|---|
| | Intent | Process | Object |
| Documentation and knowledge capture | What is the current architecture? | | |
| | Changing the location of the cargo is accomplished by descending the cargo with a GPS-guided parachute system. | Operation of this system includes dropping the cargo from altitude, cargo containing, descent decelerating, course guiding | See Figure 24 |
| Analysis | Analyze the current architecture | | |
| | The cargo will be delivered to the location of the system beneficiary by aerial delivery according the time of need of the beneficiary. The decelerator shall ensure g-loading of the cargo is within acceptable parameters for undamaged delivery. Safety for the delivery instrument is accomplished through the use of unmanned guidance to the desired location. Accuracy and precision for the delivery will be accomplished through the use of a known-reliable guidance system. This guidance system is reliable and interoperable with existing military cargo delivery systems. Additionally, the system chassis shall be compatible with cargo-delivery aircraft. | Process/ object mapping using explicit representation or object/ suppressed processes representations<br><br>See Figure 23 | Object/ hierarchy<br><br>Included in Figures 23 and 24 |
| Critique | The intended system maps directly to the goals described in the origin SPS and descriptive goals. | Reflect on the architecture:<br>The system architecture delivers the desired value, according to the parameters in the system problem statement and the descriptive goals. Although it does not generate other value processes, it is capable of utilization for similar operation in other operational environments. It interfaces cleanly with other architectural entities, as specified in the descriptive goals? The system decomposes elegantly, as nearly all components serve one specific function while avoiding the unnecessary expenditure of resources and non-value-creating interfaces. | |

**Table 8: Level 1 Analysis (JPADS Architectural Analysis Project)**

integrate the concept with the SPS parameters and the descriptive goals. This statement of intent is the first instance in which the architect has moved from solution neutral,



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through high-level concept, to include some specificity to the solution. In the Level 1 analysis, we can see the occurrence of "GPS-guided," which suggests the importance of the need for precision in delivery of the cargo. This increase in specificity translates into the processes described in Table 8.

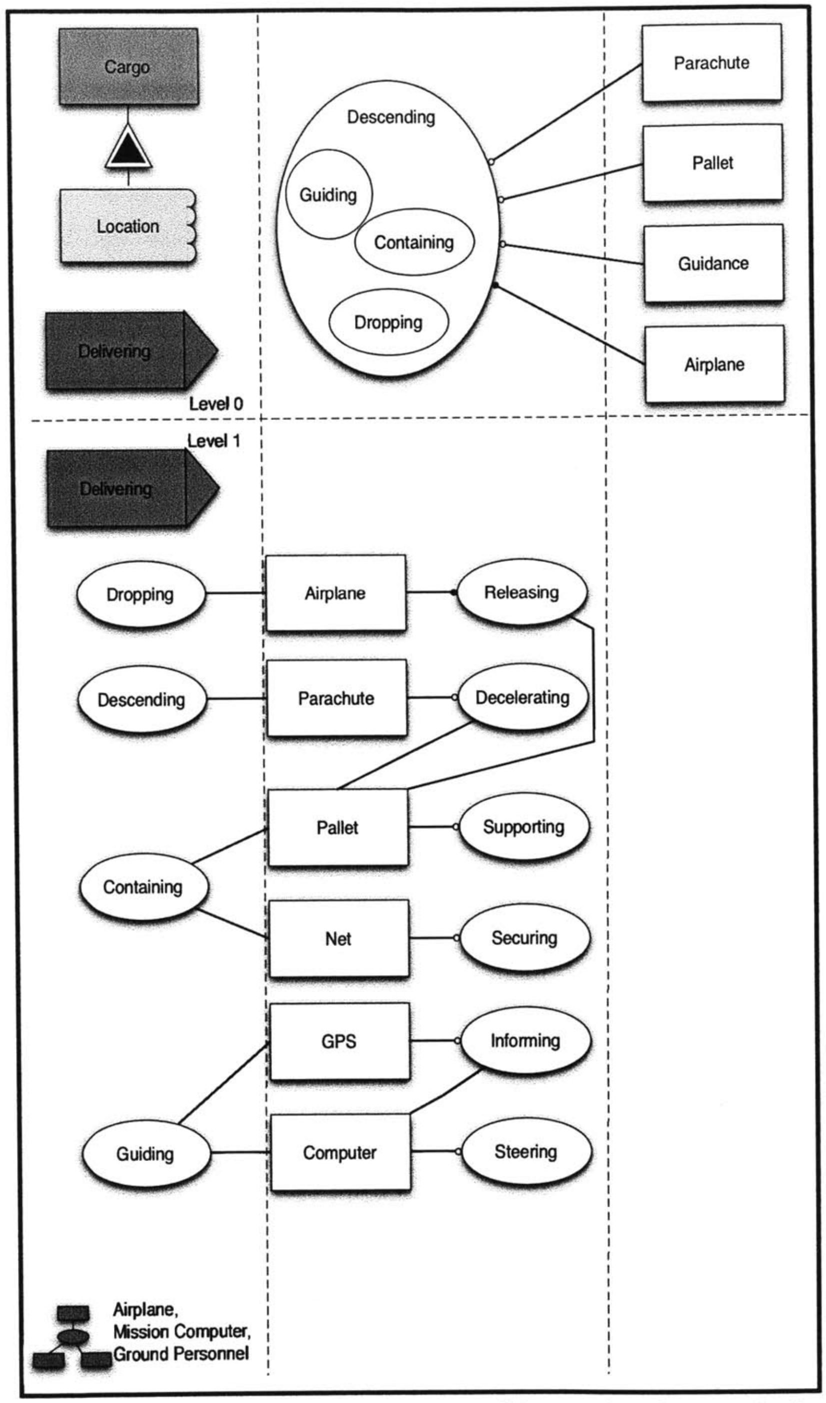


**Figure 22: Level 1 Process Map (JPADS Architectural Analysis Project)**

As shown in Figure 22 and found in Table 8, the processes involved in fulfilling the intent as described are system releasing and decelerating, cargo supporting, cargo securing, position informing, course guiding and system steering. These are accomplished by the operands, which are also shown in Figure 22.



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Beginning with the Level 1 Intent, which is described above and shown in Table 8, we can begin process mapping to determine the Level 1 Processes and Operands. Recursively adopting the Level 0 processes allows a Level 1 analysis to answer the question, "How will our system accomplish this process." The answers to that question become the processes and operands for the Level 1 analysis. This is illustrated in Figure 22. *Dropping* the cargo from a high altitude necessitates a system component to elevate it to that altitude that can likewise set it in motion to begin the system's active delivery process. This will be accomplished by an *airplane releasing* the cargo. Next, the system must contain the cargo, which is accomplished by a *pallet supporting* and a *net containing* the cargo in order to keep it physically bundled.

In order to descend the pallet/cargo/net safely to the ground, the system will use a *parachute* for *decelerating*. Finally, the system must guide itself to the intended point of delivery. This guiding is accomplished by a computer steering the system. In order for the computer to understand where it is in relation to where it needs to be and where it needs to land, we will use a *GPS* to *inform* the system regarding position data.

Now that we understand the processes and operands required to accomplish the Level 1 System Intent, we can reevaluate a first level formal decomposition. In Figure 23, we can see that our synthesis is beginning to yield some specificity as to the form of the system.

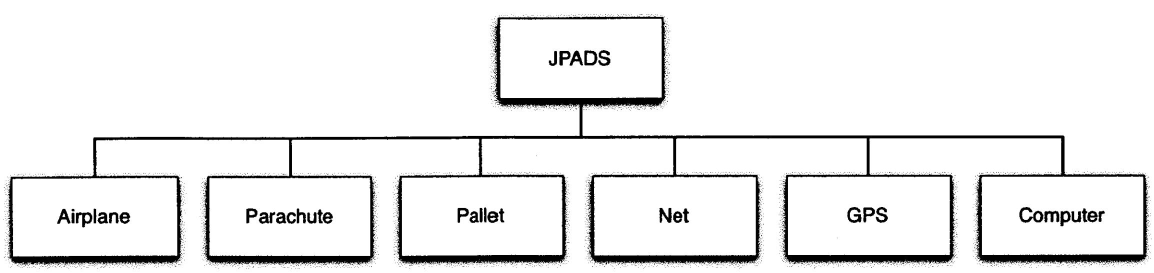


**Figure 23: First Level Formal Decomposition**



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## Section 5.2 – JPADS Level 1 Concept

Figure 24 to the right illustrates how our system model operates beginning with the beneficiary of "Cargo" and the need, which is "location." The operand of "Lightweight Cargo" must change location via flying in a safe, precise and accurate manner. In doing so, the lightweight cargo will descend utilizing precision guided capabilities leading to the breakout tree shown in Figure 24.

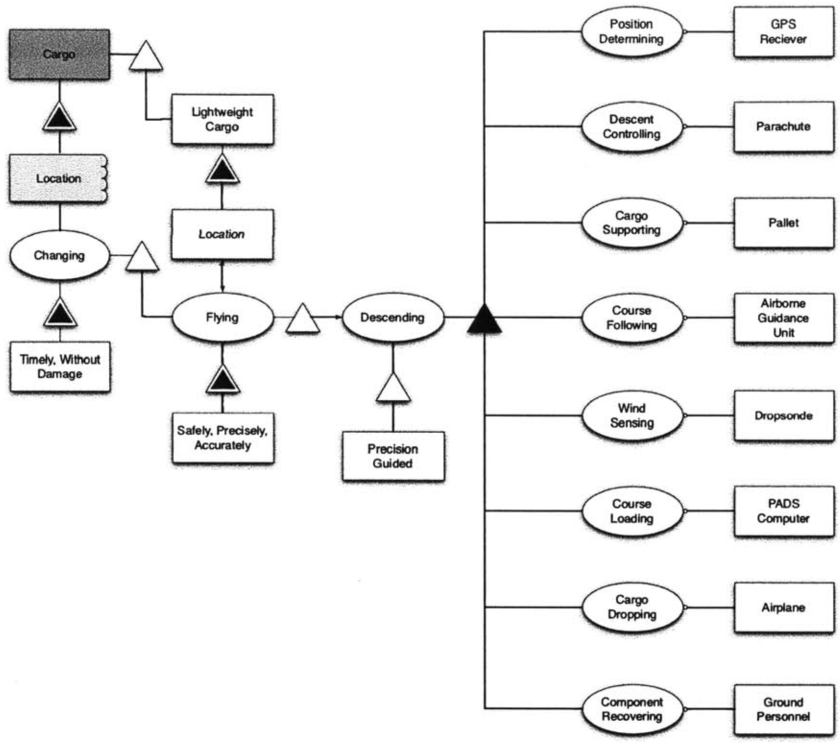


**Figure 24: Level 1 Concept (JPADS Architectural Analysis Project)**

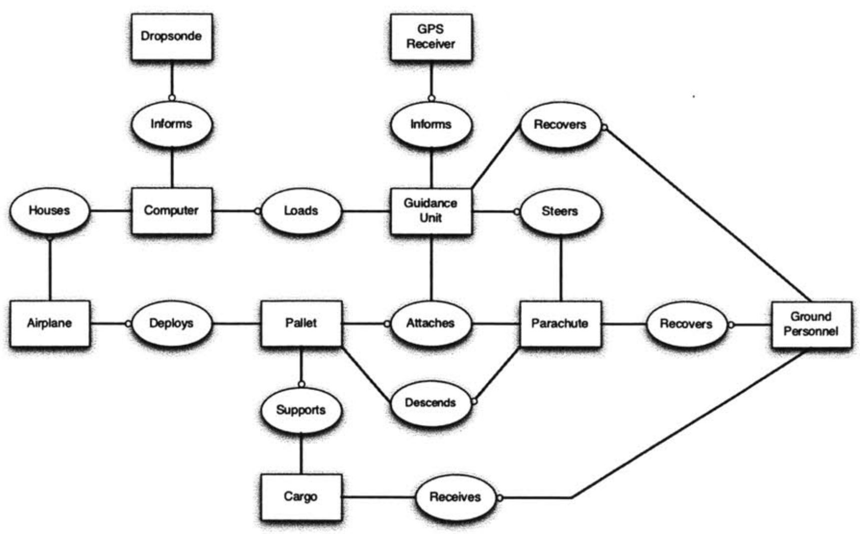


**Figure 25: Level 1, Box 3a Graphical Depiction (JPADS Architectural Analysis Project)**

The Value Related Internal Processes are Position Determining, Descent Controlling, Cargo Supporting, Course Following, Wind Sensing, Course Loading, Cargo Dropping and Component Recovering. Their respective Value Related



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Instrument Objects are the GPS Receiver, Parachute, Pallet, Airborne Guidance Unit (AGU), Dropsonde, PADS Computer, Airplane and Ground Personnel.

After examining the operational sequence and timing, we have ensured that all challenges are captured. One such challenge is the wind and weather data information critical to the successful drop of the system. This is captured using the Value Related Instrument Object of the Dropsonde. This analysis may also include contingency and emergency operations, maintenance operations and commissioning/decommissioning operations. Our intended system maps directly to the goals described in our original SPS and descriptive goals, which we identified in our previous analysis. In the next chapter, the research thesis will move into the JPADS Systems Architecture Level 2 analysis, which will go over the high level concept tree and the decomposition of several functions within the system.


