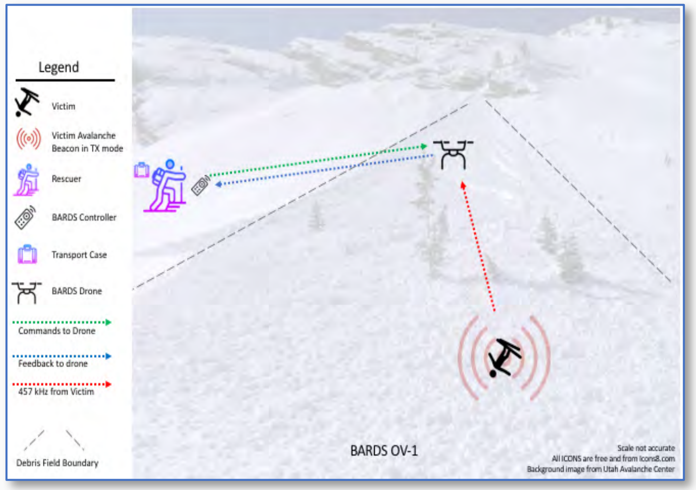
Backcountry Avalanche victim Recovery Drone System (BARDS)

SM4 – Capstone Presentation – Fall 2018
Johns Hopkins Engineering for Professionals
Whiting School of Engineering
Mentor: Steve Biemer

Doug Smith
15 Nov 2018



Overview

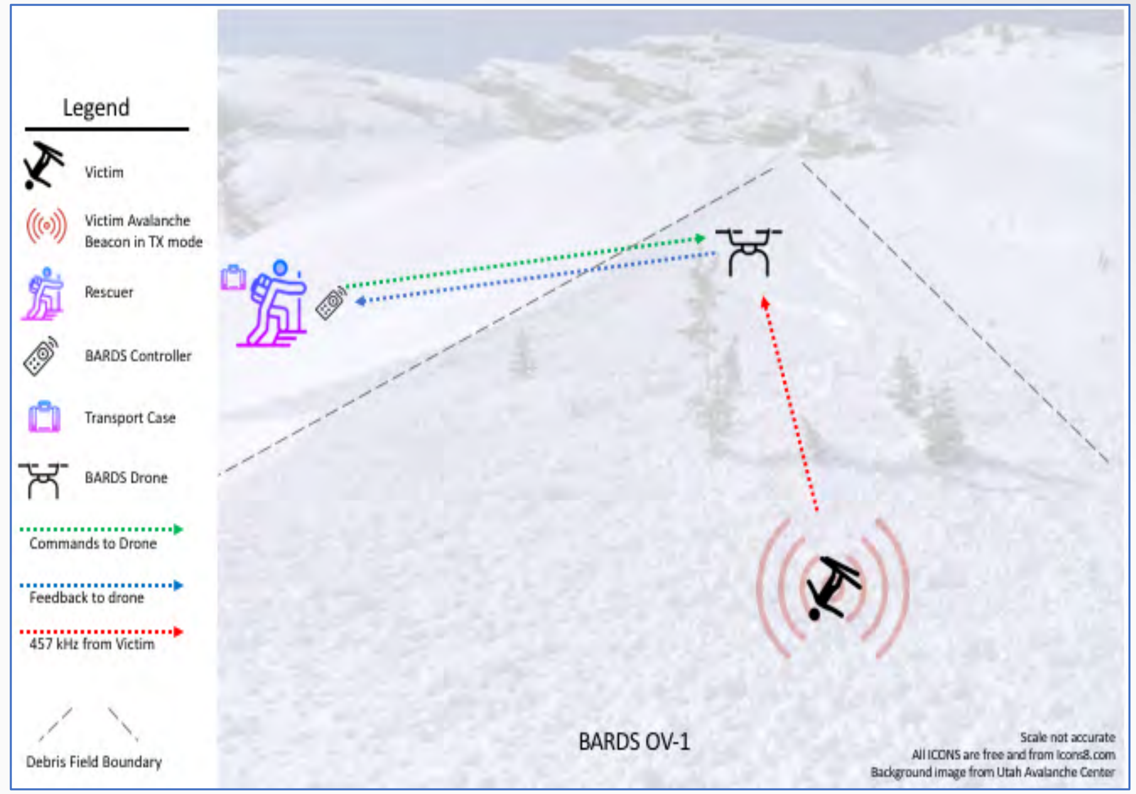
- Biography
- Introduction
- Need
- Requirements Elicitation and Summary
- CONOPS
- Functional Concept
- Physical Concept
- Trade Study
- Risk Management
- Test Plan
- System Specification & KPPs
- Summary of Final Concept and Further Work
- Lessons Learned
- Recommendations

Biography

- Personal
  - 51 Years Old; married w/four kids (20-25 years old)
  - Mountain Green, Utah
- Professional
  - Retired Air Force O-6 (1989-2014); ICBM, Space and NC3 Operations
  - Air Force instructor in three weapon systems; ISD; college instructor
  - Johns Hopkins Applied Physics Lab (2014 – current)
  - Site Lead, JHU/APL support to the ICBM Systems Directorate, Hill AFB, UT
    - Provide systems engineering support to $85B DoD ACAT ID program
- Education
  - BGS, General Studies, Auburn University Montgomery, 1989
  - MA, Aeronautical Sciences, Embry Riddle Aeronautical University, 1993
  - MS, Military Operational Arts and Sciences, Air University, 2004
- Other
  - Many outdoor activities – summer and winter
  - Physical fitness, health and cooking

BARDS Introduction

- Customized COTS Drone w/avalanche receiver, remote and case
- Autonomous and manual modes
- Five use cases
- Expedited victim marking
  - KPP – Efficacy (recovery in 3-5 min)
  - KPP – Coverage (500 m^2 in <1 min)
  - KPP – Marking (w/in 1 m^2)

