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A Flexible Architecture to Repurpose a Deployed System

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Raytheon IDS/Johns Hopkins University Overview

- Johns Hopkins Partnership with Raytheon IDS for MSSE
  - Purpose is to assist students in developing the systems engineering knowledge and skills necessary to successfully lead the planning, development and engineering aspects of large, complex systems.
- **JHU Program Goals**
  - **Acquire the knowledge and problem-solving skills required to:**
    - Guide the development of modern complex systems
    - Integrate systems and make tradeoffs between performance, cost, and schedule
    - Employ the principles of systems engineering
  - **Apply knowledge and skills to solve practical systems engineering problems**
    - Exercise skills in analysis, synthesis, and coordination of the various disciplines required to develop, engineer, and produce a complex system to meet a customer's need
    - Think through the entire complex process of system development, from analyzing requirements to deploying systems in the field

Project Background

- Systems Engineering of Deployed Systems course project posed the question: How can an aging deployed system be modified/upgraded for new modern purpose?
  - Scope for this course project was to develop a notional design and sustainment strategy for a hypothetical mission upgrade to the Joint Stand-Off Weapon (JSOW)
  - JSOW architecture was notionally repurposed as a humanitarian aid and disaster relief vehicle, called the Prompt Disaster Relief Vehicle (PDRV)
- Repurposing a deployed system requires a flexible sustainment architecture and focus on integrated logistics
- Principles applied in this academic project are applicable to real-world deployed system
  - Following slides detail the approach proposed by the project

Project Problem Statement & Solution

The following description details the problem statement used to frame the project and summarize the project team's solution:

- Current vulnerability in the effectiveness and responsiveness of global disaster relief, leading to deaths/illness and economic issues that could have been avoided
  - Recent events like the 2010 Haiti and 2015 Nepal earthquakes highlight the deficiencies in the current humanitarian relief effort
- Separately, certain US Navy JSOW weapons are being removed from the DoD weapon suite based on the undesirable impacts unexploded ordnance (UxO) rate of the sub-munitions it

Opportunity to (fictitiously) re-purpose the JSOW in support of humanitarian response to global disasters

Current Deficiencies

The primary deficiencies driving a needed upgrade are the following:

- The current system delays in providing relief can lead to additional loss of life and injuries.
- The current system is challenged in providing relief to specific location that are in need (remote areas).
- The current system relies mainly on active ports and airports for the majority of the deliveries.

Efficiency & Accuracy must be addressed during humanitarian missions

Key Requirements / Metrics

- Technical Performance Measures
  - The operational availability of the PDRV system shall be greater than 90%
  - System corrective maintenance shall be less 25% of all maintenance activities, as a percentage of maintenance downtime.
- Operational and System Requirements
  - Following aid deployment, the PDRV shall locate a safe zone and terminate flight
- Sustainability and Maintenance Requirements
  - The PDRV shall be sustained through a 3-Level maintenance concept consisting of Organizational (O), Intermediate (I), and Depot (D) level maintenance.
  - The PDRV shall allow for long-term storage in a Navy sheltered (Ns) environment (per MIL-HDBK-217) of no less than 2 years without degradation of system functionalities or capabilities.
- Reliability Centered Maintenance
  - RCM will be practiced in accordance with DoD Manual 4151.22-M.
- PHS&T Requirements
  - The contractor shall coordinate stowage and/or removal of material from assigned storage locations, performing periodic audits and inventories as outlined in NAVSUP/Navy guidance to ensure accurate synchronization between documentation and material with a 100% accuracy