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# Chapter 6: JPADS System Architecture Level 2 Analysis

## Section 6.1 – High Level Concept Tree for JPADS

For the delivery of cargo to Soldiers in restricted terrain in a safe and timely manner that does not damage the cargo being transported, there are very few processes that may be used. In order to meet all conditions specified by the System Problem Statement, the only practical method of transport is flying the cargo to the customer. For the purposes of aerial transport there are four processes identified for expansion. These

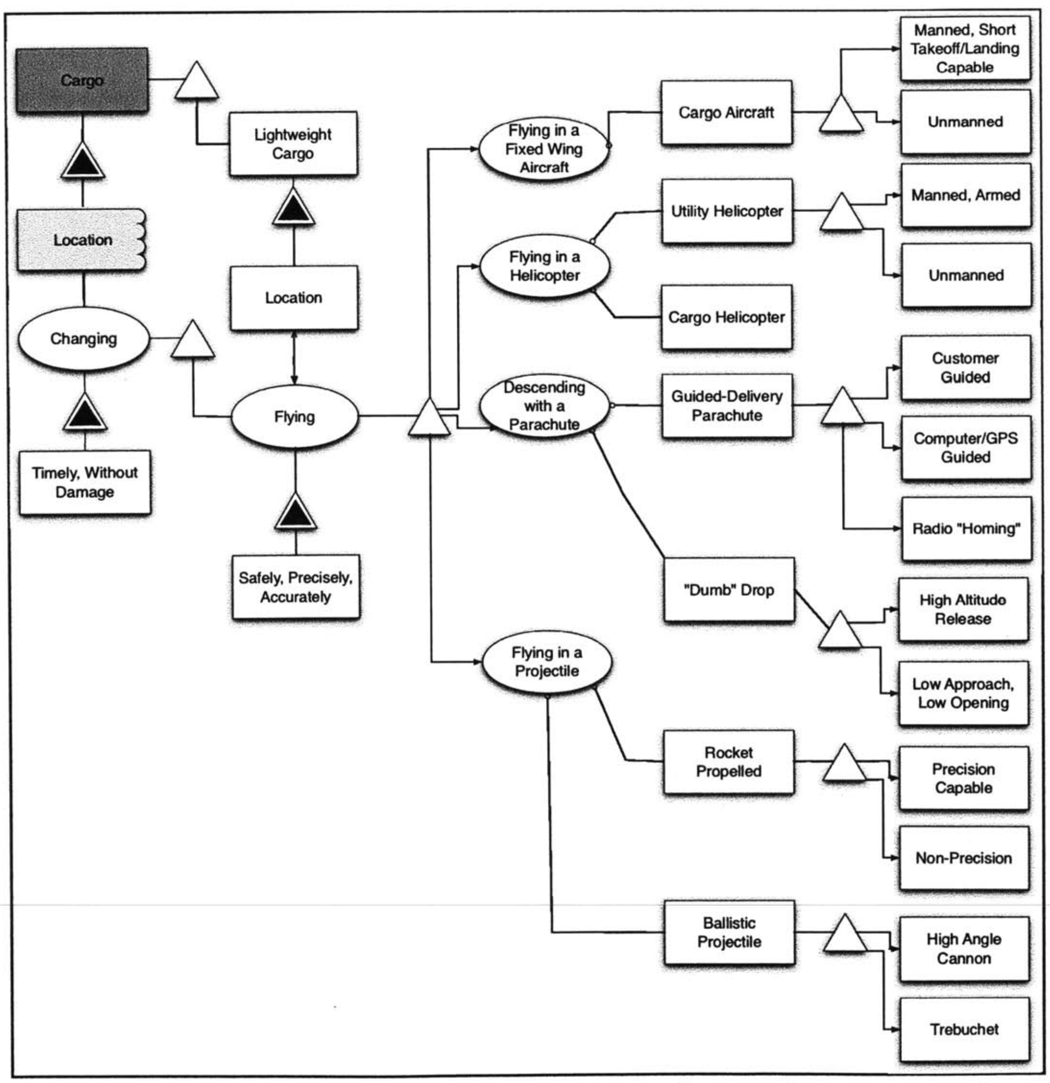


**Figure 26: High Level Concept Tree for JPADS (JPADS Architectural Analysis Project)**



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processes are flying the cargo in a fixed wing aircraft, flying the cargo by helicopter, descending the cargo with a parachute and flying the cargo to its intended location in a projectile. The description of these processes are graphically depicted in Figure 26 along with their respective operands, most of which are expanded by specialty.

The limitations placed on the system by both the operating environment and the needs of all stakeholders restricted creative problem solving. This is due primarily to two factors: first, the presence of enemy forces causes an inherent danger to the cargo, the delivery system and the primary beneficiary. Second, the limited budget imposed by the government for the development of a small system such as this one precluded extravagance in top-level system concepts. Creativity, in the sense of this project, is found primarily in the reuse of existing concepts from other military systems (Crawley, 2011).

Since the military is a not-for-profit organization with defined budgets and fast acquisition cycles for individual systems, the degree of creativity in problem solving is high within the given parameters. This is a function of the need to leverage existing systems and technologies where available in unexpected ways to solve new challenges. This type of creativity is precisely what was drawn upon to propose new solutions to this challenge. Each of the top-level concepts in the tree exist in some form elsewhere in the military, and they could be adapted to fill deliver the needed value.


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## Section 6.2 – Decomposition of the Releasing Function

The first process, releasing, is accomplished by a high-altitude aircraft with horizontal standoff from the drop zone. For the purposes of this system it was unnecessary to fully decompose the full aircraft, but instead we will focus on the portions of the aircraft that interface with the JPADS. Referencing Figure 27, at the level 2 decomposition, releasing is accomplished by the aircrew initiating movement of the cargo

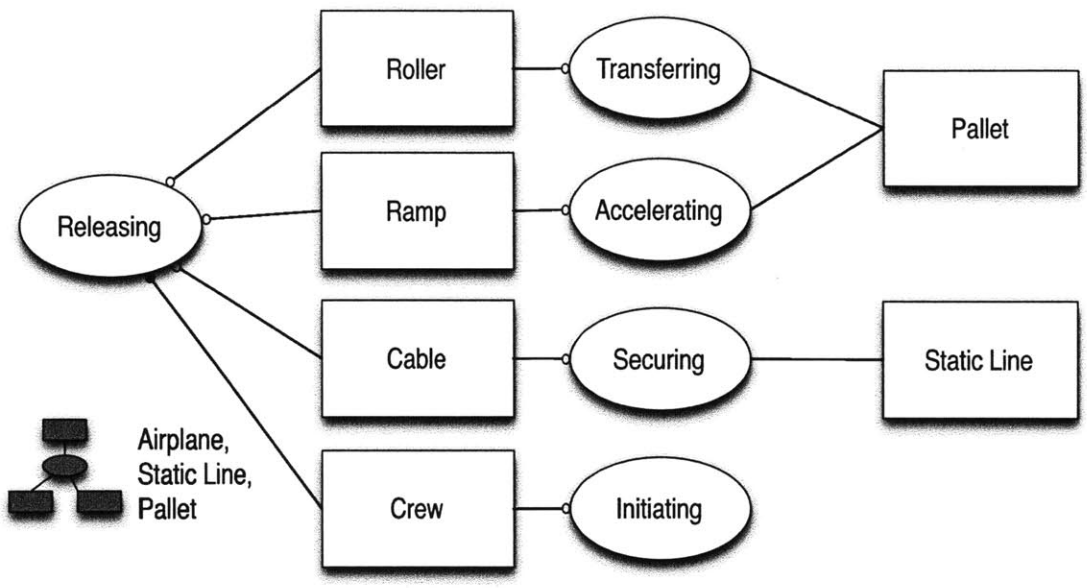


**Figure 27: Level 2 Decomposition for the Level 1 Process "Releasing" (JPADS Architectural Analysis Project)**

through pushing it along a set of rollers, which transfers the pallet-loaded cargo toward the cargo ramp. The ramp, which is located at the aft of the aircraft is angled down, so that gravity may continue to accelerate the pallet along the rollers until the pallet exits the aircraft. Finally, as the system departs the aircraft, a cable secures the static line that is attached to the deployment mechanism on the parachute.

Interfaces at this level are between the pallet and the all of the aircraft-decomposed operands. The rollers, ramp, and crew all physically touch the pallet, so



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these interactions must be accounted for. Since this system is a military system, this is accomplished through interoperability standards, meaning that if a system is to be used on military aircraft, they must conform to physical specifications that guarantee compatibility. In our case, the pallet used must be a mil-spec instrument that is already in use. The fourth process in releasing, which is securing, is accomplished by a mil-spec static line that is compatible with the aircraft as well as the parachute.

## Modularization of *Releasing*

If we move backwards from level 2 to level 1, we see that the emergent process of this part of the system is to separate the pallet (and all that is loaded on it) from the aircraft and the initiation of the parachute deployment, which is annotated in Figure 28. In system modularization we may elect to replace the aircraft's cargo ramp/roller system with another mechanism to execute these emergent processes. To replace this portion of the system, we must elevate the cargo to an appropriate altitude and then set it in motion, which is the guiding principle for modularization of this specific process.

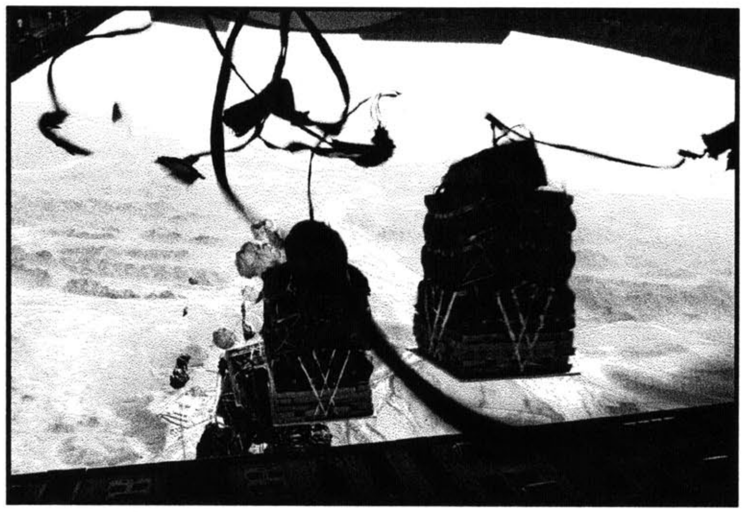

**Figure 28: Pallet-loaded Cargo Release. (Photo Credit: http://www.defense.gov, June 15, 2011)**

An alternative is a bomber-type aircraft that uses automation to drop packages from a bomb bay to a precise location on the ground. Although this configuration could



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feasibly generate the needed action, the addition of automated processes will likely increase the cost and will certainly increase the complexity of both operation and loading. A second possibility is to elevate the cargo with a helicopter and release it from a cargo bay very similar to the cargo aircraft. An alternative configuration that is made possible with a helicopter is to attach the pallet externally using chains. The helicopter can release the pallet either on the ground or at altitude using this configuration. This also produces the desired behavior, but by using a helicopter we may have the downside of only being able to execute one drop per sortie.



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## Section 6.3 – Decomposition of the Decelerating Function

The next set of operands and processes at level 2 describe the concept of *decelerating*. As shown in Figure 29, decelerating is accomplished primarily through the pressurization of air under the airfoil, also known as the canopy. Proper pressurization of

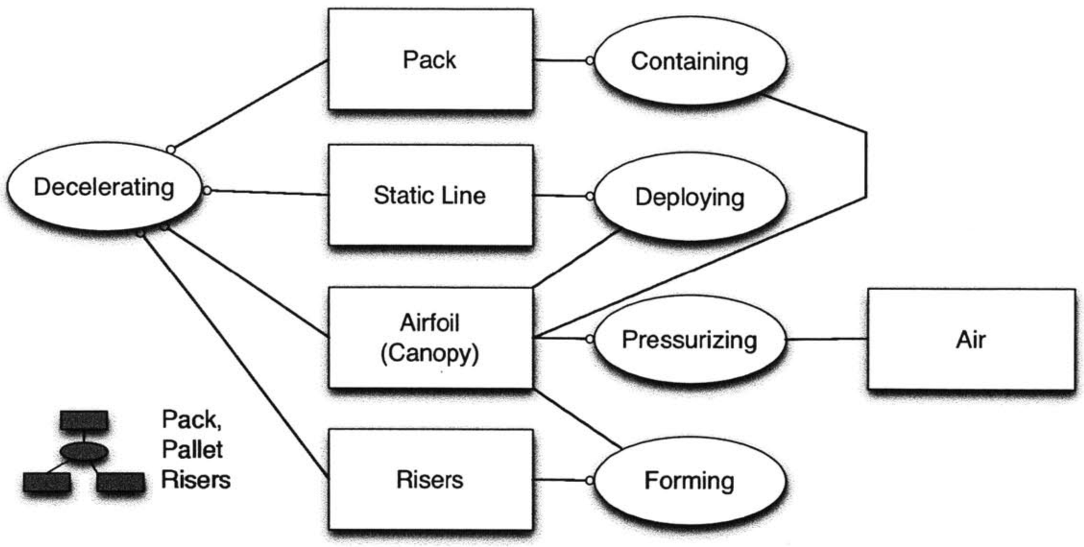


**Figure 29: Level 2 Decomposition of the Level 1 Function "Decelerating" (JPADS Architectural Analysis Project)**

air is a result of the shape of the airfoil, which results from the configuration of the risers, which forms the airfoil appropriately for the task of smooth, controlled deceleration during descent.

Initiation of the deceleration is accomplished by deploying the airfoil from the pack in which it is stored until the system is released from the aircraft as described above. This process is started through the action of the static line, which is secured to the aircraft and to the deployment initiator for the airfoil within the pack. This is depicted in Figure 28, in which the view may observe the static lines within the aircraft, which were previously attached to the airfoil. This portion of the decomposition suggests an interface between the *deceleration* elements of the system and the *releasing* elements.



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When we discuss interfaces for the decelerating elements, we have two to consider. The first, briefly discussed above, is the interface between the airfoil, the static line and the aircraft. This interface is essential in initiating the deceleration, which prevents the pallet and all that is loaded onto it from accelerating to the drop zone at 9.8 $m/s^2$, which would undoubtedly result in damage to the cargo being delivered. The second interface is the interface between the decelerating elements and the pallet. Standardization in this interface allows for variation and modularity in the decelerator.

## Modularization of *Decelerating*

Parachutes have a long and well-developed history and are often made more modular. Primary deceleration and steering via separate components is used on more aggressive versions of the JPADS system. For the JPADS-ULW variant, coupling steering and decelerating via a single airfoil is a sensible, cost-saving technique. As the heavier systems strain the decelerating function, a separate decelerator is used, as shown in the JPADS-L (Light, up to 10-kg package) image below. (Figure 30)

It is cost-efficient to utilize a single airfoil for steering and decelerating in many cases and modularization is used when requirements exceed the capability of a single, coupled system.

A key principle for the design of an airfoil is robust design. It is the decelerating and steering function that can mean the difference between success

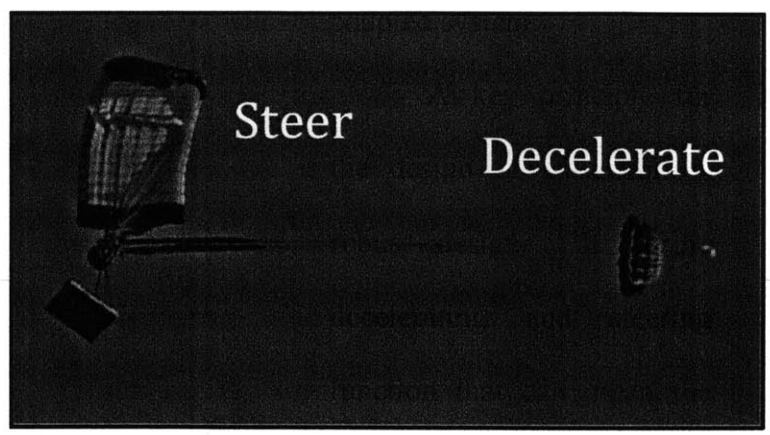


**Figure 30: Modularization of Steering and Deceleration Process (Source: www.natick.army.mil/soldier/media/fact/airdrop/JPADS_ACTD.pdf, June 15, 2011)**


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and failure. The airfoil itself must have reliability, testability and reusability. A robust design, in which "the architect must design his or her system to account for variations in the operating environment and in the components of the system," is critical for the JPADS, where the precise delivery of supplies may be the difference between mission success or failure. With a skydiver, the airfoil is always key to operator survivability.