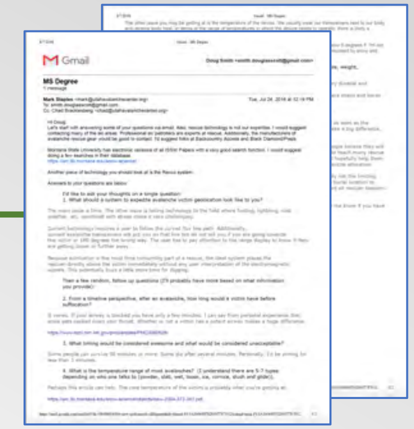


Need

- Backcountry adventure is high-reward/high-risk
- 546 avalanche fatalities in U.S. since 1998 (25 in 2017-2018)*
- Current means of recovery are relatively sound, but not efficient or timely, and NOT informed by most recent technologies
  - Manual and tedious search, possibly over wide-swath of debris
- $500-$2000 = price range for backcountry adventure gear
  - Beacon, shovel, probe, backpack, airbag

*Colorado Avalanche Information Center. *US Avalanche Accident Reports*. https://avalanche.org/avalanche-accidents. Accessed 27 Jun 18

Requirements Elicitation



Initial email w/Mark Staples

- Mission needs and requirements analysis
  - User interviews, both verbal and written
    - Mark Staples, Director, U.S. Forest Service Utah Avalanche Center
    - Darren Rabosky, Engineer and middle-aged backcountry adventurer
    - Adam Jordan, Fire Fighter/EMT, GFFD, MT; Former Director, Venture Program @ MWSB
    - Adam Smith, 22-year-old backcountry adventurer and savvy thinker
  - Other SMEs throughout (see next page)
  - Avalanche study (science behind them; dangers; examples (and deaths))
  - Backcountry use cases and resulting concept strategies
  - Avalanche beacon testing in Montana
- System objectives (SO) identified
  - SO1 – Create a more efficient victim geolocation system over the current method
  - SO2 – Perform victim geolocation in no more than five minutes from burial
  - SO3 – Create a system that is durable, easy to use, quickly deployable, and capable of both manual and autonomous operation

The "Team" (#1-#4 users; #5-#23 SMEs)

1. (USER) Mark Staples, Director, U.S. Forest Service Utah Avalanche Center
2. (USER) Darren Rabosky, Engineer and middle-aged backcountry adventurer
3. (USER) Adam Jordan, Fire Fighter/EMT, GFFD, MT; Former Director, Venture Program @ MWSB
4. (USER) Adam Smith, 22-year-old backcountry adventurer and savvy thinker
5. Ted Shuman, JHU/APL, MBSE
6. Tom Alberi, JHU/APL, MBSE
7. Dan Christiansen, BAE Systems, MBSE
8. Greg Alquist, BAE Systems, MBSE
9. Rick Dailey, NG, RF engineer, JHU SE Student
10. Tim Vielring, U.S. Army Reserve, Drone Expert, JHU SE Student
11. Adam Lord, JHU/ APL, SE and Colleague
12. Kayla Hardy, TMT, SE and Colleague
13. Joey Scavuzzo, Orbital ATK, Polymer Scientist
14. Kyle Fox, DAF, SW Engineer
15. Jeff Osborn, JHU/APL, RF Engineer and SOS Architect
16. Daniel Feldman, JHU/APL, Thoeretical Particle Physicist
17. Brock Larson, BAE Systems, Mechanical Engineer
18. Dave Bliesner, BAE Systems, Colleague and advisor
19. Mike Davenport, DAF, Electrical Engineer
20. Rob Watson, DAF, Systems Engineer
21. Capt Bob Rodgers, USAF, Electrical Engineer
22. Ky Dorsey, Mckay Dee, Psychologist
23. Joe Warfield, JHU/APL, Statistician

SMEs w/PhD: 5, 8, 13, 16, 19, 22, 23

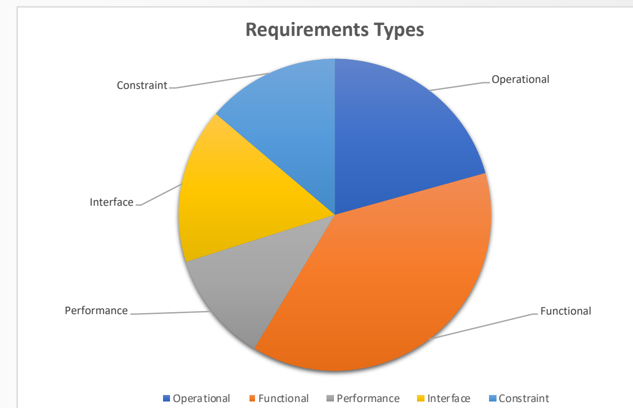
SE: Iterative, Collaborative and Augmented w/tools

Requirements Summary

- Distillation of User needs into:
  - Mission Needs
  - Operational Requirements
  - Functional Requirements
  - Performance Requirements
  - Interface Requirements
  - Constraint Requirements

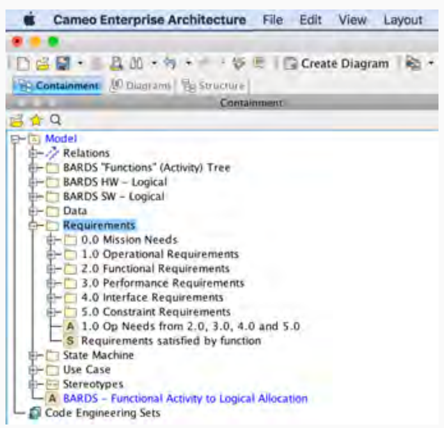
Report	Type	Total	Q	%	B	S
Requirements Analysis Report	MNS	22	3	14%	12	7
	OPER	18	5	28%	13	0
	FUNC	33	0	0	33	0
	PERF	10	9	90%	1	0
	INT	14	5	35%	9	0
	CONS	12	12	100%	0	0
	Total	87	31	35%	56	0