Drives RCM plan

Safe & accessible

Cornerstone of maintainability planning

No / minimal margins in supply chain

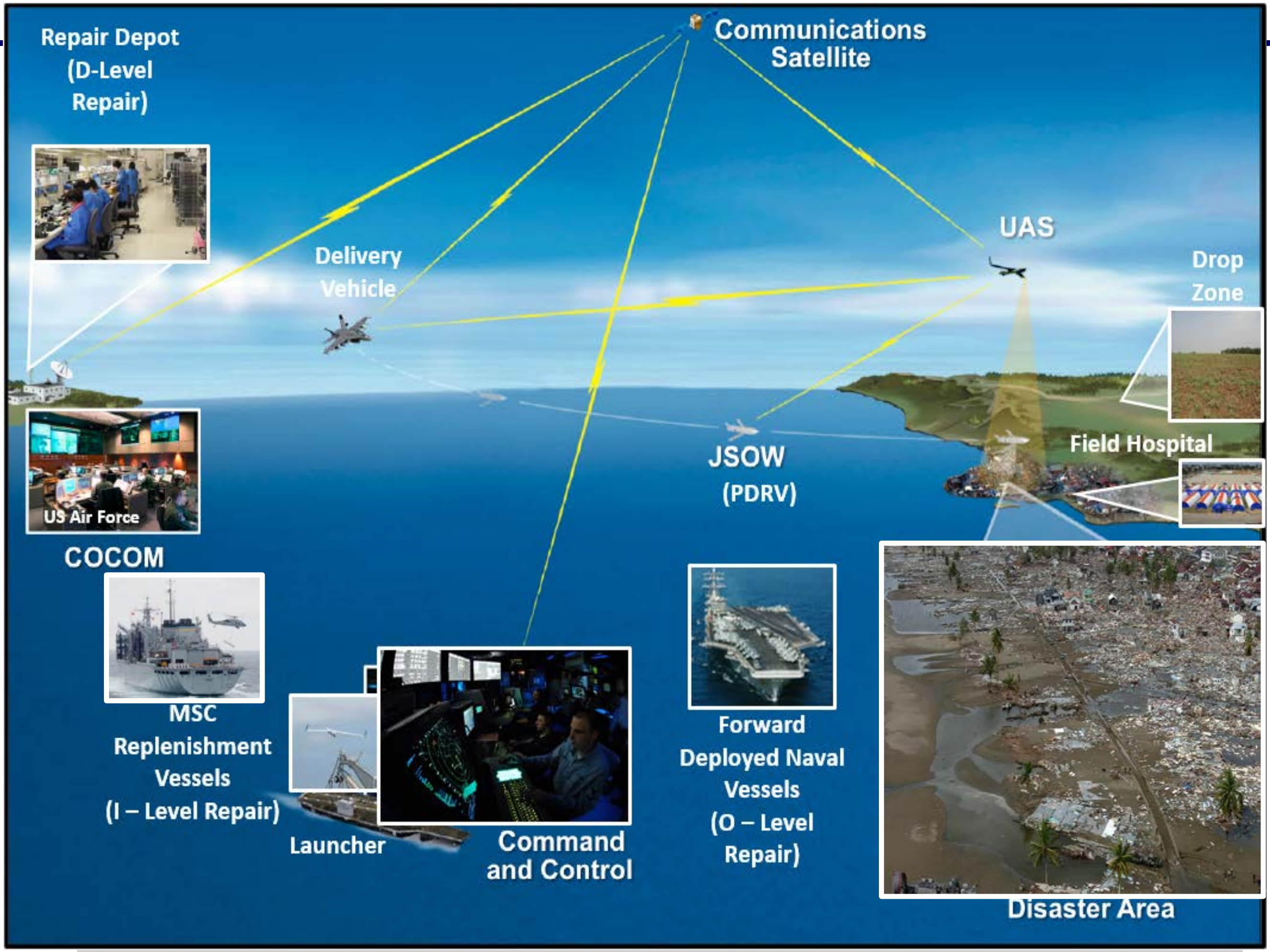
~50 Top Level System Requirements

Assumptions

- The decision of where to provide relief will be determined by the Navy;
- Reuse of Navy equipment aboard vessels carrying the PDRV to the maximum extent possible;
- Scope of PDRV deployment/support extends to all nine Unified Combatant Commands;
- Deployment of PDRV is only via aircraft or PDRV launcher;
- PDRV Payload content is available when needed; and
- Required personnel are available and accessible when needed.
- Operations of the PDRV will be handled by the Armed Forces

Assumptions made early to bound scope and design depth

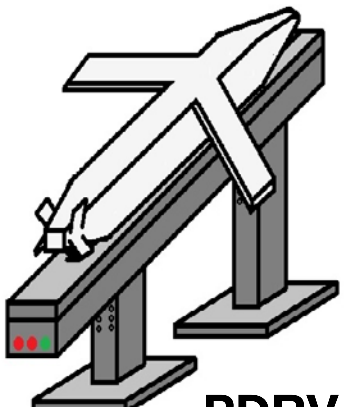
CONOPS



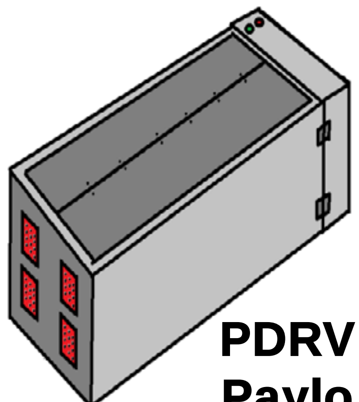
Leverage existing JSOW CONOPS to ensure maximum compatibility for PDRV upgrade

System / Technical Description

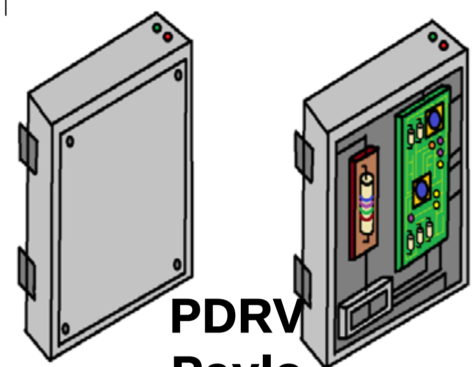
- PDRV System designed to address current deficiencies by rapidly providing humanitarian aid and relief supplies to areas around the world affected by disasters that are inaccessible by regular means
- PDRV System design consists of 8 internal subsystems and 2 external subsystems
  - Leverage existing communication and command and control of the US Navy
- Major upgrades to the legacy system include Payload, Propulsion & Launcher