The airfoil must have a flexible interface for broad application, but is constrained by the risers for forming the airfoil. Aerodynamics will present restrictions on riser connection and a flexible harness adapter would be very useful for any cargo/skydiver to connect to a standardized airfoil.

The design of modularity in the JPADS system is visible in the two down, one up methodology. If the architect is able to see linkages from the second level down to the first level down, then the architect may be able to establish non-modular components to the system. A crucial point is that some components may be in multiple "two-down" locations for good reasons that the architect is unable to change. For example, wind may show up in different locations and as a natural force within our system boundary, it may be "two-down" from multiple "one-downs." Conversely, any component that is "two-down" and under the architect's control should be evaluated for modularity.


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## Section 6.4 – Decomposition of the Steering Function

When analyzing the decomposition of the steering function, we have to consider the internal path of how this value related internal function emerges by going through the internal value related processes, which are illustrated in Figure 31 below. In Figure 31, we see the way in which steering takes place within the JPADS system. The level 1

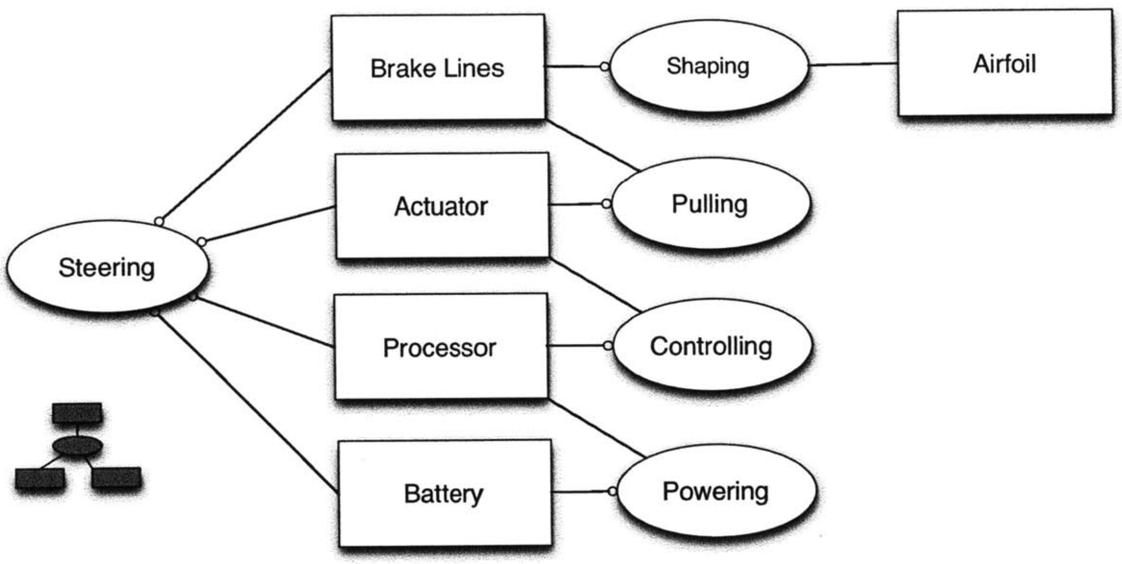


**Figure 31: Second Level Decomposition of the Steering Function (JPADS Architectural Analysis Project)**

process of steering becomes the level 2 intent and the level 2 operands include the battery, processor, actuator and brake lines. Their respective level 2 processes are powering, controlling, pulling and shaping, respectively. The instrument object is the airfoil, which is what facilitates the goal of steering through the manipulation of several of the operands. As the battery powers the processor, the processor then controls the actuator, which pulls the brake lines allowing for the re-shaping of the airfoil.

When the airfoil is reshaped, it leads to a change in direction allowing the system to change course through "steering." In the smaller JPADS systems, the airfoil "dumps" air through the manipulation of the brake lines, which "steers" the system in order to stay



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on course. The decomposition above visualizes the steering function and shows the relationship of component objects within the system, which will facilitate further analysis on modularity.

## Modularization of *Steering*

With regards to the modularization of the JPADS system looking at the "steering" function, the system will operate effectively regardless of the airfoil used, which is why this system is suitable for a variety of load sizes. When we examine the Level 2 Operands and processes, which collectively represent the level 1 abstraction *Computer*, we struggle to propose a next-level-up concept that could fulfill the emergent function of the current configuration. The only alternative to the computer would be a human to provide guidance to the drop zone; however, the addition of a manned steering element violates the *safety* portion of the system problem statement, nullifying this as a viable solution. The computer in this system is the core component around which the rest of the dynamic system is reconfigured through modularization.

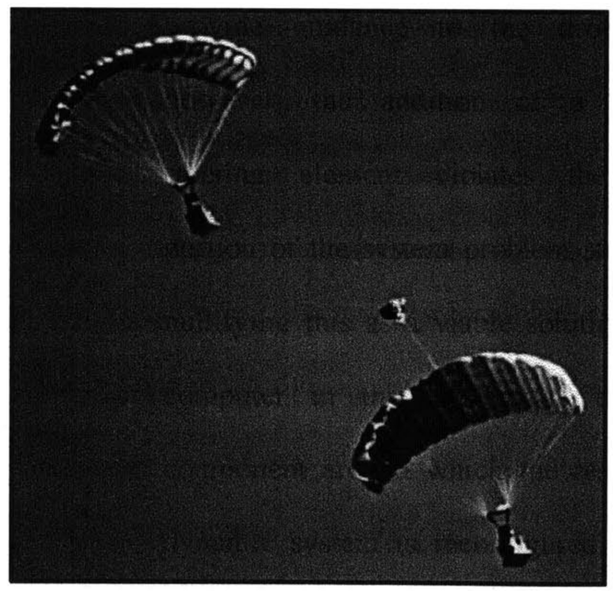

**Figure 32: Steering through the Airfoil (Source: www.natick.army.mil/soldier/media/fact/airdrop/JPADS_ACTD.pdf, June 15, 2011)**

Dependent on the size of the load, the airfoil will have a surface area larger or smaller to accommodate the load, which is where the modular design comes into play. The system operates with different size airfoils (canopies) leading to a modular system that can accommodate different load



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sizes. In larger loads, such as the 10K "Screamer" JPADS system, the system will require a "decelerator" in order to execute a more rapid deceleration prior to landing as to not damage the package being delivered to the primary beneficiaries on the ground. As you can see with the varying JPADS variants, the system is already fairly modular and the engineers behind this design had this in mind. The modularity of the JPADS increases the system's flexibility allowing for a wide variety of uses dependent on the environment and needs of the user.

When we consider the interfaces in the steering elements, computer to pallet and computer to brake lines, we see further evidence that this system is built for scalability through modularity. In effect, the computer is designed to pull brake lines in order to keep itself on a predetermined flight path. The computer is ambivalent to what type of steering parachute/airfoil is on the other end of the brake lines, which enables it to be used on a wide variety of JPADS configurations with no adjustment to its form or function.


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## Section 6.5 – Decomposition of the Informing Function

In the decomposition of the *Informing* function, shown in Figure 33, we consider the internal path of how this value-related internal function emerges by going through

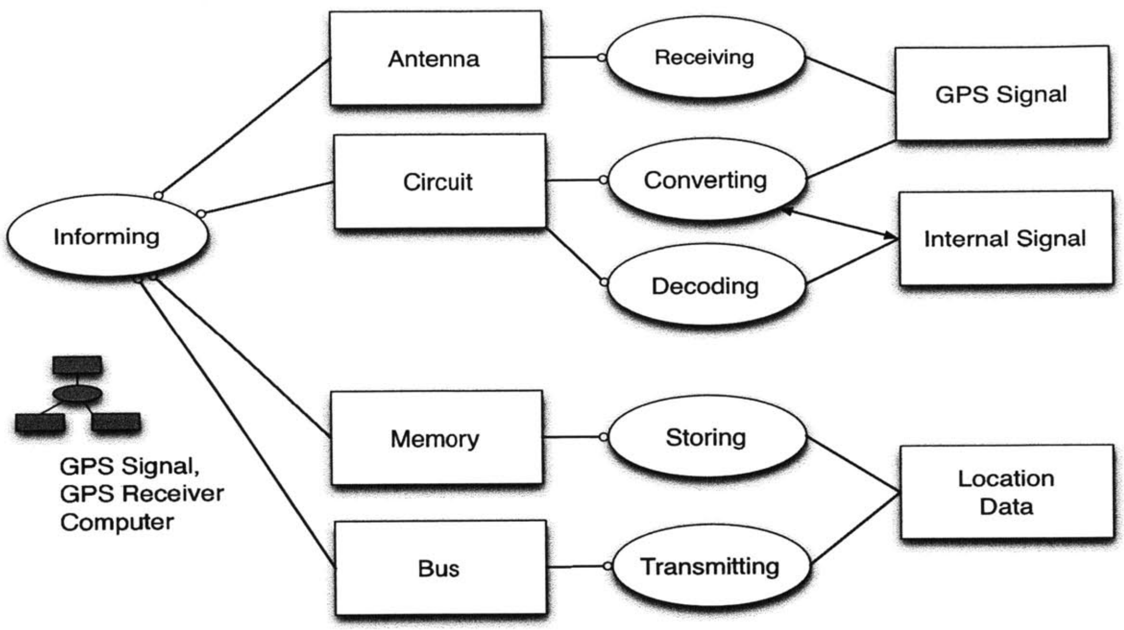


**Figure 33: Decomposition of the Level 1 "Informing" Function (JPADS Architectural Analysis Project)**

internal value related processes. One way of looking at *Informing* is to understand that in order for the *GPS* to deliver the location of the system to the computer, its *Antenna* has to *Receive* the *GPS Signal* and *Convert* it into *Internal Signal* (basically convert a wave form of energy into a corpuscular form of energy or a flow of electrons, if you will, but this is already a decomposition to Level 3, so we leave it at the level of Internal Signal, which describes the fact that transformation is underlying, but doesn't go into the next detail level). The *Circuit* of the *GPS* then processes this signal and *Decodes* it into *Location Data* of a unit. This *Location Data* is then *Stored* in the log format in *Memory* and is ready for being delivered to the outside. *Bus* subcomponent of the *GPS* then retrieves the *Location Data* from *Memory* and *Transmits* it to the AGU computer outside.



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## Modularization of *Informing*

Due to the assumption that at each level of modularization there is a guiding principle, we will choose the principle of modularity for evaluation of the GPS subsystem decomposed to Level 2. The descriptive version of this principle promises an architect the benefits of an object-oriented configuration: scalability, testing, maintenance, upgradeability and expandability. In order to receive all these benefits, we need to identify those interfaces that are relevant (or might become relevant) for different versions of the JPADS and the specific informing functions required for those versions. Excessive complicatedness in the name of versatility leads to a costly and difficult to use system.

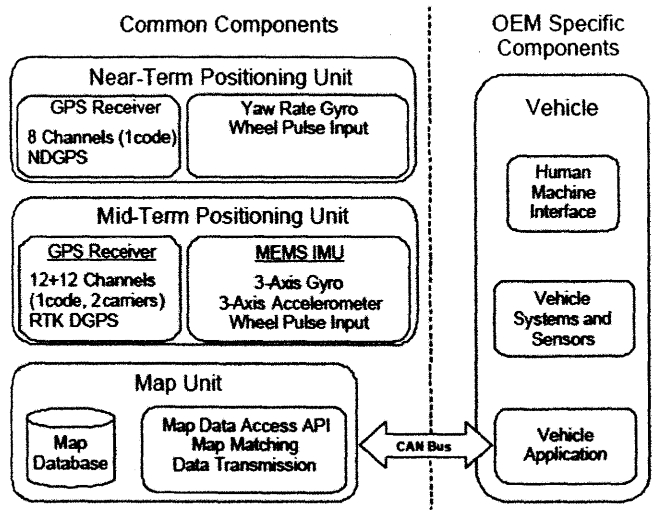


**Figure 34: Components of a GPS Reciever by USDOT ITS**

This research has considered several existing solutions where the GPS based location service is used. USDOT Intelligent Transportation Systems projects that attempt to create precision vehicle control system is a similar public project, in which results are openly published and can be cited without compromising national security (Appendix H: Common Vehicle Components and Architecture). Precision is of the utmost priority in this research as it directly relates to safety. The solution derived through this research is outlined in Figure 34. All components of the navigation system are divided into common



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groups and an OEM specific group, defining system interface between these two groups as the Controller Area Network (CAN) bus, commonly used across the automotive industry.

While this seems like a viable solution for civil applications, such as a vehicle In-Vehicle Infotainment (IVI) system, the JPADS cannot rely solely upon commercially available technologies and data in order to fulfill its mission without compromising the goals of stakeholders defined in earlier research. In order to solve this problem, we have considered several possible scenarios and designed the following modularization and interfaces of the Informing system that are necessary for platform and flexibility of the JPADS (JPADS is modular as a subsystem, but further flexibility of future designs will ensure easier integration into various Department of Defense (DoD) programs, i.e. the large-scale DoD system).

External location and environment monitoring sensors (i.e. wind sensors) that are not currently a part of JPADS must contribute to the *Informing* process. Therefore, they have to be included in what used to be called the GPS subsystem, now defined as a new modular, reconfigurable system that would be more appropriately named the "Location Information Module." The "Location Information Module" has a "GPS Interface" based on the Interface Control Document ICD-GPS-870 and the "GPS Correction Interface" group that consist of a proprietary JPADS interface that will be defined by the JPADS group in their future work, a LIDAR interface and an ISR interface, as illustrated in Figure 37 (Interface Control Documents). These interfaces will provide information that will be complementary to each other and deliver substantial benefits as additional sensor components for the *Informing* process can be changed based on the type of the system


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and the precision requirements. With stable interfaces (rather than ad hoc), they will be easily upgraded to the newest versions shall they become available.

Currently, pre-loaded terrain maps are used within the JPADS MP. Improvement via terrain scanning is necessary to calculate the optimal safe deceleration, and the research suggests using the Light Detection and Ranging (LIDAR) system data, combined with GPS data, in order to provide accurate identification of target location and the best possible trajectory (Lidar Sensor Design). Figure 35 illustrates the concept of LIDAR operations. A standard LIDAR interface will greatly improve the overall system.