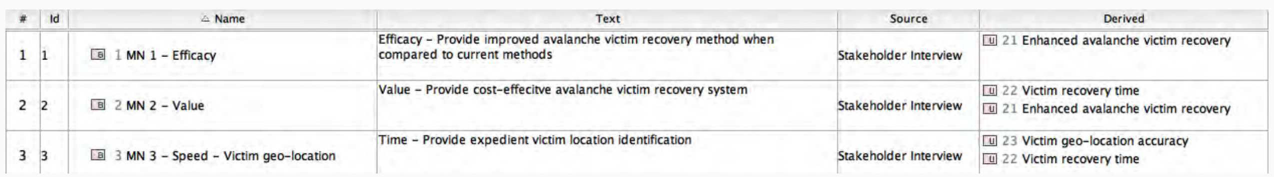
Initial Requirements Work



Requirements Types – Initial

- Captured in Cameo Enterprise Architecture



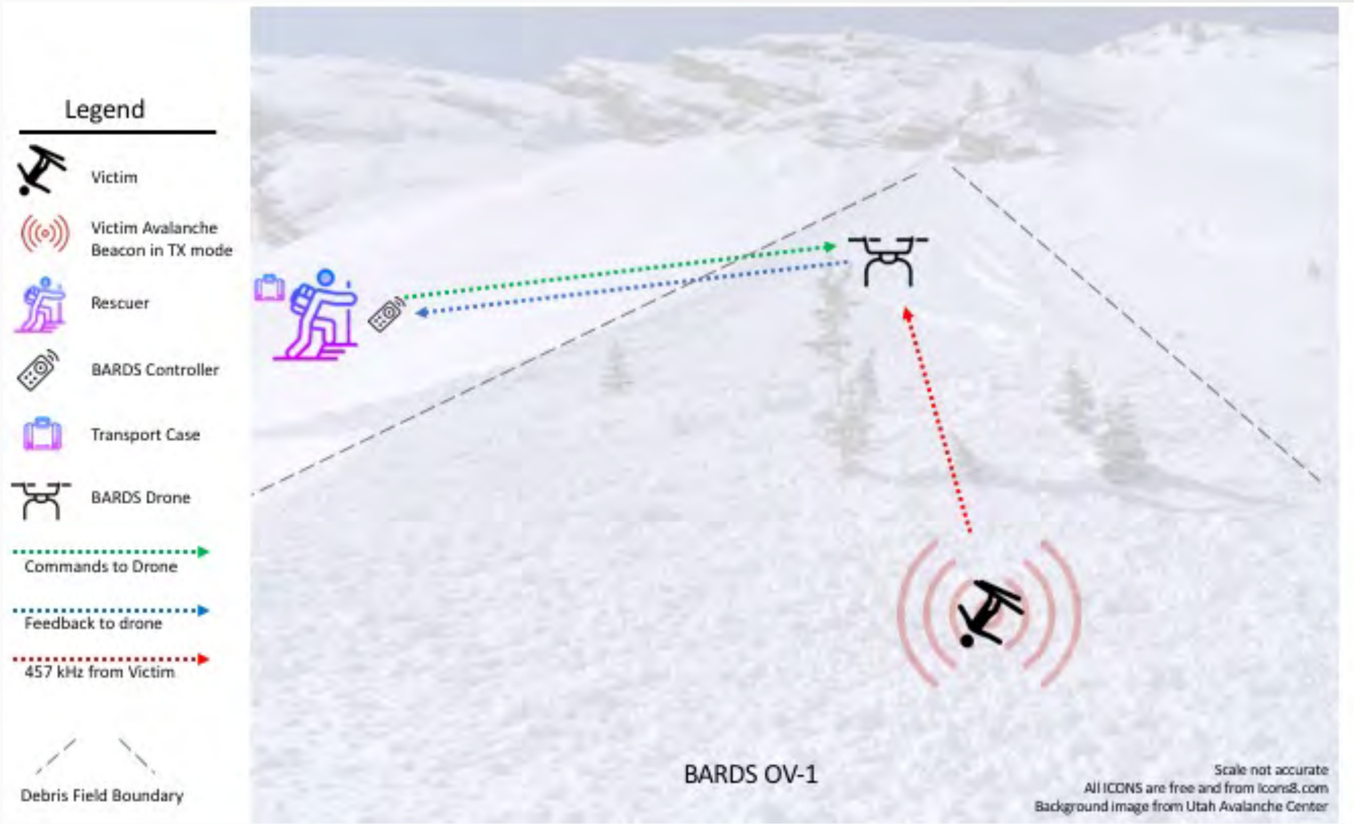


#	Id	Name	Text	Source	Derived
1	1	1 MN 1 – Efficacy	Efficacy – Provide improved avalanche victim recovery method when compared to current methods	Stakeholder Interview	21 Enhanced avalanche victim recovery
2	2	2 MN 2 – Value	Value – Provide cost-effecitve avalanche victim recovery system	Stakeholder Interview	22 Victim recovery time 21 Enhanced avalanche victim recovery
3	3	3 MN 3 – Speed – Victim geo-location	Time – Provide expedient victim location identification	Stakeholder Interview	23 Victim geo-location accuracy 22 Victim recovery time

Requirements captured in Cameo EA

CONOPS – OV-1

- COTS drone, custom payload
- COTS remote
- COTS case, custom inserts
- Custom SW and algorithms