PDRV & Launcher



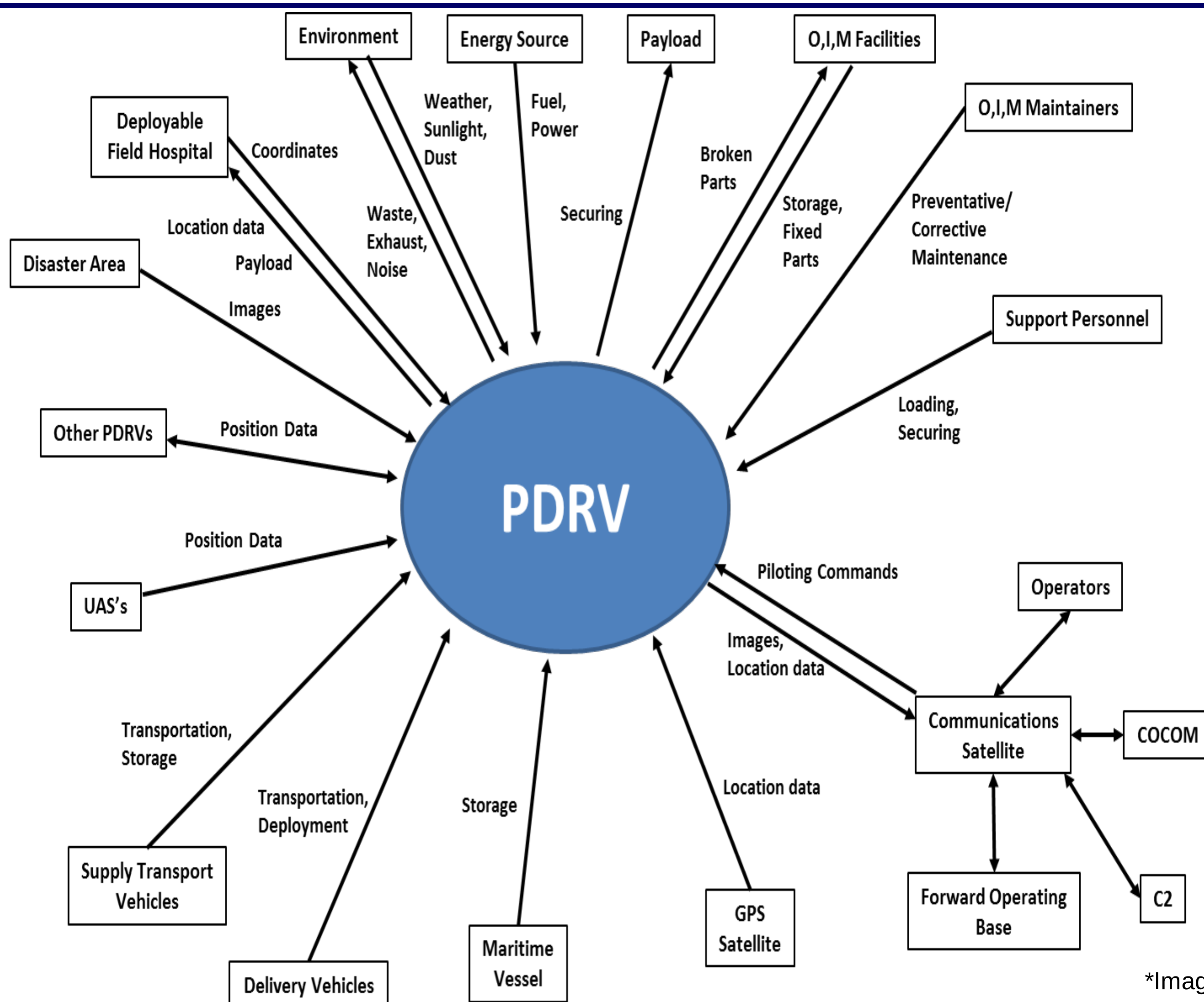
PDRV Payload Bay Module



PDRV Payload Control Module

PDRV Provides Rapid Relief Supplies to areas in need utilizing common JSOW design architecture

Context Diagram



Inset: US NAVY

*Images referenced on page 31

System Pedigree

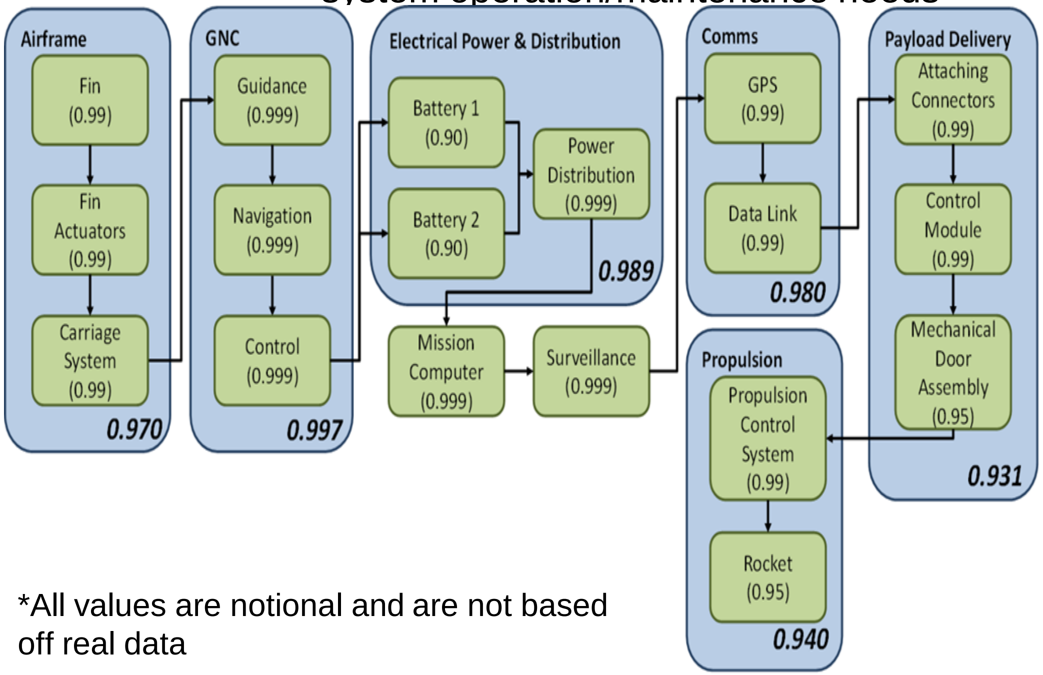
System Component	Source / Prime	Modified Legacy / New
Airframe	Raytheon	JSOW-ER Mod
Propulsion System	Raytheon	JSOW-ER Mod
Electrical Power and Distribution	Raytheon	JSOW-ER Mod
GNC System	Raytheon	JSOW Block III and JSOW-ER Mod
Mission Computer	Raytheon	JSOW-ER Mod
Communications System	Raytheon	JSOW Block III Mod
Surveillance System	Raytheon	JSOW Block III Mod
Payload Delivery	Raytheon	JSOW Block III Mod
Payload Launcher	Raytheon	New
Payload Package	Vendor / Depot	New

8 modified subsystems; 2 proposed new subsystems

MTBFs and Reliability Block Diagram

System Component	MTBF (Hours/Failure)	Reliability
Fin Assembly	500	0.9900
Fin Actuator Assembly	500	0.9900
Carriage System	500	0.9900
Guidance System	5000	0.9990
Navigation System	5000	0.9990
Control System	5000	0.9990
Battery 1	50	0.9048
Battery 2	50	0.9048
Power Distribution	5000	0.9990
Mission Computer	5000	0.9990
Surveillance System	5000	0.9990
GPS	500	0.9900
Data Link	500	0.9900
Attaching Connectors Assembly	500	0.9900
Control Module	500	0.9900
Mechanical Door Assembly	100	0.9512
Propulsion Control System	500	0.9900
Rocket	100	0.9512