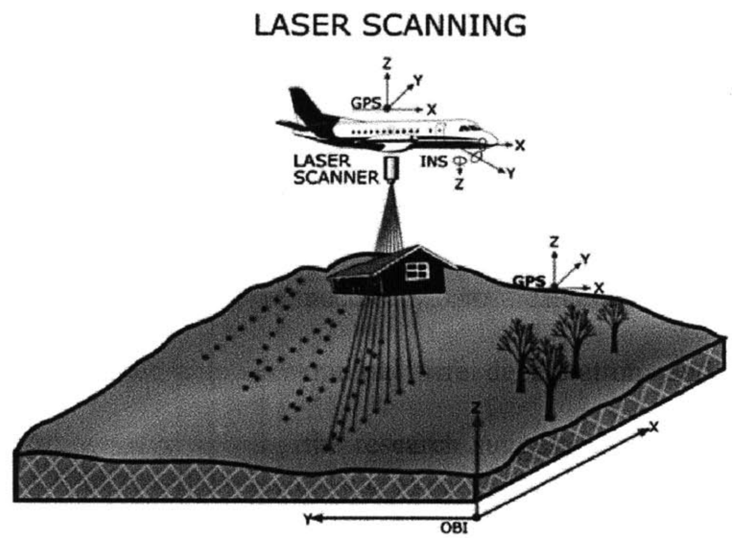

**Figure 35: Light Detection and Ranging (LIDAR)**

Finally, Intelligence, Surveillance and Reconnaissance (ISR) program data must also be used to complement the *Informing* subsystem and provide additional levels of security and precision where available. This program uses national, DoD, and allies' ISR capabilities, human intelligence, measurement and signature intelligence, signals intelligence, imagery intelligence and open source intelligence (Joint Functional Component Command for Intelligence, Surveillance and Reconnaissance). The collection of data is invaluable and an interface must exist to utilize this extensive information. The chart below outlines possible combination of ISR data using various sources of information.


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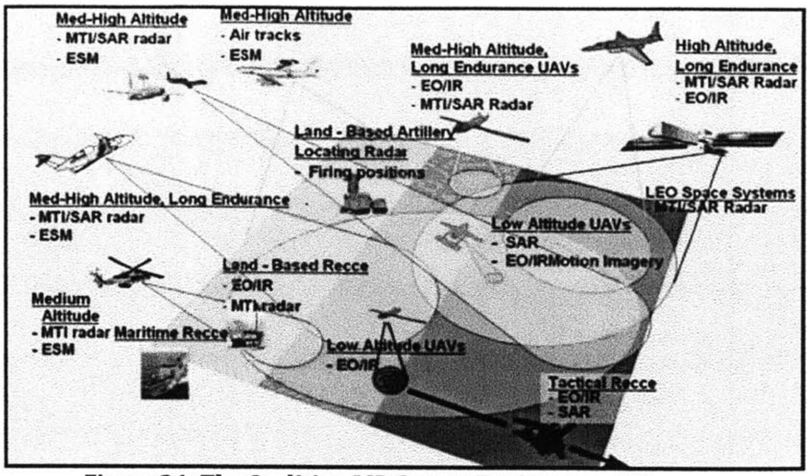


**Figure 36: The Coalition ISR Sensor Environment (Source: http://www.defenseindustrydaily.com, June 17, 2011)**

The resulting chart of Location Information Module with defined interfaces is shown below in Figure 37.

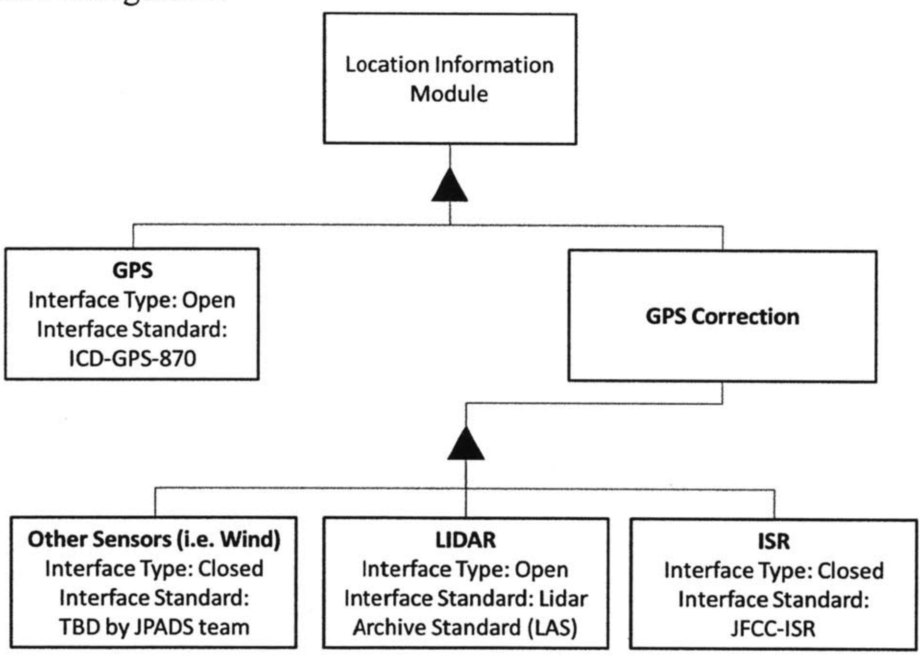


**Figure 37: Potential Configuration and Interfaces for the Location Information Module**

It must be mentioned that the addition of LIDAR to the system, as well as the interfaces necessary to integrate ISR platforms, will significantly increase the cost of the system, which violates the descriptive goal "the system should be inexpensive." This capability vs. cost argument returns us to one of our first discussions regarding the worth of building modular capability into the system in order to configure the system for


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variable operating environments. Additional capabilities such as LIDAR may be necessary for addition when the system is deployed into complex terrain, such as Afghanistan where mountains, ravines, high altitude plateaus, and man made features are present throughout. Open desert with little geographical complexity, such as central and southern Iraq, do not necessitate such fidelity in position informing because there is less terrain to avoid.

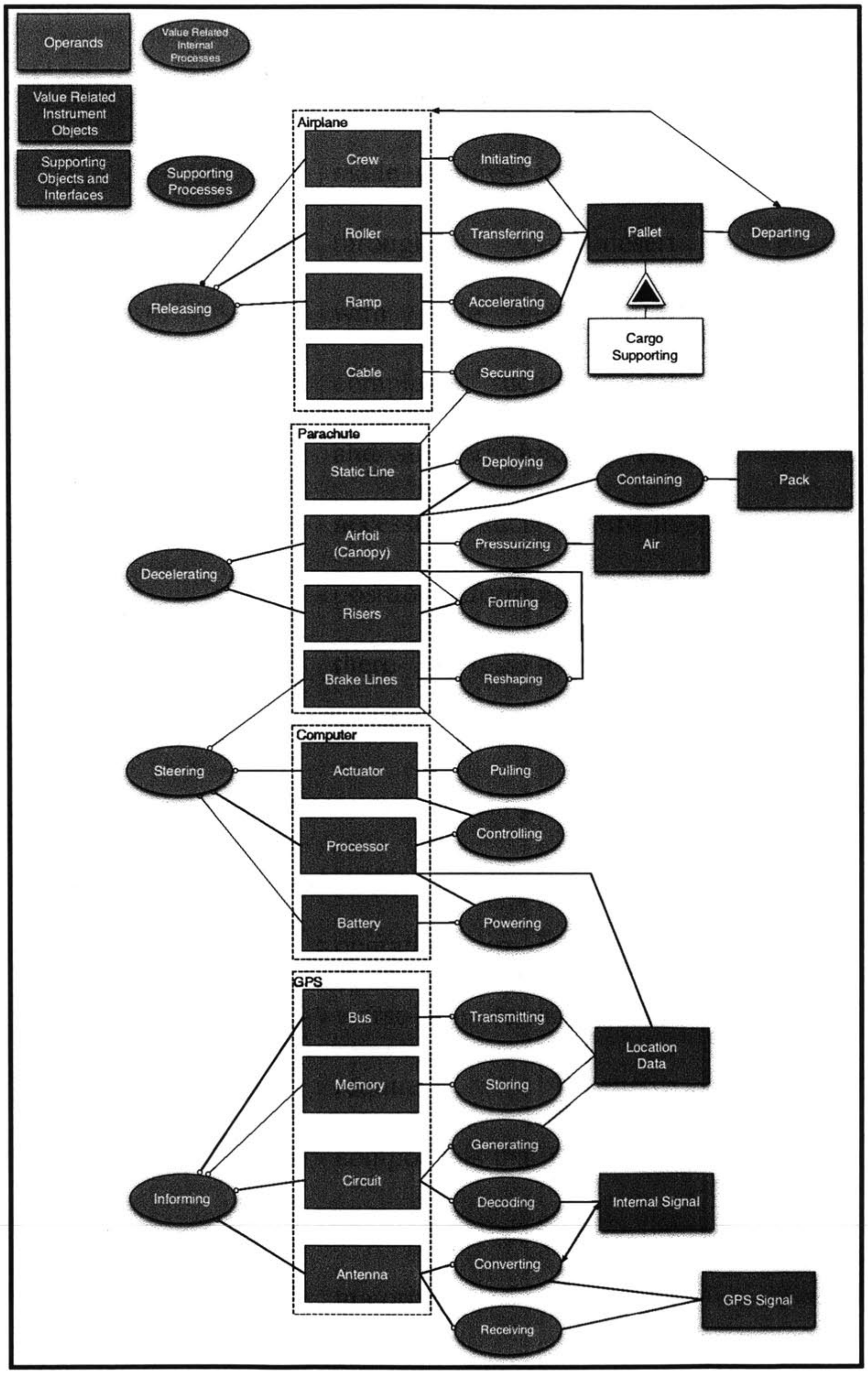


**Figure 38: Level 2 Decomposition of JPADS (JPADS Architectural Analysis Project)**

Building a rigid system that is capable of operating in even the worst-case terrain would require expensive components that are simply not necessary in the majority of operating environments. If, however,



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the added capability can be added as necessary when the mission requires, then the overall system cost is reduced, and the system is made viable from a cost standpoint across a broad range of operations.

This research has gone into depth in the analysis of the system modularity and has shown that the JPADS is a system that is built with this concept in mind. In Figure 38 above, the full Level 2 decomposition is illustrated for the purpose of demonstrating the capability of the system for modularity. Bearing in mind the discussion of each process above, the research has grouped level 2 operands by the level 1 formal abstractions to which they decompose. The research has shown that through a level 2 analysis, suggestions for alternatives to each of the level 1 elements of form are viable, with the exception of the computer for steering.

The JPADS is a system that can tolerate a change in one or more components and continues to deliver the needed value to the system's primary beneficiary. As illustrated in Figure 38, the interfaces between the elements of form at level 1 (detailed at level 2 in the figure) are elegantly designed and standardized to accommodate changes in the system.



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## Section 6.6 – "ilities" in the JPADS System

In the development of military equipment such as the JPADS, architects must consider the following "ilities" listed below. The following is not an all-inclusive list of "ilities" that are relevant to the JPADS; however, these are the most critical to ensure long term success and sustainability. This stems from the need to develop a system that can seamlessly integrate with existing military systems and one that will have a manageable life-cycle cost. The architects understand the importance of designing a system that will last the test of time and the following list identifies those "ilities" that will make this happen.

1. Interoperability: Systems must be capable of seamless interaction with other military systems both in terms of form and function. For JPADS, for example, the system must physically interact with several types of cargo-carrying aircraft, so the form of JPADS must be consistent with the standards that detail the physical dimensions of the system. Likewise, the system must communicate with other military systems over UHF radio and MILSPEC wireless data transfer protocols.
2. Recoverability: The high-cost components of the system must be recoverable by the expected customer to be used again later. For JPADS ULW, the guidance unit and the parachute must be of a size that it may be recovered by one person (each). If the architecture of the system is too large or complex for soldiers to recover while conducting combat operations, then it will not meet the stakeholders' needs for re-use.


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3. Maintainability: Basic system maintenance must be accomplished by the user. This is primarily preventive maintenance accomplished through cleaning and replacement of components with tools already available by the user. It is impractical to require specialized tools, training, equipment, or personnel to reset the system for use.
4. Survivability – Since the system is to be re-used up to 15 times, it must be rugged enough to withstand the conditions in which it operates. Closely related to maintainability, the architecture must comply with this -ility in order to meet the stakeholder requirement for re-use.
5. Scalability – The JPADS is a family of systems that are each capable of delivering a specific range of sized cargo. The architecture of the system must be scalable, so that it can be applied to all JPADS configuration without changing the concept or general configuration of the system.



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## Section 6.7 – System Architecture Analysis: Final Thoughts

As this research demonstrated, a good architecture is one that meets the needs of the stakeholders in a satisfactory manner and one that doesn't violate the accepted principles of systems architecture. A suitable architecture is also one that abides by the respective "ilities" that apply to the architectural design, such as maintainability, interoperability, customizability and understandability. What this research has shown is an architect must conduct a thorough analysis of all stakeholders of a new or existing architecture in order to clearly identify the direct beneficiary, their goals and needs, which will facilitate detailed planning, development and examination of the architecture behind the system that will meet those goals and needs. The research above provides a rich analysis of the JPADS architecture from the system's formal decomposition, the JPADS System Problem Statement, the subsidiary and expanded goals and a detailed analysis on the decomposition of critical functions within the system. This analysis will provided great insight into the next section of the research thesis, which will utilize the Design Structure Matrix (DSM) to analyze the numerous interfaces and interactions within the JPADS in order to propose potential improvements to the system.



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# Chapter 7: JPADS Design Structure Matrix (DSM) Analysis

## Section 7.1 – Introduction to DSM

The DSM is a Systems Engineering analysis tool that illustrates where important interactions take place between components and subcomponents of a system, which could lead to opportunities to improve a system, organize a project more effectively or create design teams based on potential iterations, dependencies and rework cycles. "The DSM is a two-dimensional matrix representation of the structural or functional relationships of objects, variables, tasks or teams" (de Weck, 152). This could have numerous positive implications for improvements to not only the current system, but in the development of future systems. With regards to the JPADS, the DSM will assist in the investigation to identify improvements to the system based on the structural and functional relationships between objects within the JPADS. This chapter will provide a detailed analysis on the initial DSM of the current 2K JPADS variant and will identify areas where the current system can be improved. Once this analysis is complete, the research thesis will provide an updated and improved DSM followed by some key takeaways from this analysis.