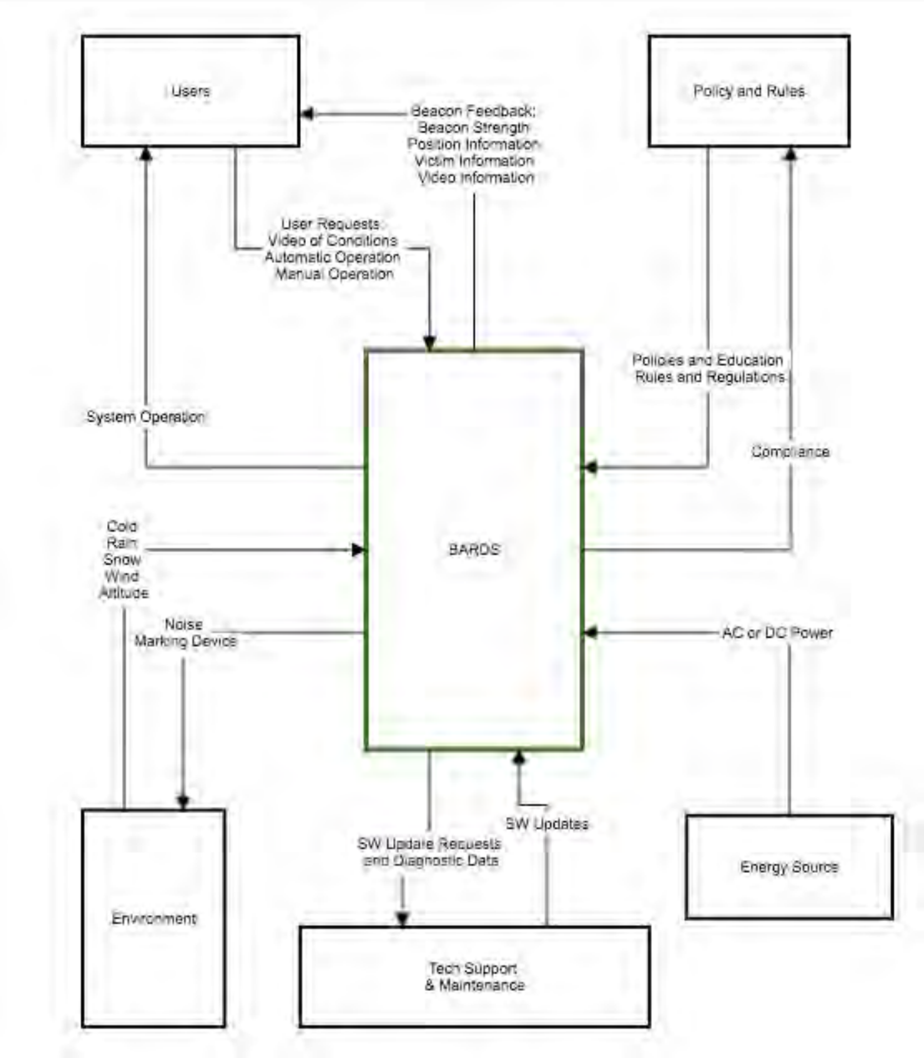
OV-1

CONOPS

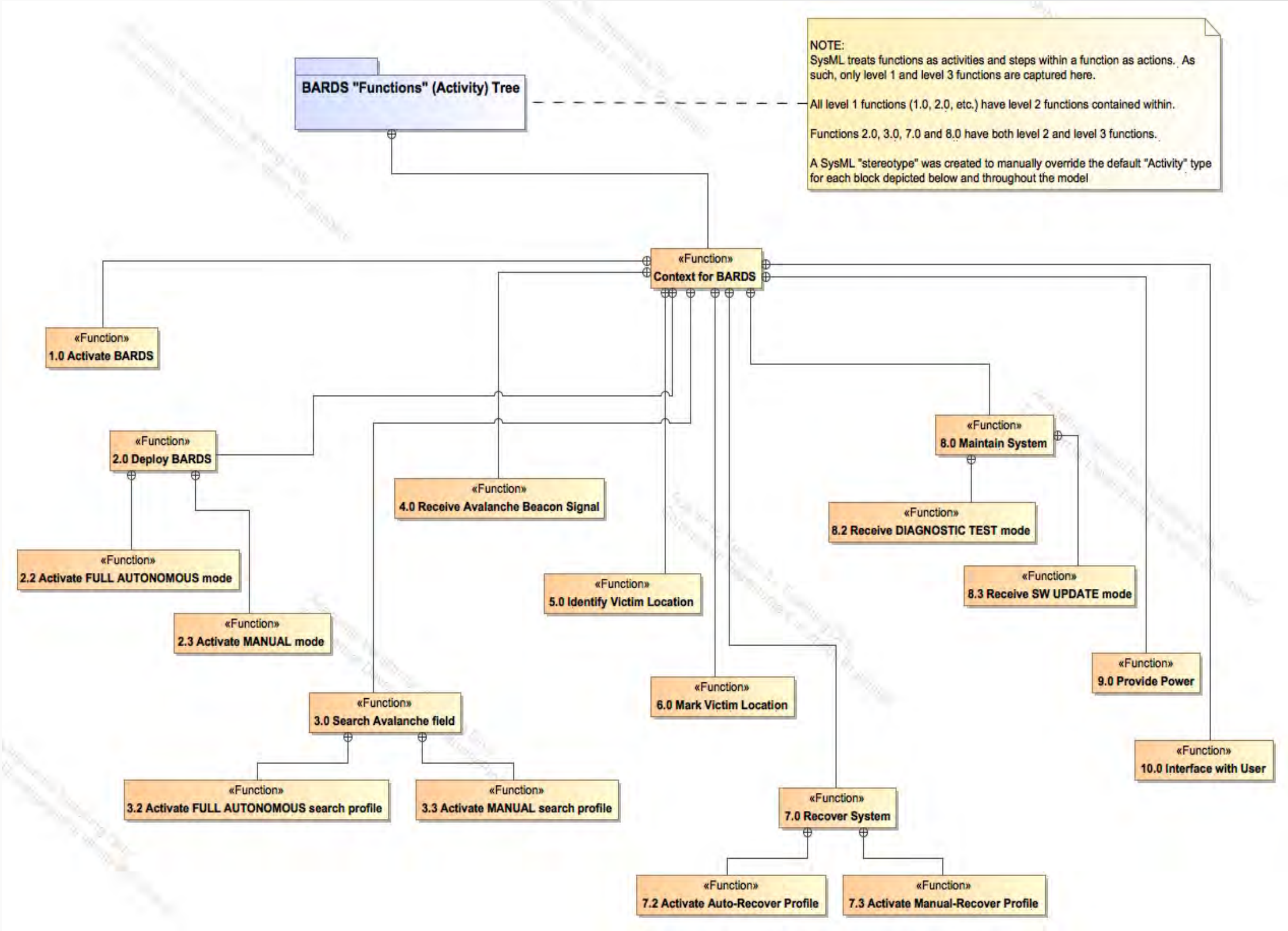
- Drone-based avalanche victim geolocation and marking
- Use Cases
  - UC1 – Emergency use by adventurer or rescue crew
  - UC2 – Avalanche condition evaluation
  - UC3 – Training use by a backcountry adventurer
  - UC4 – Unboxing, system checkout, and system storage
  - UC5 – Maintenance
- Use Case 1
  - Drone transported in backpack
  - Quickly deployed by user into autonomous mode
  - Drone searches for victim avalanche beacon
  - Drone marks victim location with paint balls
  - Drone searches for other victims, then recovers