- Developed a notional RBD and predictions for new and existing hardware
  - Need to consider failure rates, failure modes, single point failures, and other vulnerabilities introduced by new elements
    - Enables abilities to plan for maintenance, predict spares, and understand nominal system operation/maintenance needs



*All values are notional and are not based off real data

Maintenance Concept

Repair Depot
(D-Level Repair)

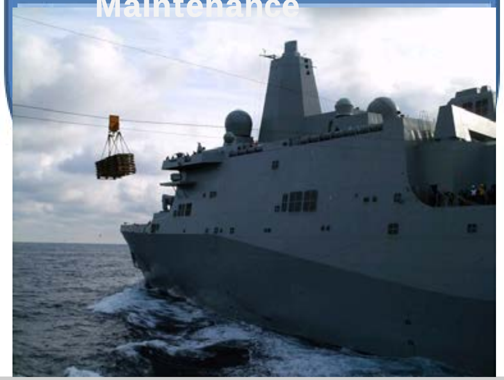
Major repair activities:

- Major Component Repair & Replacement
- SW & Firmware updates
- Complex troubleshooting
- M&S
- Repair & Refurbish of reusable parts

MSC Replenishment Vessels
(I – Level Repair)

Maintenance activities and Minor Repairs:

- Component HW Repair & Replacement
- Diagnostic Test & Analysis
- Corrective Maintenance



Fwd Deployed Vessels
(O – Level Repair)

Maintenance activities:

- Inspection, Diagnostics, Preventative Maintenance

Testing Equipment and Training Support 3 Levels of Maintenance

Maintenance Personnel

Location (D, I, O)	Personnel	Level	# Needed
D	Technician	Master	1
D	Maintenance Engineer (Raytheon)	E03+	2
D	Software Engineer (Raytheon)	E03+	2
D	Lab Technician (Raytheon)	E03+	1
D	Logistician	E03+	1
I	Machinist, Civil Service Mariner	Senior	1
I	USCG Licensed Engineers	3rd Grade	3
I	Electrician, Civil Service Mariner	Senior	1
I	Logistician, Civil Service Mariner	Senior	1

D-Level

I-Level

O-Level

No specialized or new personnel needed to maintain the RDRV

Recommended Course of Actions (FMECA)

- **Performed focused FMECA analysis on key areas of upgrade to determine and mitigate any new failure modes introduced into design**

- **Payload Delivery Subsystem Key to Mission Success**
  - Failure to deploy payload = Mission Failure
- **FMECA Complete - 2 Major Issues Identified**

- **Issue:** Payload module opens payload doors uncommanded during launch
- **Effect:** Mechanical interference with launcher platform during launch operations, leading to severe mechanical damage to the PDRV system, unintended delivery of payload, and failure of the PDRV mission **<u>(RPN = 400)</u>**
- **Potential Cause:** CCA element failure (e.g., short circuit); Faulty PDRV communications controller interface
- **Action Taken:** Incorporated fail-safe mechanism into servomotors to prevent doors opening uncommanded in event of a CCA/system failure **<u>(New RPN = 40)</u>**

- **Issue:** Payload doors fail to open during mission
- **Effect:** Payload is not delivered at the intended time, resulting in failure of PDRV mission
- **Potential Cause:** Multiple (CCA failures; servomotors failure; interface failures; power failures; etc.)
- **Action Taken** … ators; Redefinition of PDRV CONOPS and mission success criteria

Corrective Actions Taken to Mitigate Payload Module Fail

Logistics Support Planning

- Multifaceted approach through several key logistics analysis efforts performed throughout program development
  - **Logistics Support Analysis (LSA)**
    - Requirements; Logistics data elements
  - **Level of Repair Analysis (LORA)**
    - Lowest Replaceable Unit (LRU) identification; Maintenance/site/facilities planning considerations
  - **Logistics Management Information (LMI) development**
    - Database planning for logistics data elements
  - **Spares Analysis**
    - Identification of recommended LRU quantities at the various levels & locations of maintenance

Planning performed early in life cycle to integrate logistics considerations and requirements in system design and development

LSA / LMI Data Elements

- **Part Identification:**
  - Part Number, Cage Code, Lot Code, Batch Code, National Stock Number, Reference Number Category Code, Reference Number Variation Code, Service Agency Designator Code
- **System Identification:**
  - Reference Designation, Indenture Level, Revision, System Quantity
- **Physical Characteristics:**
  - Weight, Weight (Packaged), Height, Height (Packaged), Width, Width (Packaged), Length, Length (Packaged)
- **Handling/Storage Characteristics:**
  - Hazmat Code, Precious Metals Indicator Code, Electrostatic Discharge Code, Hazardous Materials Indicator Code, Hazardous Characteristics Code
- **Maintenance Characteristics:**
  - LRU/RPP Identification, Source/Maintenance/Repair Code, Demilitarization Code, Shelf Life
- **Sparing Data:**

LMI data forms the backbone of all future logistics, operations, and maintenance activities

Level of Repair Analysis (LORA)

Level	Item	Level of Repair	Disposition	Make/Buy	System Quantity
PDRV					
0	PDRV System	Depot	Disposal	Make	1
Airframe					
1	Fin Assembly	Depot	Disposal	Buy	1
2	*Fin*	Depot	Disposal	Buy	2
1	Fin Actuator	Depot	Disposal	Buy	1
1	Carriage System	Intermediate	Rework to Print	Buy	1
GNC					
1	Guidance System	Depot	Rework to Print	Buy	1
1	Navigation System	Depot	Rework to Print	Buy	1
1	Control System	Depot	Rework to Print	Buy	1
Electrical Power and Distribution					
1	Battery 1	Organizational	Remove & Replace	Buy	1
1	Battery 2	Organizational	Remove & Replace	Buy	1
1	Power Distribution	Depot	Rework to Print	Buy	1
Mission Computer					
1	Mission Computer	Depot	Remove & Replace	Buy	1
Surveillance System					
1	Surveillance System	Depot	Rework to Print	Make	1
Communications					
1	GPS	Intermediate	Remove & Replace	Buy	1
1	Data Link	Intermediate	Remove & Replace	Buy	1
Payload Delivery					
1	Attaching Connectors Assembly	Intermediate	Rework to Print	Buy	1
2	*Connector*	Intermediate	Remove & Replace	Buy	4
1	Control Module	Organizational	Remove & Replace	Make	1
1	Mechanical Doors Assembly	Intermediate	Rework to Print	Buy	1
2	*Payload Door*	Intermediate	Rework to Print	Buy	2
2	*Mechanical Arms*	Intermediate	Rework to Print	Buy	4
2	*Servomotor*	Intermediate	Remove & Replace	Buy	2
Propulsion					
1	Propulsion Control System	Intermediate	Remove & Replace	Buy	1
1	Rocket	Intermediate	Remove & Replace	Buy	1