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## Section 7.2 – Initial JPADS DSM and Analysis

The current JPADS basic architecture and the top-level functionalities are illustrated below in Figure 39. From this diagram, we can see that the two primary software modules are the Precision Airdrop Planning System (PAPS) and the Wind-profile Precision Aerial Delivery System (WindPADS). In Figure 39, the main functions of the WindPADS are illustrated using the green bordering while the primary functions of the PAPS is illustrated in red bordering, which all fall within the JPADS Laptop Computer (Wright, 2005). The PAPS has both a Graphical User Interface (GUI) and a Graphical Map Interface (GMI) while the WindPADS has a GUI, which facilitates the interfaces shown below. The PADS uses FalconView for the system's GMI. The Georgia Tech Research Institute developed FalconView, which is a mapping system that the military and other elements within the DOD use as it provides map data for

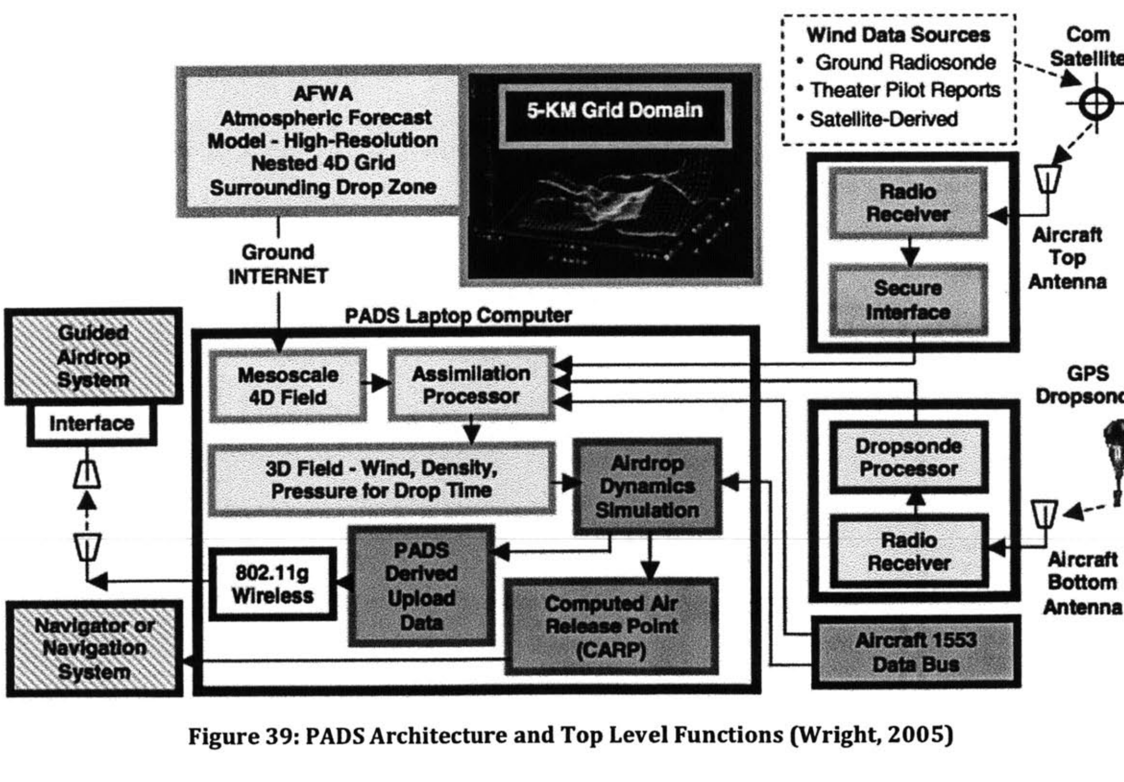


**Figure 39: PADS Architecture and Top Level Functions (Wright, 2005)**



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operational uses and is utilized in such programs as the JPADS MP, among others. The PAPS output is transferred wirelessly to the aircrew and to the system AGUs, which are located on the JPADS either on the aircraft or on the flight line during payload operations waiting to get loaded on an aircraft. The quotation below gives a good articulation of the interactions that occur next between the PAPS and the AGUs.

> "The PAPS output is transferred to the aircrew and to AGUs of onboard guided airdrop systems wirelessly in flight and wirelessly or wired during ground payload preparation. The PADS high-level GUI enables the operator to activate GUIs for mission planning data entry (aircraft type, drop zone, payload weight, load station, decelerator type, guided system selection, release and performance data, aircraft airdrop parameters, altimeter setting); for weather data acquisition and assimilation; for calculating the ballistic payload CARP; for calculating the guided payload CARP and allowable CARP range (earliest/latest CARPs along the run-in course); for aircraft navigation data monitoring en route to the CARP; and for upload of Mission Files (winds and PI) to the AGUs of guided systems before payload release" (Wright, 2005).

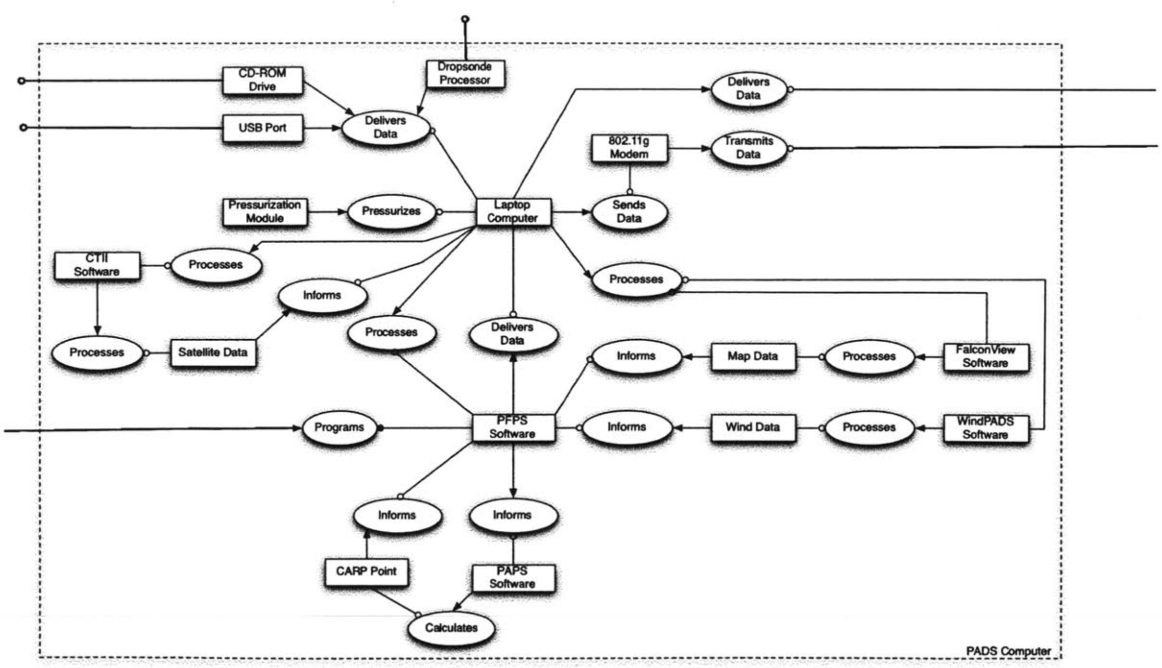


**Figure 40: JPADS Mission Planner Block Diagram (Systems Engineering DSM Analysis Project, 2011)**

This is not an all inclusive illustration of every function that takes place within the PAPS;


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however, several of the key interfaces are shown to give an idea of the number of interactions that occur within the system, which will facilitate the DSM analysis discussion later in this chapter. An additional illustration that shows the key interactions between all the different components within the JPADS is shown above in Figure 40. This is the JPADS mission block diagram and gives a graphical depiction of the different interactions that take place between the different processes, MP laptop computer, the software and other elements within the system.

In Figure 41 below, the JPADS baseline DSM is shown, which has four main groupings. These four distinct groups are labeled Wind Data Distribution, Cargo Delivery, System Recovery and Conflict. To give an example of an interaction that occurs within this DSM, when looking at the component Dropsonde, the Dropsonde gives updated weather data to the Aircraft, the PADS Computer and the AGU, which is captured by placing a "1" in the box linking the components with the interaction. The horizontal row "gives something" to the vertical row while the vertical row "needs something" from the

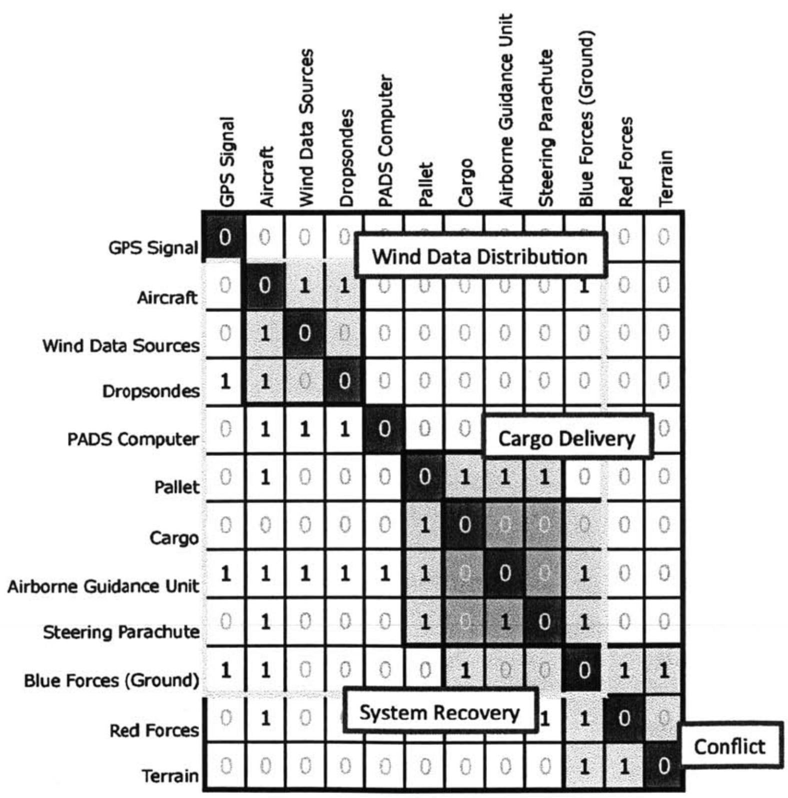


**Figure 41: JPADS Baseline DSM**



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horizontal row. Another example is the aircraft provides a launch platform for the pallet.

There is one "killer loop" outlined in yellow, which cannot be avoided. The aircraft and the ground forces each give and receive information to and from each other. This creates a killer loop because this information exchange is critical to the operation of the system and it cannot be decoupled.

Once the JPADS goes into operation, the Active Scenario Baseline DSM in Figure 42 captures the interactions that occur, which are primarily between the steering components of the JPADS and the computer software manipulating the controls. The two groups are the Mechanical Steering group and the GPS-Based Directional Control. One might ask themselves what's missing in this DSM? What key component isn't captured in the active scenario baseline DSM in Figure 42 that is critical to ensuring operational success? The next section will answer these important questions.

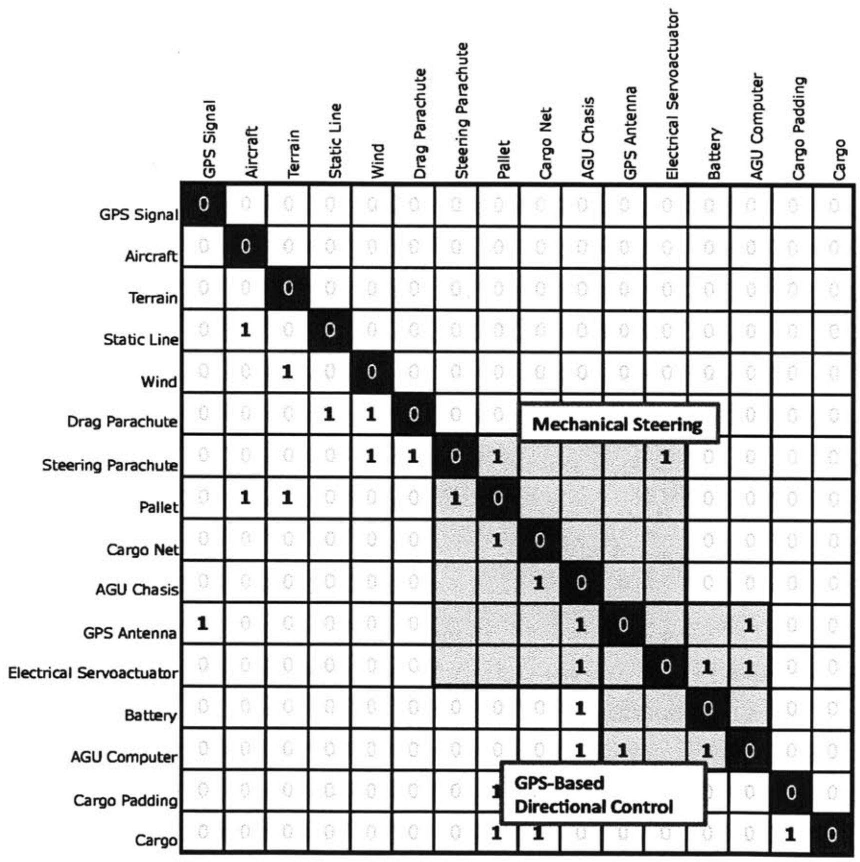


**Figure 42: Active Scenario Baseline DSM**



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## Section 7.3 – Recommended Improvements to the JPADS

Over the course of the stakeholder and system architecture analysis, two key aspects of the guided logistical resupply platform were not captured, which include a terrain avoidance feature and the ability to account for wind and weather fluctuations while in flight. By conducting a thorough systems architecture analysis of the JPADS and then applying the architecture to the DSM, the research provided a visual opportunity to identify "improvement gaps." Once the investigation provided a detailed DSM with important groupings within the system, it became apparent that both a wind data sensor and a terrain avoidance feature are missing in the design. Illustrated below in Figure 43 is the JPADS System Boundary Diagram, which shows the key components within the JPADS and the numerous interactions that occur between components of the system. Highlighted in blue is the area that is missing the important functions outlined in this

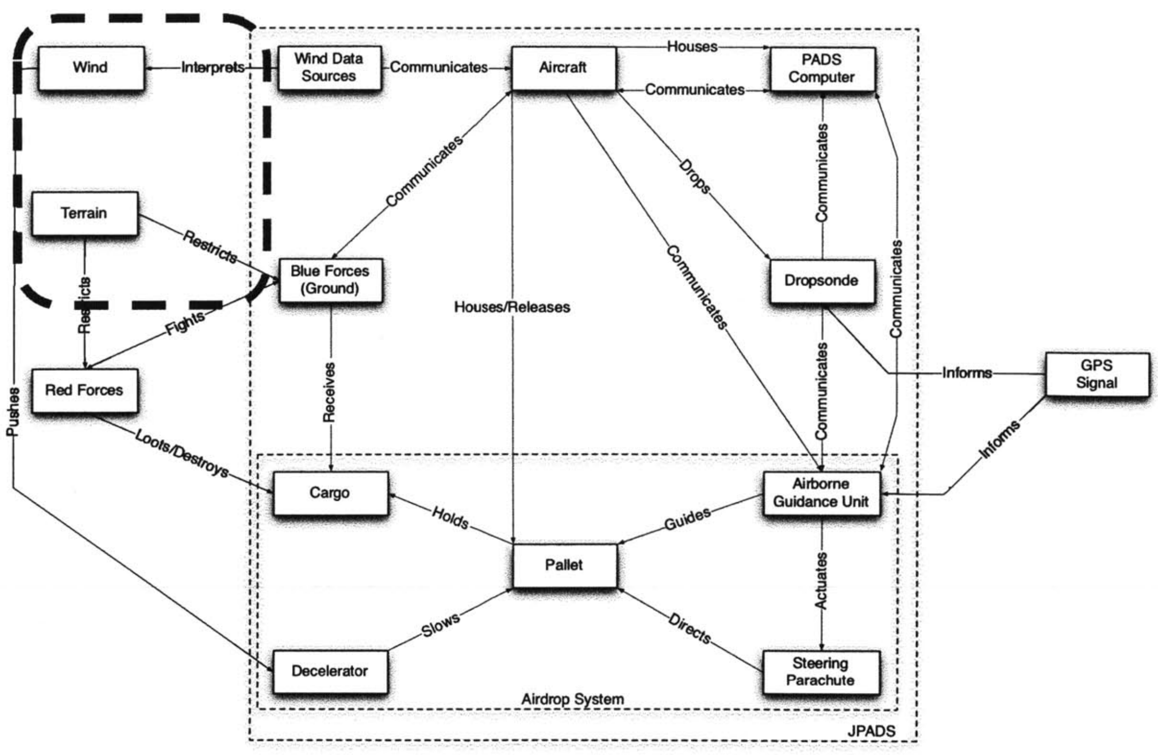


**Figure 43: JPADS System Boundary Diagram (Systems Engineering DSM Analysis Project, 2011)**


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research. With the integration of additional critical goals for variants within the JPADS family, potentially a higher end design for more sensitive military operations, it becomes important to include the additional features. Below are the critical goals discussed in Chapter 4. The additional goals vital to the JPADS are added and highlighted in blue.