Use cases allow the SE to articulate functions

Functional Concept – Context and Level 1 FBD



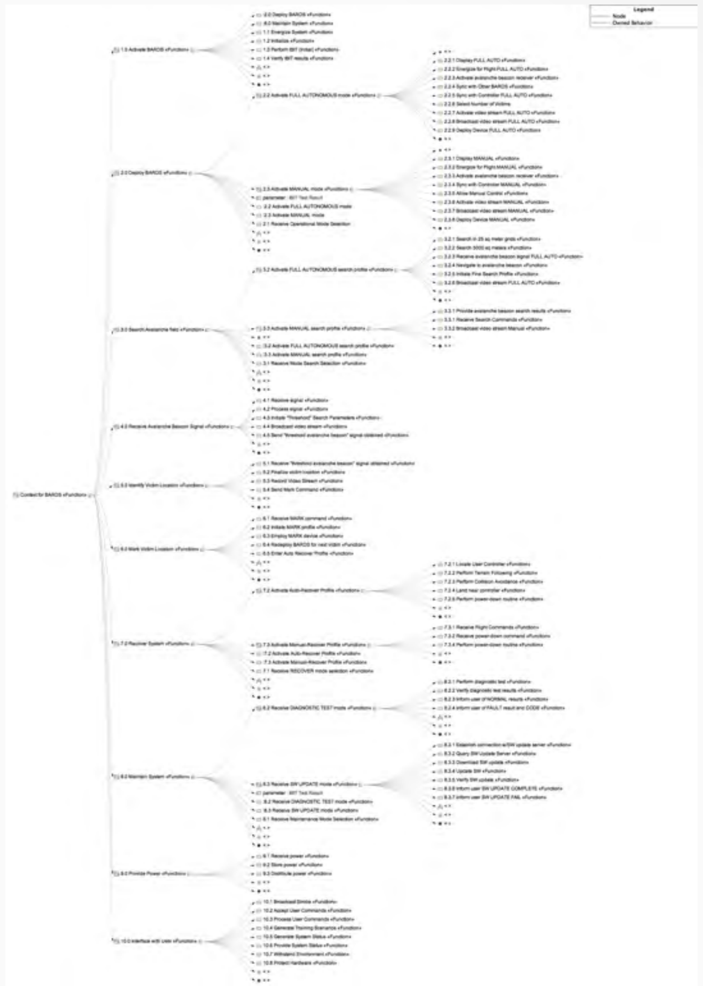
Context Diagram



Level 1 Functional Block Diagram

Functional Concept – Ten Functions

- 1.0 Activate BARDS
- 2.0 Deploy BARDS
- 3.0 Search Avalanche field
- 4.0 Receive Avalanche Beacon Signal
- 5.0 Identify Victim Location
- 6.0 Mark Victim Location
- 7.0 Recover System
- 8.0 Maintain System
- 9.0 Provide Power
- 10.0 Interface with User



Function Tree from Cameo EA

Level 1	Level 2	Level 3	ID#	Function
1			**1.0**	**Activate BARDS**
	1		1.1	Energize System
	1		1.2	Initialize
	1		1.3	Perform IBIT
	1		1.4	Verify IBIT results
1			**2.0**	**Deploy BARDS**
	1		2.1	Receive Operational Mode Selection
	1		2.2	Activate FULL AUTONOMOUS mode
		1	2.2.1	Display FULL AUTO
		1	2.2.2	Energize for Flight FULL AUTO
		1	2.2.3	Activate avalanche beacon receiver
		1	2.2.4	Sync with other BARDS
		1	2.2.5	Sync with Controller
		1	2.2.6	Select Number of Victims
		1	2.2.7	Activate video stream
		1	2.2.8	Broadcast video stream
		1	2.2.9	Deploy Device to Search Field
	1		2.3	Activate MANUAL mode
		1	2.3.1	Display MANUAL
		1	2.3.2	Energize for Flight MANUAL
		1	2.3.3	Activate avalanche beacon receiver
		1	2.3.4	Sync with Controller
		1	2.3.5	Allow Manual Control
		1	2.3.6	Activate video stream
		1	2.3.7	Broadcast video stream
		1	2.3.8	Deploy Device to Search Field
1			**3.0**	**Search Avalanche field**
	1		3.1	Receive Mode Search Selection
	1		3.2	Initiate FULL AUTO search profile
		1	3.2.1	Search in 25 sq meter grids
		1	3.2.2	Search 5000 sq meters
		1	3.2.3	Receive avalanche beacon signal
		1	3.2.4	Navigate to avalanche beacon
		1	3.2.5	Initiate Fine Search Profile
		1	3.2.6	Broadcast video stream
	1		3.3	Receive MANUAL search commands
		1	3.3.1	Provide avalanche beacon search results
		1	3.3.2	Broadcast video stream
1			**4.0**	**Receive Avalanche Beacon Signal**
	1		4.1	Receive signal
	1		4.2	Process signal
	1		4.3	Initiate "Threshold" Search Parameters
	1		4.4	Broadcast video stream
	1		4.5	Send "threshold avalanche beacon" signal obtained
1			**5.0**	**Identify Victim Location**
	1		5.1	Receive "threshold avalanche beacon" signal obtained
	1		5.2	Finalize victim location
	1		5.3	Record video stream
	1		5.4	Send Mark Command