- **O-Level Considerations**
  - Limit maintenance loading
  - Limit spares allocation
    - Space constraints
  - Aligns with personnel skill level
    - Easy R&R (quick connect/disconnect)
- **I-Level Considerations**
  - Take advantage of engineering/mechanical personnel backgrounds
    - Allocated rework to print
  - Take advantage of MSC vessel non-mission based downtime
    - More opportunities to perform maintenance
- **D-Level Considerations**
  - Reserve most difficult / equipment intensive tasks
    - Tools/personnel available
  - Sole source of disposal

*All values are notional and are not based off real data

LORA ensures cost and efficiency optimization of maintenance activities at all supported levels

Supply Support / Sparing

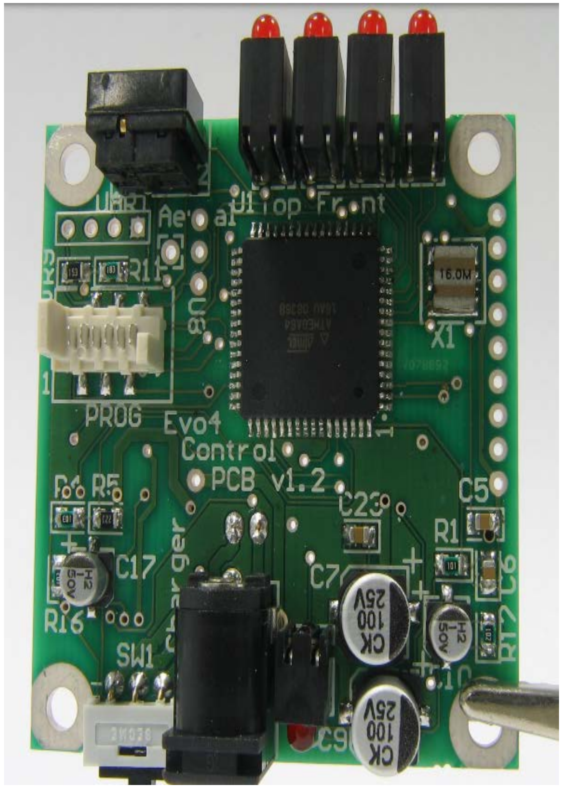
- Performed using reliability predictions and LORA data and several assumptions (listed in report)
- D-Level omitted due to logistics lead time
  - Will procure material as-needed in advance of maintenance activity