***Critically:***

- Must be compatible with existing cargo delivery infrastructure (interoperability)
- Must engage suppliers and contractors in long term stable relationships with good revenue streams to them (mildly constraining, contractor relationship)
- Must accommodate required supplies (constraining, physical dimensions, carrying capacity of the descender)
- Must be able to control its speed and position while descending (constraining, limits to speed and offset)
- Must be traceable by ground forces (constraining, must be able to provide location information)
- Must minimize drop displacement (constraining, distance, accuracy and steering ability of the descender)
- Must be NOT traceable by enemy forces (constraining, secure channels of information exchange)
- Must have a terrain avoidance feature in order to effectively avoid obstacles along the flight path (Constraining, requires additional technological components)
- Must have a wind data sensor feature in the AGU in order to provide real time wind and weather updates to ensure accuracy (Constraining, requires additional technological components)

The updated critical goals list shows a requirement to incorporate a terrain avoidance feature and a wind and weather data sensor in order to ensure the most effective guided logistical resupply system. The next two sections will illustrate the incorporation of the wind data sensor and terrain avoidance feature in order to visualize the recommended changes to the JPADS.


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## Section 7.4 – The Wind Data Sensor

In order to fully capture the criticality of having a wind data sensor incorporated into the JPADS, Figure 44 illustrates the challenge of fluctuating winds. When the MP calculates the planned trajectory of the JPADS to get to its PI, actual conditions in the air and on the ground will differ and potentially fluctuate sharply. As shown in Figure 44, the measured wind profile could be drastically different than the actual, which is

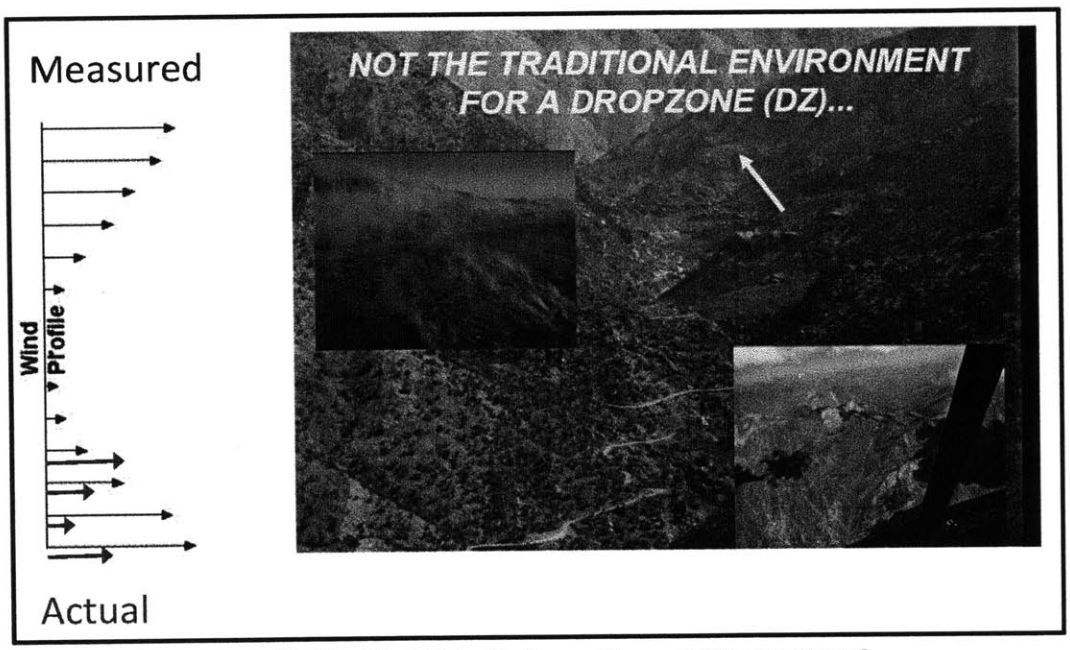


**Figure 44: The Wind Data Challenge: Measured Versus Actual**

highlighted in red. The picture above shows terrain from Afghanistan, which really brings this to light. With the ever changing terrain and wind conditions in our COE, it is critical to have this feature on the JPADS to ensure a timely wind analysis can be made by the MP and in flight to ensure accuracy and precision. At the end of the day, the Soldiers on the ground need this gear to accomplish their mission. The wind sensor goals include:

- The system can be dropped inside a wide air-volume without decreasing landing-accuracy capability



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- A soft landing is carried out into the wind and with a flare maneuver (may help in local terrain avoidance)
- The system can fly under different meteorological conditions
- The system is flexible to fly with a range of parafoil types and suspension weights

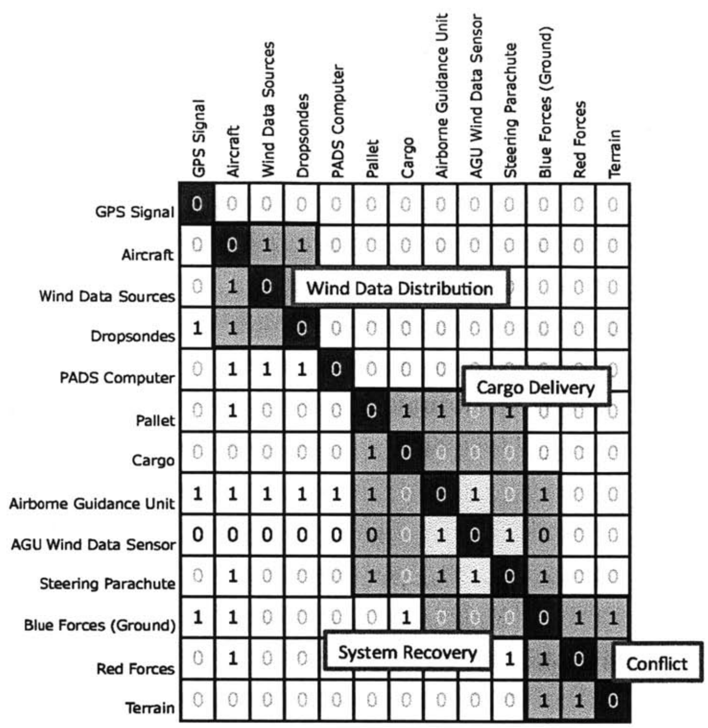


Figure 45: Integrated Wind Data Sensor

In order to show what this looks like using the DSM, updated DSM diagrams are included to show the recommended improvements using a wind data sensing device. In Figure 45 to the right, the AGU Wind Data Sensor is added to the DSM to illustrate the interactions that occur between the Wind Data Sensor and other components in the system, to include the AGU and Steering Parachute. The inclusion of the Wind Data Sensor will provide real time

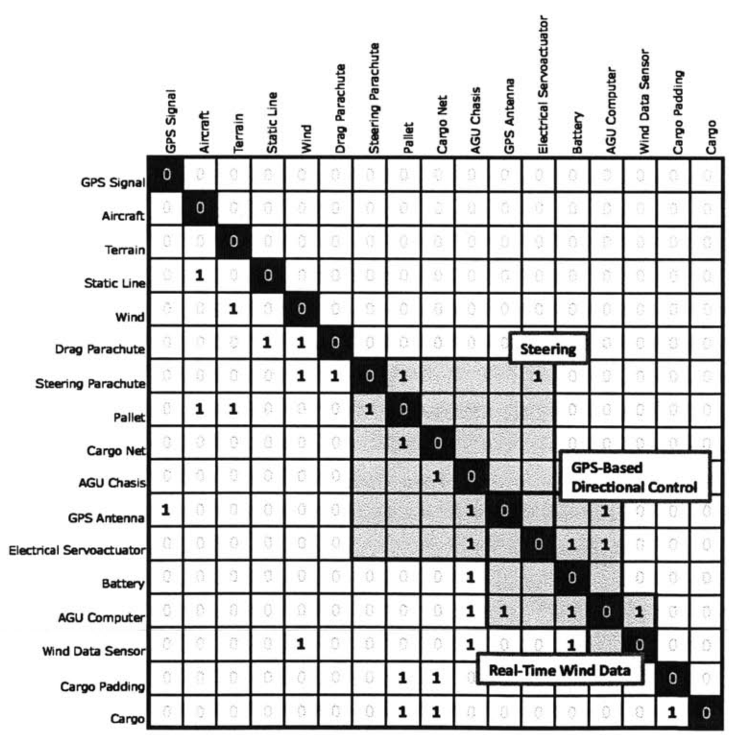


Figure 46: Integrated Wind Data Sensor in the Active Scenario



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wind data to the AGU in order to update the flight path based on changing conditions during flight and on the ground.

The U.S. Army Natick Soldier Research Development and Engineering Center placed a requirement to identify sources with the means to measure wind direction, speed and magnitude at differing altitudes "above a remote stationary position" while interfacing with the Army's JPADS 2K system. The wind sensing system must have the ability to interface with a computer based ground station and must be capable of "measuring wind direction and magnitude directly above a potential drop zone" for the JPADS. The measurements must occur at 0 feet, 100 feet, 500 feet and 1,000 feet with "additional gates" at 500 foot increments. "The sensing system must have a stand-alone, rechargeable power supply and must be deployable, sustainable and maintainable in all weather and altitude conditions without degradation of measurement precision" (Griffin, 2011). Based on this and previous research and analysis, the project sponsors working on the JPADS confirmed the need to incorporate a wind data sensor into the existing JPADS. The next section will cover the criticality of having a terrain avoidance feature included, as well.


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## Section 7.5 – The Terrain Avoidance Feature

Next, the research will investigate why including a terrain avoidance feature into the JPADS is vital to the accuracy and effectiveness of the system. Figure 47 below captures this challenge using imagery from Afghanistan to show the true nature of the

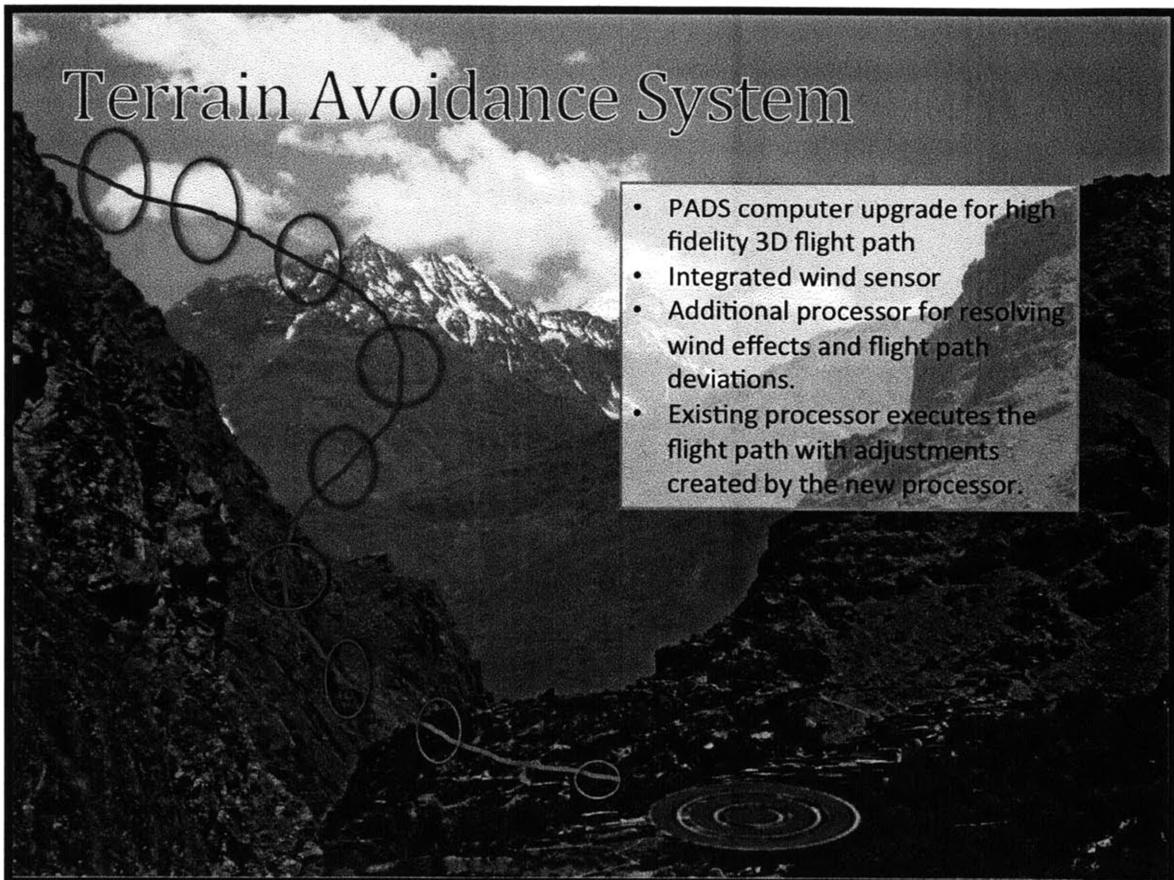


**Figure 47: Terrain Avoidance System (Systems Engineering DSM Analysis Project, 2011)**

terrain the system is up against. The terrain avoidance feature will require a PADS computer upgrade for a high fidelity 3D flight path and the before-mentioned integrated wind sensor. The system will also require an additional processor for resolving wind effects and flight path deviations and the existing processor will execute the flight path with the adjustments created by the new processor. In order to make this change, the



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JPADS will require an improved AGU. The user of the improved AGU is the pallet, as this is the piece of equipment carrying the supplies to the Soldiers on the ground and is the "prize," so to speak. One need of the pallet is to avoid terrain en-route from the plane to the Drop Zone (DZ). As of March 2012, report indicate that the project sponsors have incorporated a terrain avoidance feature into the JPADS, which has led to vast improvements with accuracy and precision (Foran, 2011). With the inclusion of a modified and improved AGU, the JPADS now has the ability to avoid terrain en-route to the PI and also has a one-time-use canopy to avoid recovery requirements.