Level 1	Level 2	Level 3	Total
5	19	25	49

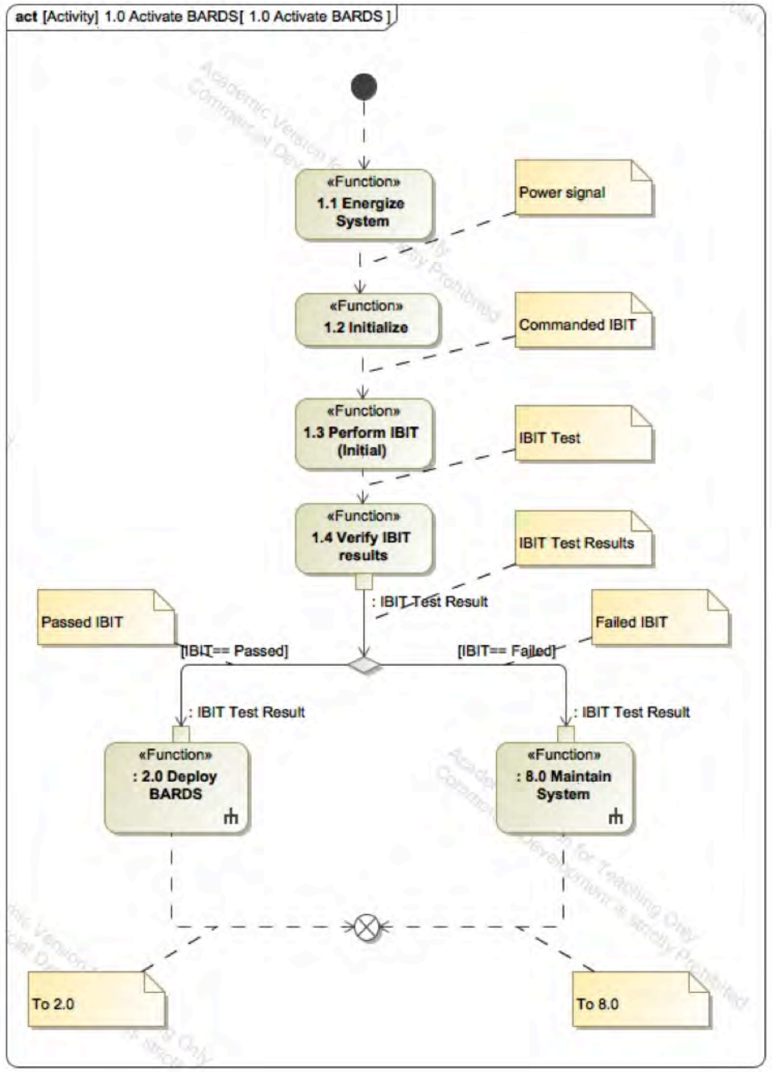
Level 1	Level 2	Level 3	ID#	Function
1			**6.0**	**Mark Victim Location**
	1		6.1	Receive MARK command
	1		6.2	Initiate MARK profile
	1		6.3	Employ MARK device
	1		6.4	Redeploy BARDS for next victim
	1		6.5	Enter Auto Recover Profile
1			**7.0**	**Recover System**
	1		7.1	Receive RECOVER mode selection
	1		7.2	Activate Auto-Recover Profile
		1	7.2.1	Locate User Controller
		1	7.2.2	Perform Terrain Following
		1	7.2.3	Perform Collision Avoidance
		1	7.2.4	Land near controller
		1	7.2.5	Perform power-down routine
	1		7.3	Activate Manual-Recover Profile
		1	7.3.1	Receive Flight Commands
		1	7.3.2	Receive power-down command
		1	7.3.3	Perform power-down routine
1			**8.0**	**Maintain System**
	1		8.1	Receive Maintenance Mode Selection
	1		8.2	Receive DIAGNOSTIC TEST mode
		1	8.2.1	Perform diagnostic test
		1	8.2.2	Verify diagnostic test results
		1	8.2.3	Inform user of NORMAL results
		1	8.2.4	Inform user of FAULT result and CODE
	1		8.3	Receive SW UPDATE mode
		1	8.3.1	Establish connection w/SW update server
		1	8.3.2	Query SW Update Server
		1	8.3.3	Download SW update
		1	8.3.4	Update SW
		1	8.3.5	Verify SW update
		1	8.3.6	Inform user SW UPDATE COMPLETE
		1	8.3.7	Inform user SW UPDATE FAIL
1			**9.0**	**Provide Power**
	1		9.1	Receive power
	1		9.2	Store power
	1		9.3	Distribute power
1			**10.0**	**Interface with User**
	1		10.1	Broadcast Strobe
	1		10.2	Accept User Commands
	1		10.3	Process User Commands
	1		10.4	Generate Training Scenarios
	1		10.5	Generate System Status
	1		10.6	Provide System Status
	1		10.7	Withstand Environment
	1		10.8	Protect Hardware

Level 1	Level 2	Level 3	Total
5	22	19	46

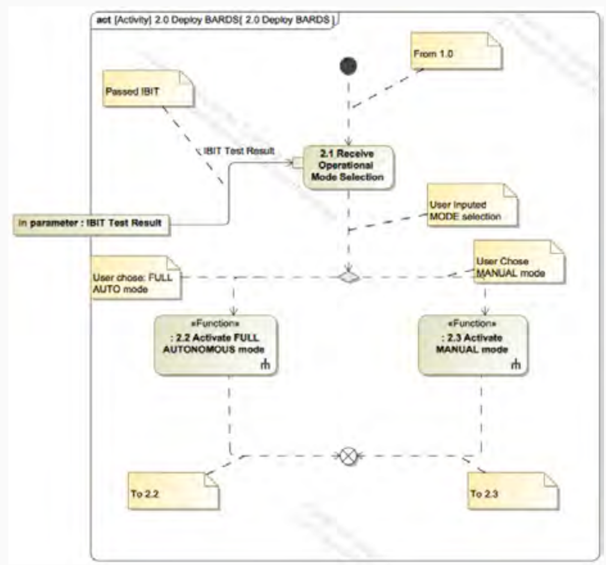
Level 1	Level 2	Level 3	Total Functions
10	41	44	95