*All values are notional and are not based off real data

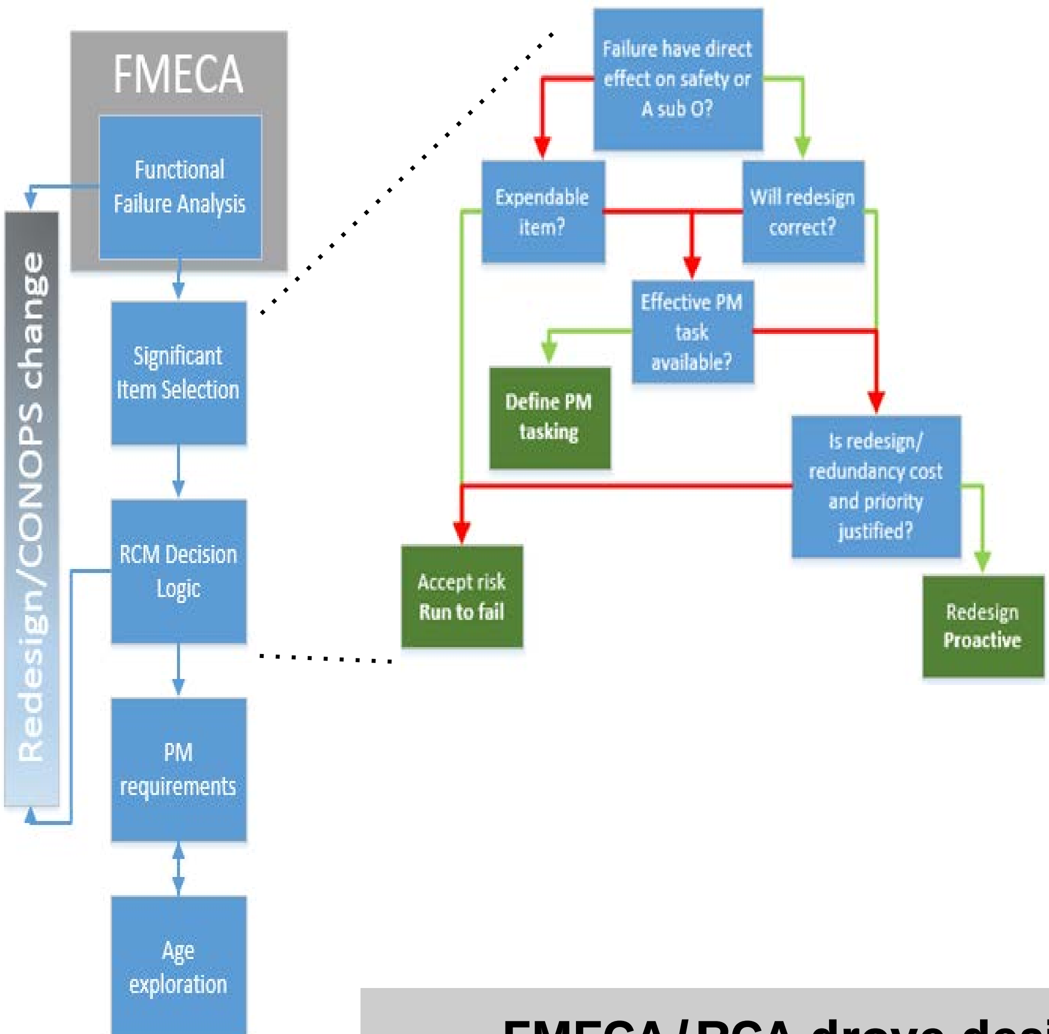
Level	Item	MTBF	Reliability	Level of Repair	Disposition	Make/Buy	System Quantity	Time to Repair	MTBF (FPMH)	Spares Quantity (1 PDRV)	Spares Quantity (10 PDRVs)
PDRV											
0	PDRV System		0.8228	Depot	Disposal	Make	1				
Airframe											
1	Fin Assembly	500	0.99	Depot	Disposal	Buy	1		2000		
2	*Fin*	1000	0.995	Depot	Disposal	Buy	2		1000		
1	Fin Actuator	500	0.99	Depot	Disposal	Buy	1		2000		
1	Carriage System	500	0.99	Intermediate	Rework to Print	Buy	1	168	2000	2	7
GNC											
1	Guidance System	5000	0.999	Depot	Rework to Print	Buy	1		200		
1	Navigation System	5000	0.999	Depot	Rework to Print	Buy	1		200		
1	Control System	5000	0.999	Depot	Rework to Print	Buy	1		200		
Electrical Power and Distribution											
1	Battery 1	50	0.9048	Organizational	Remove & Replace	Buy	1	2	20000	1	2
1	Battery 2	50	0.9048	Organizational	Remove & Replace	Buy	1	2	20000	1	2
1	Power Distribution	5000	0.999	Depot	Rework to Print	Buy	1		200		
Mission Computer											
1	Mission Computer	5000	0.999	Depot	Remove & Replace	Buy	1		200		
Surveillance System											
1	Surveillance System	5000	0.999	Depot	Rework to Print	Make	1		200		
Communications											
1	GPS	500	0.99	Intermediate	Remove & Replace	Buy	1	168	2000	2	7
1	Data Link	500	0.99	Intermediate	Remove & Replace	Buy	1	168	2000	2	7
Payload Delivery											
1	Attaching Connectors Assembly	500	0.99	Intermediate	Rework to Print	Buy	1		2000		
2	*Connector*	2000	0.9975	Intermediate	Remove & Replace	Buy	4	168	500	2	7
1	Control Module	500	0.99	Organizational	Remove & Replace	Make	1	4	2000	1	1
1	Mechanical Doors Assembly	100	0.9512	Intermediate	Rework to Print	Buy	1		10000		
2	*Payload Door*	250	0.98	Intermediate	Rework to Print	Buy	2	168	4000	4	21
2	*Mechanical Arms*	5000	0.999	Intermediate	Rework to Print	Buy	4	168	200	1	4
2	*Servomotor*	1780	0.9972	Intermediate	Remove & Replace	Buy	2	168	562	1	5
Propulsion											
1	Propulsion Control System	500	0.99	Intermediate	Remove & Replace	Buy	1	168	2000	2	7
1	Rocket	100	0.9512	Intermediate	Remove & Replace	Buy	1	168	10000	5	25

Obsolescence Management

- Enacted Obsolescence Management for PDRV program
- Early identification of propulsion control system CCA as obsolescence risk
  - Low cost mass produced CCA that provides control functionality for the PDRV propulsion element
  - Procured from COTS based supplier with rapid deployment of upgrades/updates
    - History of discontinued products and product line support
- Mitigation plan - Lifetime buy
  - Determined annual failures of component against total fielded assets and projected PDRV life span
  - Lifetime buy indicated 20,000 units sufficient to cover lifetime worth of failures



Reliability Centered Maintenance



- **RCA analyses concurrent with FMECA generation**
- **Analysis drove proactive design changes (redundancy) and CONOPS changes (degraded modes)**
- **RCA drove PM schedules for 5 critical items related to payload**
  - Initially once monthly, ... ycle ... coincides with NAVY 56

FMECA / RCA drove design changes and maintenance CONOPS

Reliability Centered Maintenance

- The contractor shall implement a reliability centered maintenance plan to be evaluated annually.
- RCM shall be used to ensure effective maintenance processes are implemented.
- RCM shall be used as a logical decision process for determining optimum failure management strategies, including maintenance approaches, and establishing the evidence of need for both reactive and proactive maintenance tasks.
- RCM will be practi
- RCM will follow NA software, training, and certification.

Critical Item	Proposed PM Tasking	Initial interval	Can be performed by
Latch	Visually inspect fasteners for signs of corrosion or change	1 monthly	Civil Service mariner (machine)
Connector	Visually inspect connector for signs of corrosion or change	1 monthly	Civil Service mariner (electrical)
Door	Application of lubricant; Functional test door open and door close on command	1 monthly	Civil Service mariner (machine)
Door motor	Functional test door open and door close on command Visual inspection servos/motor	1 monthly	Civil Service mariner (electrical)
Door arms	Functional test door open and door close on command	1 monthly	Civil Service mariner (machine)