**Improved AGU Requirements**

- System shall predict flight path for terrain avoidance from aircraft to DZ (PADS)
- System shall dynamically adjust flight path IOT react to changes in wind during flight (AGU and wind data sensor)

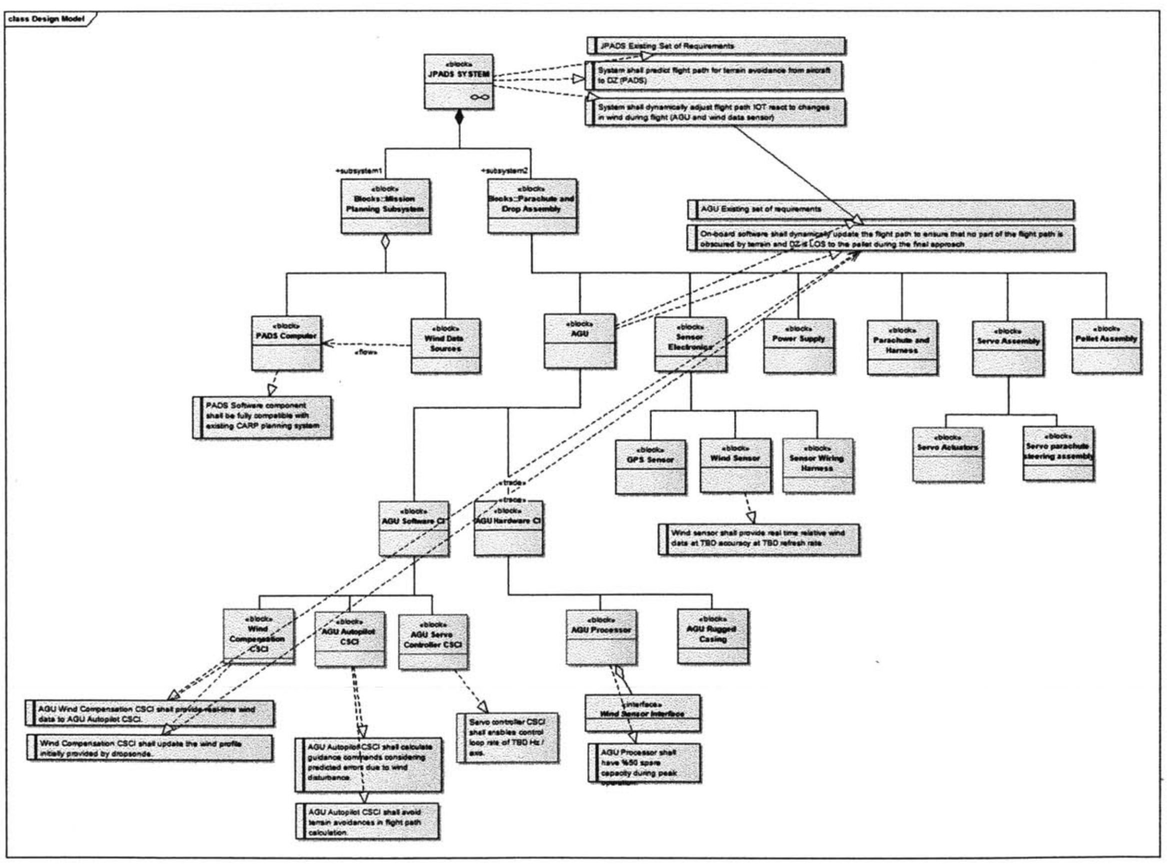


**Figure 48: Improved AGU Illustration (Systems Engineering DSM Analysis Project, 2011)**



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- System must be recoverable and not increase the weight of the AGU by more than a predetermined percentage (Blue Forces)
- PADS Software component shall be fully compatible with existing CARP planning system
- On-board software component shall operate dynamically with AGU for maintaining flight path
- System shall utilize wind data from the AGU wind data sensor
- On-board software shall dynamically update the flight path to ensure that no part of the flight path is obscured by terrain and DZ is LOS to the pallet during the final approach
- Timing of the flair is critical based on the height of the package (addition to the system)

A diagram that illustrates the improved AGU is shown above in Figure 48. The updated DSM that incorporates the Terrain Avoidance System is shown in Figure 49 below. The groupings remain the same with Wind Data Distribution, Cargo Delivery, System Recovery and Conflict; however, the updated and improved AGU shows new interactions and interactions that no longer exist, which are highlighted in yellow. When the JPADS is in flight, Figure 50 illustrates the new DSM that includes the groupings Flight Path Calculation and GPS-Based Flight Path Following. The improved JPADS with an updated AGU will fly using a three dimensional, GPT-based flight path that can adjust while in flight. The wind data sensor will enable this

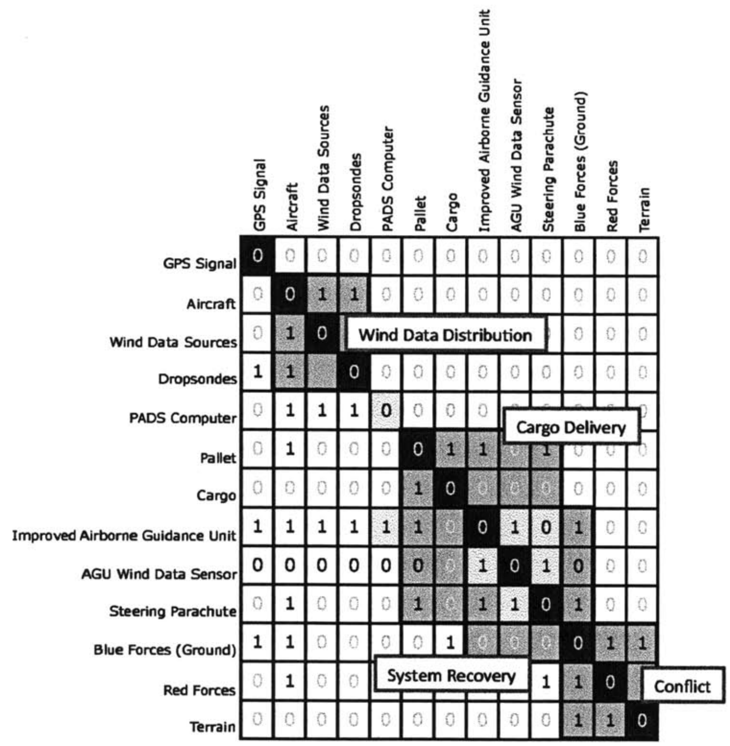


**Figure 49: Terrain Avoidance System**


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| | GPS Signal | PADS Computer | Aircraft | Terrain | Terrain Model | Static Line | Wind | Drag Parachute | Terrain Avoidance Processor | Steering Parachute | Pallet | Cargo Net | AGU Chasis | GPS Antenna | Electrical Servoactuator | Battery | AGU Computer | Wind Data Sensor | Cargo Padding | Cargo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GPS Signal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PADS Computer | 0 | 0 | 1 | Flight Path Calculation | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Aircraft | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Terrain | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Terrain Model | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Static Line | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wind | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Drag Parachute | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | GPS-Based Flight Path Following | | | | | | | | 0 | 0 | 0 |
| Terrain Avoidance Processor | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | 1 | 1 | 1 | 0 | 0 |
| Steering Parachute | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | | 0 | 1 | | | | 1 | | | | 0 | 0 |
| Pallet | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | | 1 | 0 | | | | | | | | 0 | 0 |
| Cargo Net | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | 1 | 0 | | | | | | | 0 | 0 |
| AGU Chasis | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | 1 | 1 | 0 | | | | | | 0 | 0 |
| GPS Antenna | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | 1 | 0 | | | 1 | | 0 | 0 |
| Electrical Servoactuator | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | 1 | | 0 | 1 | 1 | | 0 | 0 |
| Battery | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | 1 | | | 0 | | | 0 | 0 |
| AGU Computer | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | | | | 1 | 1 | | 1 | 0 | 1 | 0 | 0 |
| Wind Data Sensor | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | | | | | 1 | | | 1 | | 0 | 0 | 0 |
| Cargo Padding | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cargo | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

**Figure 50: Terrain Avoidance in Flight**

by drift prediction based on real time wind measurements, which will require a highly integrated, cooperative design. The new components will include updated PADS computer software, an additional processor in the AGU and a wind data sensor to make this happen. These new components are added into the improved DSM in Figure 50 above showing their respective interactions. The inclusion of the Wind Data Sensor and the Terrain Avoidance Feature will lead to a much improved JPADS capable of performing at a much higher level.



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## Section 7.5 – JPADS DSM Conclusions

As the research has shown, the DSM is an effective analysis tool that highlights where important interactions take place between components and subcomponents of a system and can assist researchers in identifying critical improvement gaps. Based on the analysis above, this research will lead to opportunities to improve the JPADS system. This will have numerous positive implications for improvements to the JPADS based on the structural and functional relationships between objects within the JPADS and components not currently included in the design, such as the Wind Data Sensor and Terrain Avoidance Features. This chapter provided a detailed analysis on the initial DSM of the current 2K JPADS, identified areas where the current system can be improved and provided an updated and improved DSM followed by an explanation why both terrain avoidance and wind data sensing it important to the operational success of the JPADS.



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# Chapter 8: Research Summary and Conclusions

## Section 8.1 – JPADS Technical Recommendations

There are several technical recommendations that will facilitate meeting the proposed improvements to the current JPADS architecture resulting in an upgraded system that will produce increased accuracy and precision. The first technical recommendation will center around a means to provide real time wind data to the system in order to adjust the flight path based on changing wind conditions while the second technical recommendation will provide a much needed terrain avoidance feature to navigate through challenging terrain.

One technological advance touched on briefly in earlier chapters revolved around a Light Detection and Ranging (LIDAR) system, which provides a means to acquire remote wind sensing. With the incorporation of this technology, the "laser light is projected into the atmosphere and the returns from aerosols or molecules are detected and analyzed, primarily using Doppler techniques," which provides the updated wind sensing data (Benney, 2005). Project teams are currently exploring two LIDAR strategies on the JPADS that will meet this need. The first strategy would place a LIDAR wind sensor in the actual carrier aircraft in order to provide updated measurements while in flight prior to the drop mission. The MP would use this updated data similar to how they currently use the data from the dropsondes released from the aircraft prior to the JPADS launch. The sensors would require ranges between six and ten kilometers and "would provide timelier and more accurate wind knowledge, improving landing accuracy for both ballistic and guided systems" (Benney, 2005).


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The second strategy is to place a smaller, lower range LIDAR wind sensor on the actual JPADS to provide or "feed" real-time "look-ahead" wind data to the autonomous flight software in order to improve the system's landing accuracy (Benney, 2005). Small Business Innovative Research (SBIR) contracts are supporting both strategies; however, the main challenge is overcoming the cost barrier to this system improvement. Figure 35 in Chapter 6 provides a visual illustration of the LIDAR in order to visualize this concept.

The second technical recommendation will focus around terrain avoidance. There are currently numerous upgrades to the JPADS including GN&C augmentations and "porting of the Draper Lab / Natick Soldier RD&E Center (NSRDEC) software to the MDS3 AGU7" (Benney, 2005). Details that capture the proposed technical recommendations follows:

> "Integration of a RADAR based height sensor for both terrain avoidance and near ground flare has begun and will be augmented with the incorporation of Defense Terrain Elevation Data (DTED) within the AGU for the planned area near the impact point GPS coordinate. In addition, peer to peer communications will be utilized to provide measured wind information from lower systems in a stick to upper systems to enhance accuracy and for in-flight and ground impact tracking" (Benney, 2009).

The incorporation of a LIDAR system could also provide terrain avoidance assistance using this technology. This section briefly covered several of the proposed technical recommendations that fall in line with the research conclusions. The next section will discuss the benefit of using DSM in the JPADS analysis over using other Systems Engineering tools and methodologies.


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## Section 8.2 – The Benefit of using DSM in the JPADS Analysis

The DSM is an extremely valuable and beneficial Systems Engineering tool used in this research for its ability to organize the JPADS system in a coherent manner in order to identify clusters, interactions and interdependencies within the system. The DSM illustrated where important interactions took place between components and subcomponents of the JPADS, which is what led to improvement opportunities for the system captured in the research. This will have numerous positive implications for improvements to not only the current JPADS, but in the development of future systems. With regards to the JPADS, the DSM assisted in the investigation to identify improvements based on the structural and functional relationships between objects within the JPADS. The "improvement gaps" identified using the DSM provided a means to organize the updated and improved system in order to articulate the recommended upgrades. Another Systems Engineering tool that this research could have incorporated is the Axiomatic Design approach, which will be covered in the next section.



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## Section 8.3 – Other Methods of Analysis

In this section, we will briefly cover the principles of Axiomatic Design as a systems engineering methodology or tool to evaluate and analyze a system. The basic hypothesis of the axiomatic approach to design is that there are fundamental axioms that govern the design process (Suh, 1995). There are two axioms that one will identify by examining the common elements that will always be present in good designs, whether those designs are product, process or systems based (Suh, 1995). The four domains of the design world are illustrated in Figure 51

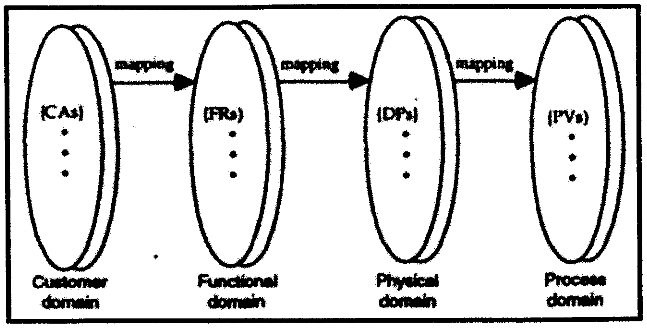


**Figure 51: Four Domains of the Design World are Characteristic Vectors of Each Domain (Suh, 1995)**

| | DP11 | DP12 | DP21 | DP22 | DP23 | DP31 | DP32 | DP33 |
|---|---|---|---|---|---|---|---|---|
| FR11 | x | | | | | | | |
| FR12 | | x | | | | | | |
| FR21 | | | x | | | | | |
| FR22 | | | | x | | | | |
| FR22 | | | | | x | | | |
| FR31 | | | | | | x | | |
| FR32 | | | | | | | x | |
| FR33 | | | | | | | | x |

| **Function** | | **Design Parameter** | |
|---|---|---|---|
| **FR1** | **Acquire wind data** | **DP1** | **Dropsonde System** |
| **FR11** | **Sense Wind and Convert to Data** | **DP11** | **Wind Sensor** |
| **FR12** | **Send Wind Information to Aircraft** | **DP12** | **UHF Transmitter** |
| **FR2** | **Collect wind data** | **DP2** | **Aircraft** |
| **FR21** | **Receive data from Dropsonde** | **DP21** | **Aircraft UHF Receiver** |
| **FR22** | **Process data from receiver** | **DP22** | **Aircraft computer** |
| **FR23** | **Communicate data to JPADS computer** | **DP22** | **Aircraft computer communications port** |
| **FR3** | **Predict Flight path besd upon wind data** | **DP3** | **JPADS Sysetm** |
| **FR31** | **Process Dropsonde data** | **DP31** | **JPADS Computer** |
| **FR32** | **Predict Palette trajectory** | **DP32** | **Software** |
| **FR33** | **Communicate trajectory to AGU** | **DP33** | **communications port** |

**Figure 52: JPADS Axiomatic Design**



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above and include the customer, functional, physical and process domains. The first axiom is called the Independent Axiom and it states that "the independence of Functional Requirements (FR) must always be maintained, where FRs are defined as the minimum number of independent requirements that characterize the design goals" (Suh, 1995). The second axiom is called the Information Axiom and "it states that among those designs that satisfy the Independence Axiom, the design that has the highest probability of success is the best design" (Suh, 1995). Based on knowing the design axioms of a system, we can derive theorems and conclusions founded on detailed analysis using the Axiomatic approach. In Figure 52 above, an initial Axiomatic Design of the JPADS is included to give an idea of some initial FRs and corresponding Design Parameters (DPs).