Functions List

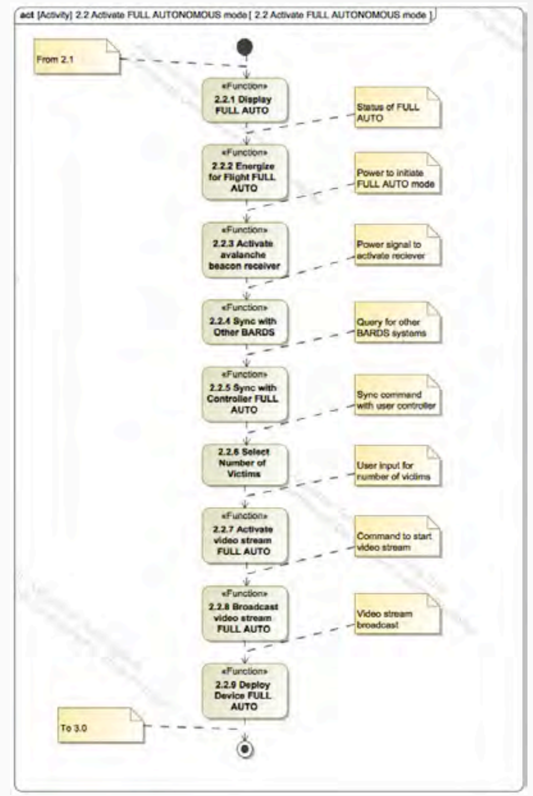
Functional Concept – Lower Level FBDs



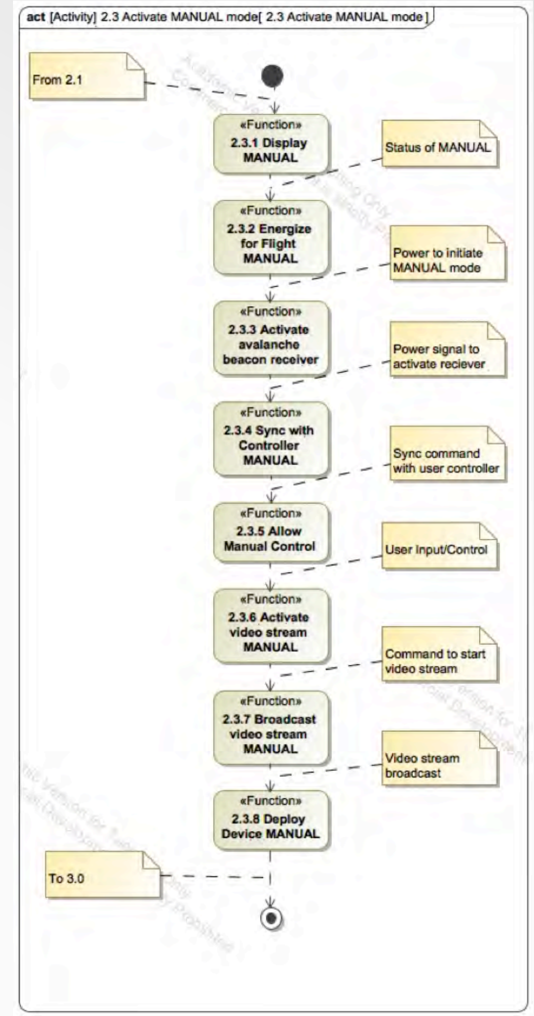
Level 2 FBD – Function 1.0



Level 2 FBD – Function 2.0



Level 3 FBD – Function 2.2

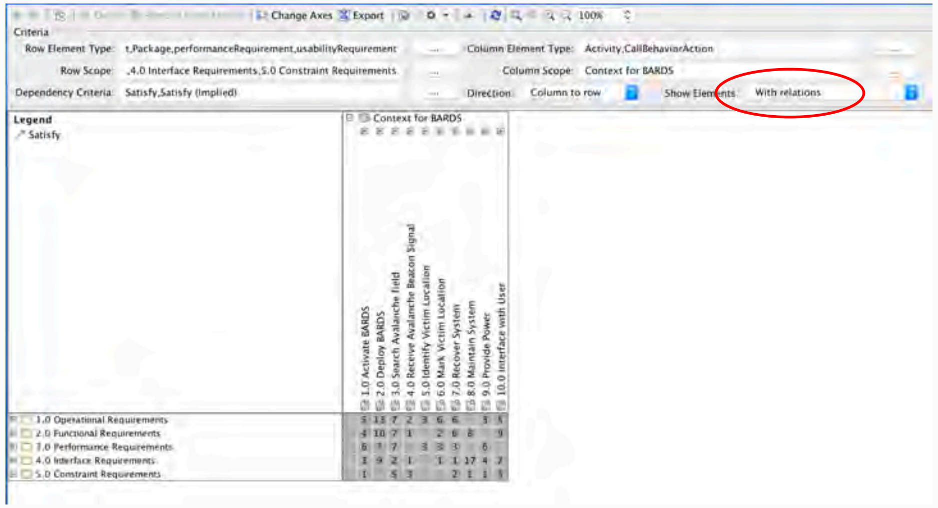


Level 3 FBD – Function 2.3

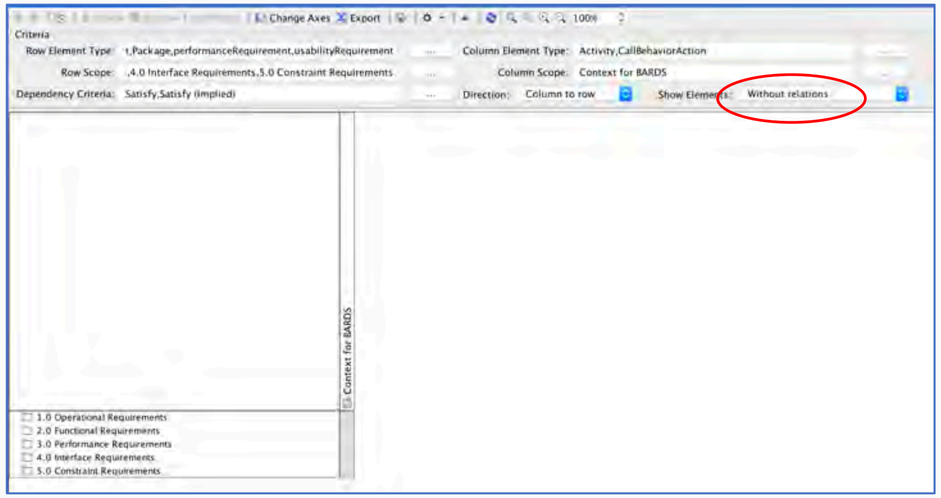
Functional Concept – N2 Diagram

Inputs = ↓ Outputs = ←	-Environment	-Environment -ETSI 300 718 -FCC -EC/EU -Rescue TTPs	-Environment -ETSI 300 718 -FCC -EC/EU	-Environment -ETSI 300 718 -FCC -EC/EU	-Environment -ETSI 300 718 -FCC -EC/EU	-Environment -ETSI 300 718 -FCC -EC/EU	-Environment -ETSI 300 718 -FCC -EC/EU	-BARDS Servers -USB 3.0	-Commercial power	-HSI Standards -Training Materials
	1.0 Activate BARDS	-Initial Power -IBIT						CBIT		-System Health & Status (H&S)
		2.0 Deploy BARDS	*Search* Algorithm (Auto or Manula)	*Recevie* Algorithm	*Refine Search* Algorithm	*Victim Geo-location* Algorithm	*Recover* Algorithm	-Maintenance Commands -CBIT		-System H&S -Video Feed