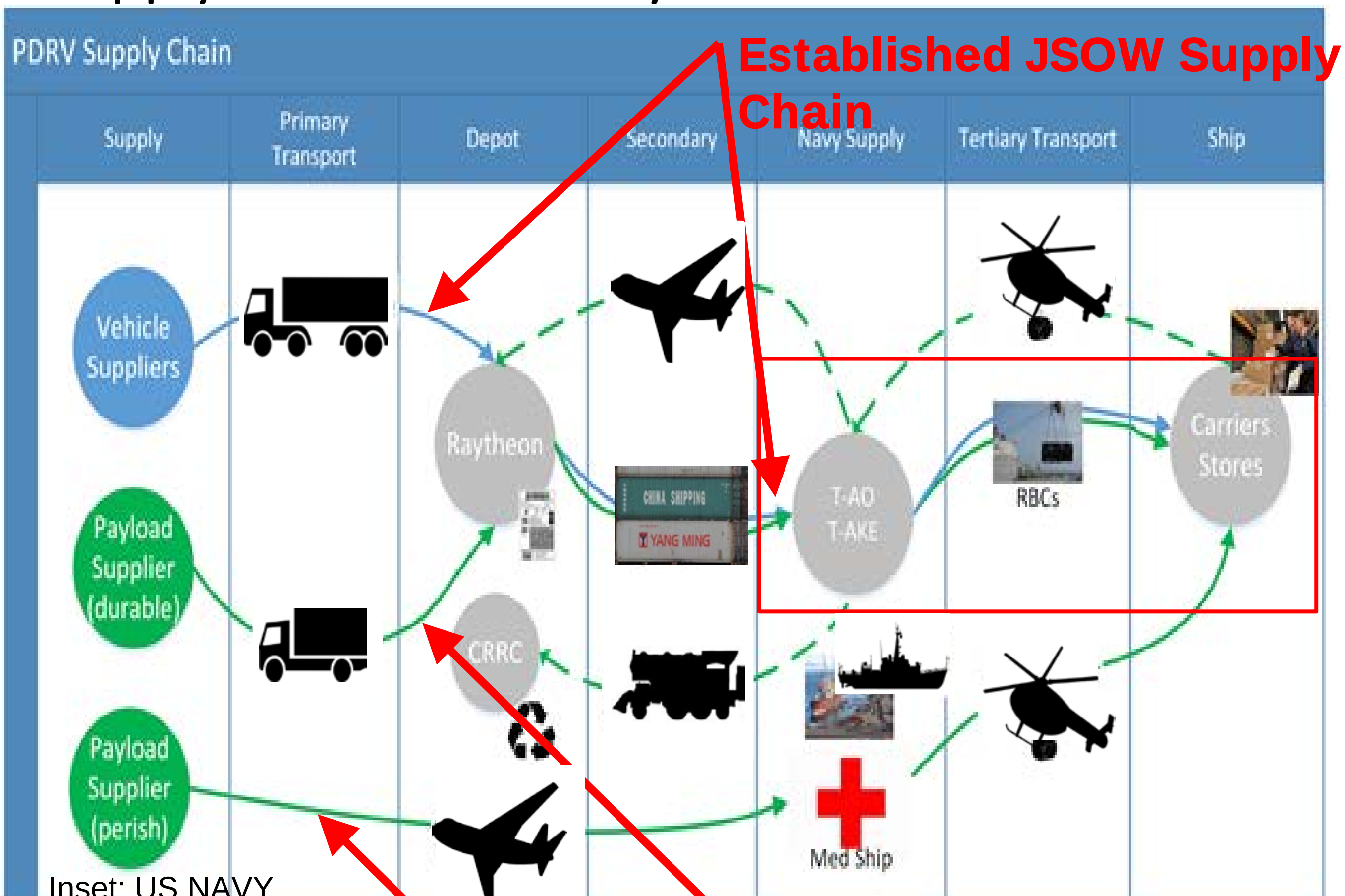
PHS&T Methodology

- Utilize existing US Navy and JSOW PHS&T methods when possible
- Configuration 1 includes airframe w/ payload subsystem, pre-packaged
  - Payload Type 1 is long-shelf life items (water purification, electronic goods, non-perishable items)
  - Up to 2 years uninterrupted storage with vehicle
- Configuration 2 airframe & empty payload bay for modular Payload Type 2 for incorporation on aircraft carrier
  - Payload Type 2 - short-shelf life (refrigerated items, medical, etc)
  - Storage and

Direction of Supplies	Supply list	PHS&T considerations
Supplier to Depot/OEM	PDRV Vehicle,Launcher Platform, Payload Supply Type 1, Payload Supply Type 2	Commerical shipping, Navy Depot Storage, standard form factor packaging
Shipyard Warehouse storage to MSC Vessels	PDRV Vehicle, Launcher Platform, Payload Supply 1	Modular supply containers, utilize shipping crates, crane equipment, forklift
Medical Navy Vessel to Aircraft Carrier	Payload Supply Type 2	Modular supply containers, underway replenishment
MSC Vessel to Aircraft Carrier	PDRV Vehicles (Unloaded and loaded types), Payload Supply Type 1, Launcher Platform	Underway replenishment, Vertical replenishment

PDRV Supply Chain

- Efficient supply chain enabled by a two-configu



Inset: US NAVY

Config 1 (durable) supply chain

Config 2 (perishable) supply

Manufacturing / Production Considerations

Potential Manufacturing / Production Issues and Considerations	Action/Mitigation
Re-use of drawings for design and integration	Provide a JSOW test asset for the design, integration and manufacturing teams.
Standing up a new manufacturing team/line	JSOW-ER production line about to stand up and there is potentially an opportunity to share resources
New subcontractors may be used for new subsystems	Continued rigorous screening of any COTS items to ensure only materials on the 'allowed' list are used
Payload securing for potentially dangerous medical supplies	Extra emphasis will need to be placed on sealing the Payload Delivery system

Taking advantage of current JSOW manufacturing techniques and resources will help alleviate most of the risk associated with the PDRV

Training

- Training consists of instructor led and web-training as needed at each repair level and for Operators.
  - Occurs during active duty training, or weekend reserve training activities
- Proposed training specifies additional training for the PDRV upgrades, the Launcher device, and the Payload delivery system in addition to existing Navy