## Section 8.4 – Future Research

In an effort to continue meaningful research in a critical field within our military, there are several future research recommendations that will provide valuable insight to project sponsors continuing work on the JPADS. The first recommendation is to proceed with a detailed architectural analysis on the most improved JPADS 2K and ULW variants once details are released on the upgraded systems. This analysis can incorporate the DSM while a second recommendation could utilize the Axiomatic approach in order to fully analyze the improved system.

A third research recommendation is to incorporate Robust Design analysis into the JPADS analysis in order to fully evaluate the current engineered DPs utilizing software such as rdExpert developed by Dr. Phadke. This approach would require a complete immersion with the JPADS engineers in order to gather critical data points, DPs, tolerances, etc. to run the required simulations on the JPADS. This research could



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have tremendous opportunities to cutting cost as the initial test runs would be carried out via simulation prior to field and operational testing.

The Robust Design method is an effective and efficient tool used to arrive at optimal design parameters through the use of a signal to noise strategy incorporated with an effective simulator and should be used by product developers and systems engineers in order to reduce cost and streamline product development. The rdExpert Program allows an analyst, researcher or engineer to apply this strategy in an effective manner, which will save time and money. As a systems engineer, this is another tool to apply the systems methodology to solving complex challenges. This method will reduce cost as operational testing is both extremely expensive and time consuming. The cost of testing, validation and verification can be minimized using the Robust Design method.

This research thesis demonstrated that the JPADS is an impressive system capable of meeting a critical need for the Soldiers operating in remote, restricted and hostile terrain. With the introduction of a few system upgrades, some of which engineers are currently developing, the JPADS will go a long way in ensuring the Soldiers on the ground have what they need to accomplish their mission. With the introduction of a wind sensor and terrain avoidance feature, our ground forces will have the means to carry out their mission in areas once untouched or unreachable due to logistical challenges. The JPADS will help overcome this challenge, ensuring the U.S. Military has the ability to project to those who need assistance.


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## References

Appendix H: Common Vehicle Components and Architecture. *Common Vehicle Components and Architecture*. Web. 04 Feb. 2012. <http://ntl.bts.gov/lib/jpodocs/repts_te/14161_files/apph.htm>.

Altman, Joel., et al., *Design of a Windspeed Monitoring System for Autonomously-Guided Cargo Parachutes.* Graduate Research Paper, Graduate School of Aerospace Engineering. Worcester Polytechnic Institute. Worcester, MA. 2010.

Axe, David. "Marines' Robot Cargo-Copter Takes Flight in Afghanistan." *Wired.com*. 19 Dec. 2011. Web. 06 Mar. 2012. <http://www.wired.com/dangerroom/2011/12/robot-helicopter/>.

Banerjee, Nirmalya, Joshua Eaton, Deniz Eralp, Matthew Renzi, and Shane Scott. *JPADS Systems Engineering DSM Analysis Project: Analyzing the JPADS using DSM.* Rep. 2011. Print.

Benney, Richard, Kristen Lafond, and Michael Henry, et al. *Joint Medical Distance Support and Evacuation Joint Capability Technology Demonstration.* Tech. Print.

Benney, Richard, Justin Barber, and Joseph McGrath. *"The Joint Precision Airdrop System Advanced Concept Technology Demonstration."* Web. 21 Feb. 2012. <http://faculty.nps.edu/oayakime/ADSC/PATCAD%20-%20Benney%20-%20The%20Joint%20Precision%20Airdrop%20System%20Advanced%20Concept%20Technology%20Demonstration.pdf>.

Benney, Richard et. al. *DOD JPADS Programs Overview & NATO Activities*. Rep. Natick: U.S. Army Natick Soldier Research, Development and Engineering Center, MA. Print, 2007.

Benney, Richard, Justin Barber, Joseph McGrath, Jaclyn McHugh, Greg Noetscher, and Steve Tavan. *"The New Military Applications of Precision Airdrop Systems." Faculty.nps.edu*. Infotech@Aerospace, 26 Sept. 2005. Web. 23 Apr. 2012. <http://faculty.nps.edu/oayakime/ADSC/PATCAD%20-%20Benney%20-%20The%20New%20Military%20Applications%20of%20Precision%20Airdrop%20Systems.pdf>.

Benney, Richard, Mike Henry, Kristen Lafond, and Andrew Meloni. *"DOD New JPADS Programs & NATO Activities." Www.nps.edu*. 20th AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar, 4 May 2009. Web. 23 Apr. 2012. <http://www.nps.edu/academics/centers/adsc/papers/jpads%20-%20benney%20-%20dod%20new%20jpads%20programs%20and%20nato%20activities.pdf>.

Born, K. "Quartermaster Aerial Delivery: The Story of the Airborne Rigger." Army Quartermaster Foundation, Inc. Web. 07 Feb. 2012.



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<http://www.qmfound.com/riggers.htm>.

Callander, B. D. "The Evolution of Air mobility," *Air Force Times*, 81, p.2. 1998.

Carrabba, P., *THE RIGHT PLACE AT THE RIGHT TIME- An Analysis of High Altitude Airdrop and The Joint Precision Airdrop System.* Graduate Research Paper, Graduate School of Engineering and Management. Air Force Institute of Technology. Wright-Patterson AFB, OH. April 2004.

Chrohman, J. S. "Operation Provide Promise- Resupplying the Bosnians," *Quartermaster Professional Bulletin*. Summer 1993. [On line] Available: http://www.qmfound.com/bosnians.htm

Crawley, *E. Systems Architecture, MIT Course: ESD.34, Lecture 1 Slides,* 2011.

Department of the Air Force. Flying Operations, Computed Air Release Point Procedures. AFI 11-231, 1 July 1998. [On Line]. Available: http://www.e-publishing.af.mil/shared/media/epubs/AFI11-231.pdf

Department of the Air Force. Flying Operations, C-130 Aircrew Training. AFI 11-2C-130 Volume 1, 1 November 1998. [On Line]. Available: http://afpubs.hq.af.mil

Department of the Air Force. Flying Operations, C-130 Operations Procedures. AFI 11-2C-130 Volume 3, 1 November 1998. [On Line]. Available: http://afpubs.hq.af.mil

de Weck, O., Lyneis, J. "Successfully Designing and Managing Complex Projects," MIT Press, First Edition, 2011.

Foran, Alexandra. "Soldiers in Afghanistan Rely on Airdrop for Logistical Support." *Soldiers in Afghanistan Rely on Airdrop for Logistical Support.* Www.army.mil, 6 Mar. 2012. Web. 18 Apr. 2012. <http://www.army.mil/article/75107/Soldiers_in_Afghanistan_rely_on_airdrop_for_logistical_support/>.

Gemas, David L., *A Systems Engineering Approach to Analyzing Weather Input Sensitivities of the Joint Precision Air Drop System.* Graduate Research Paper, Graduate School of Engineering and Management. Air Force Institute of Technology. Wright-Patterson AFB, OH. June 2007.

Griffin, Allison. "A--Request for Information - Wind Sensing System." *Federal Business Opportunities (FBO)*. Department of the Army, 9 Mar. 2011. Web. 17 Apr. 2012. <https://www.fbo.gov/index?s=opportunity&mode=form&id=50e32b341a6930c521a0f5f70a297282&tab=core&tabmode=list&=>.

Henry, Michael, and et al. *Development of a 2,000-10,000-lb. Improved Container Delivery System.* Tech. Sudbury: U.S. Army Natick Soldier Research, Development and Engineering Center, MA. Print.



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Interface Control Documents. *GPS.gov: Official U.S. Government Information about the Global Positioning System (GPS) and Related Topics*. 12 Mar. 2012. Web. 04 Apr. 2012. <http://www.gps.gov/technical/icwg/>.

Joint Functional Component Command for Intelligence, Surveillance and Reconnaissance. *Wikipedia*. 25 Feb. 2012. Web. 4 Apr. 2012. <http://en.wikipedia.org/wiki/Joint_Functional_Component_Command_for_Intelligence,_ Surveillance_and_Reconnaissance>.

Joseph-Michel and Jacques-Étienne Montgolfier. *Encyclopedia Britannica. Encyclopedia Britannica Online*. Encyclopedia Britannica Inc., 2012. Web. 16 Feb. 2012. <http://www.britannica.com/EBchecked/topic/1404137/Montgolfier-brothers>.

JPADS: Making Precision Air-Drops A Reality. *Daily Defense News for Military Procurement Managers, Contractors, Policy Makers.* Web. 14 Sept. 2011. <http://www.defenseindustrydaily.com/jpads-making-precision-airdrop-a-reality-0678/>.

Klumpp, R. A., *Strategic Brigade Airdrop: Past, Present, Future?* Graduate Research Paper, Graduate School of Logistics and Acquisition. Air Force Institute of Technology. Wright-Patterson AFB, OH. November 1996.

Larter, David. "War-zone Airdrops Reach Record-breaking pace - Air Force News | News from Afghanistan & Iraq - Air Force Times." *Air Force News, Pay & Benefits, Careers, Entertainment, Photos - Air Force Times HOME.* Air Force Times, 28 May 2011. Web. 16 Feb. 2012. <http://www.airforcetimes.com/news/2011/05/air-force-war-zone-airdrops-record-pace-052811w/>.

Leonardo Da Vinci: Da Vinci's Parachute -- Britannica Online Encyclopedia. *Encyclopedia - Britannica Online Encyclopedia.* Web. 13 Feb. 2012. <http://www.britannica.com/EBchecked/media/92211/Design-for-a-parachute-by-Leonardo-da-Vinci-from-the>.

Leipold, J.D. "Army Testing New Airdrop System for Afghanistan." *US Army Homepage*. 23 Feb. 2010. Web. 06 Mar. 2012. <http://www.army.mil/article/34848/>.

Lidar Sensor Design. *Lidar Sensor Design.* Penn State University. Web. 4 Apr. 2012. <https://www.e-education.psu.edu/lidar/book/export/html/1798>.

McGowan, S. *Airlift in Vietnam* [On Line]. Web. 22 Feb. 2012. Available: http://www.sammcgowan.com/vietnam.html

Military Airlift Command, office of History. *Anything, Anywhere, Anytime: An Illustrated History of the Military Airlift Command,* 1941-1991. Scott Air Force Base, IL: Headquarters Military Airlift Command, May 1991.



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Military Specification Document M67854-10-I-1004. *Navy Electronic Commerce Online*. Web. 2 Mar. 2012. <https://www.neco.navy.mil/>.

Naumov, Sergey, Joshua Eaton, Matthew Renzi, and Shane Scott. *JPADS Architectural Analysis Project*. Rep. 2011. Print.

Neuffer, E. A., "Afghan food drops found to do little good." *Boston Globe*. 26 March 2002. [On line] Available: http://www.converge.org.nz/pma/cra0283.htm

Palumbo, Natalia, and Jimmy Taylor. "Bi-Annual Theater Aerial Delivery Symposium." *Military News and Military Information*. U.S. Military, 30 Apr. 2011. Web. 18 Apr. 2012. <http://www.blackanthem.com/News/U_S_Military_19/Bi-Annual-Theater-Aerial-Delivery-Symposium_printer.shtml>.

Parfit, M., "Letting Us Down Gently: The Art of the Parachute," *Smithsonian*. p. 58. August 1990.

Reinert, Bob. "Sky's the Limit for Airdrops." *US Army Homepage*. 05 Oct. 2011. Web. 06 Mar. 2012. <http://www.army.mil/article/66478/>.

Ring, Jack, and Wayne Wymore. *Concept of Operations (CONOPS) of a Systems Engineering Education Community (SEEC)*. Rep. Seattle, WA. March 15, 2004. Print.

Siegel, N., "Legacy of Flight," *Aviation History*. p. 74. September 1998.

Suh, N P. "Axiomatic Design of Mechanical Systems." *Journal of Mechanical Design* 117.B (1995) : 2.

Sunzi, and James Clavell. *The Art of War*. New York: Delacorte, 1983. Print.

Sweetman, B., "US Air Force Probes Technological Frontiers," *International Defense Review*. P. 1. 1 June 1996.

System Architecture / FrontPage. Web. 10 Sept. 2011. <http://sysarch.pbworks.com/w/page/7241231/FrontPage>.

USA. Acquisition, Technology and Logistics. Office of the Under Secretary of Defense. By Kristen J. Baldwin. *Systems Engineering Guide for Systems of Systems*. Aug. 2008. Web. 10 Oct. 2011. <http://www.acq.osd.mil/se/docs/SE-Guide-for-SoS.pdf>.

U.S. Army Natick Soldier Research, Development and Engineering Center RDNS-WPA-T. *Detailed Test Plan for AEWE Spiral G: Helicopter Sling Load and Airdrop Operations Utilizing the K-Max Aircraft*. Rep. Natick, MA. Print.

U.S. Army Natick Soldier Research, Development and Engineering Center RDNS-WPA-T. *USA Natick Soldier RDEC Aerial Delivery Overview*. Rep. Natick, MA. May

20, 2010. Print.

U.S. Army Natick Soldier Research, Development and Engineering Center RDNS-WPA-T. *Joint Medical Distance Support and Evacuation (JMDSE) Joint Capability Technology Demonstration (JCTD)*. Rep. Natick, MA. Print.

U.S. Army Natick Soldier Research, Development and Engineering Center RDNS-WPA-T. *USA Natick Soldier RDEC Aerial Delivery Overview & Future Personnel Airdrop S&T Considerations*. Rep. Natick, MA. Print.

Williams, B. L.; Studer, K. K.; Studer, N. E., "Operation Provide Promise: the airdrop phase," *Quartermaster Professional Bulletin*. Autumn 1993. [On line] Available: http://www.qmfound.com/operation_provide_promise.htm.

Wright, Robert, Richard Benney, and Jaclyn McHugh. *Precision Airdrop System*. Tech. Natick: U.S. Army Natick Soldier Research, Development and Engineering Center, MA. 2005. Print.



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