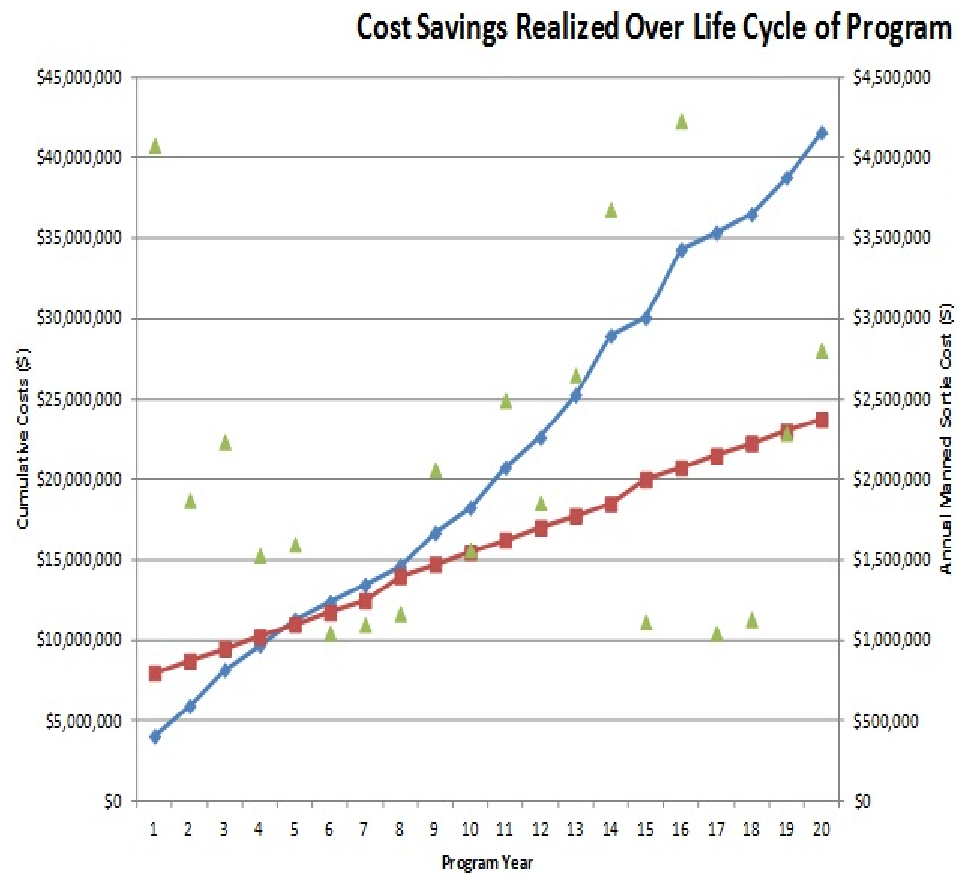
Training Type	Description
D-Level Maintenance Training	PDRV payload delivery disassembly, diagnostic testing, HW repair, SW updates, re-use of recoverable parts, disposal
I-Level Maintenance Training	PDRV payload delivery disassembly, diagnostic testing and HW repair
O-Level Maintenance Training	Inspection of PDRV payload delivery system (airworthiness), replacement of LRUs,automatic diagnostic testing

Life Cycle Cost Analysis (LCCA)

- Desire to stress importance of ensuring safe PDRV deployment and cost savings for life cycle of program
  - Developed launcher platform in order to address these concerns
- Research figures indicated F/A-18 aircraft incurred and average $17.2k cost for a single deployment during Operation: Desert Storm
- Cost simulation was ran using an exponential distribution of projected number of manned sorties over an estimated program lifespan of 20 years
- Compared

*Source: “Cost and Performance of Major U.S. and U.K. Desert Storm Air-to-Ground Aircraft and TLAM (6/12/97)”

Life Cycle Cost Analysis (LCCA)



Projected Number of Manned Sorties	Annual Manned Sortie Cost	Cumulative Sortie Cost	Annual Launcher Costs	Launcher Platform Cumulative Costs
237	$4,076,400	$4,076,400	$8,000,000	$8,000,000
109	$1,874,800	$5,951,200	$750,000	$8,750,000
130	$2,236,000	$8,187,200	$750,000	$9,500,000
89	$1,530,800	$9,718,000	$750,000	$10,250,000
93	$1,599,600	$11,317,600	$750,000	$11,000,000
61	$1,049,200	$12,366,800	$750,000	$11,750,000
64	$1,100,800	$13,467,600	$750,000	$12,500,000
68	$1,169,600	$14,637,200	$1,500,000	$14,000,000
120	$2,064,000	$16,701,200	$750,000	$14,750,000
91	$1,565,200	$18,266,400	$750,000	$15,500,000
145	$2,494,000	$20,760,400	$750,000	$16,250,000
108	$1,857,600	$22,618,000	$750,000	$17,000,000
154	$2,648,800	$25,266,800	$750,000	$17,750,000
214	$3,680,800	$28,947,600	$750,000	$18,500,000
65	$1,118,000	$30,065,600	$1,500,000	$20,000,000
246	$4,231,200	$34,296,800	$750,000	$20,750,000
61	$1,049,200	$35,346,000	$750,000	$21,500,000
66	$1,135,200	$36,481,200	$750,000	$22,250,000
133	$2,287,600	$38,768,800	$750,000	$23,000,000
163	$2,803,600	$41,572,400	$750,000	$23,750,000
			Cost savings over life of program	$17,822,400
			Avg. # of missions/year	127
			Avg. savings/year (based on # of missions/year)	$2,184,400

*All values are notional and are not based off real data

Trade off upfront costs in order to realize safety risk mitigation and cost savings over life of the program

Conclusion

- Integrated logistics supports fictional solution that addresses the humanitarian aid and disaster relief mission
  - Focus on leveraging existing US Navy Logistics plan, JSOW architecture and support, equipment, personnel and maintenance processes
  - Realized several opportunities to decrease overall life cycles costs and improve supportability compared to other available options
- Principles applied in this academic project are applicable to real-world deployed systems
  - Reflects best practices to be taken when hardware

Flexible sustainment architecture and focus on integrated logistics can be applied to real world deployed systems

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