			3.0 Search Avalanche field	Search Location Results				CBIT		-System H&S -Video Feed
			"Expand Search" Command	4.0 Receive Avalanche Beacon Signal	Avalanche Beacon Results		"Recover" commanded	CBIT		-System H&S -Video Feed
				"Refine Search" Command	5.0 Identify Victim Location	Victim Location Results		CBIT		-System H&S -Video Feed
			Renter Search Profile for next victim		"Mark Victim" Command	6.0 Mark Victim Location	"Recover" commanded	CBIT		-System H&S -Video Feed -Marking Paint
							7.0 Recover System	CBIT		-System H&S -Recover Mode/Return
	-SW Update -CBIT	-SW Update -CBIT	-SW Update -CBIT	-SW Update -CBIT	-SW Update -CBIT	-SW Update -CBIT	-SW Update -CBIT	8.0 Maintain System		-System H&S -Mnx Ops -SW Updates
	Power	Power	Power	Power	Power	Power	Power	Power	9.0 Provide Power	-System H&S -Power
	User Inputs	User Inputs	User Inputs	User Inputs			User Inputs	User Inputs	User Inputs	10.0 Interface with User

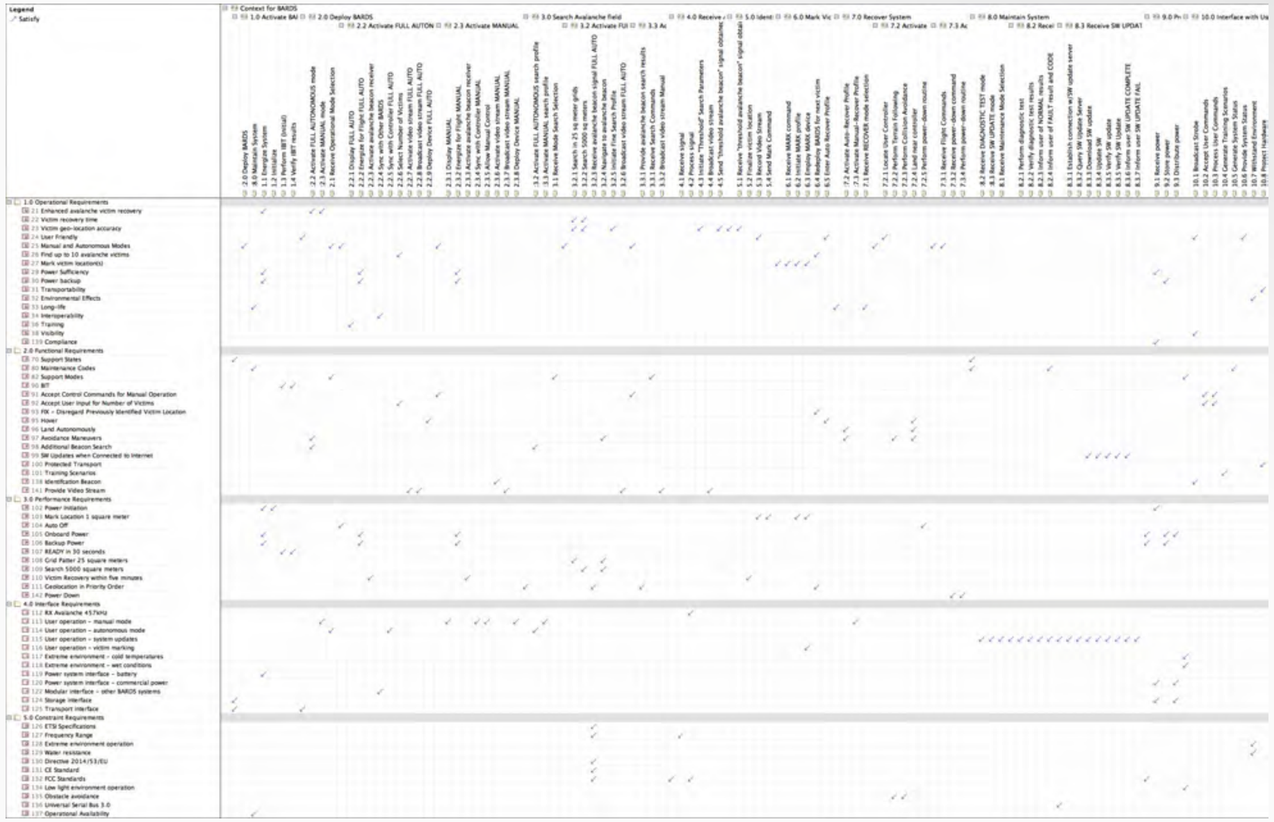
Functional Concept – Traceability



Functions to Requirements – WITH relations

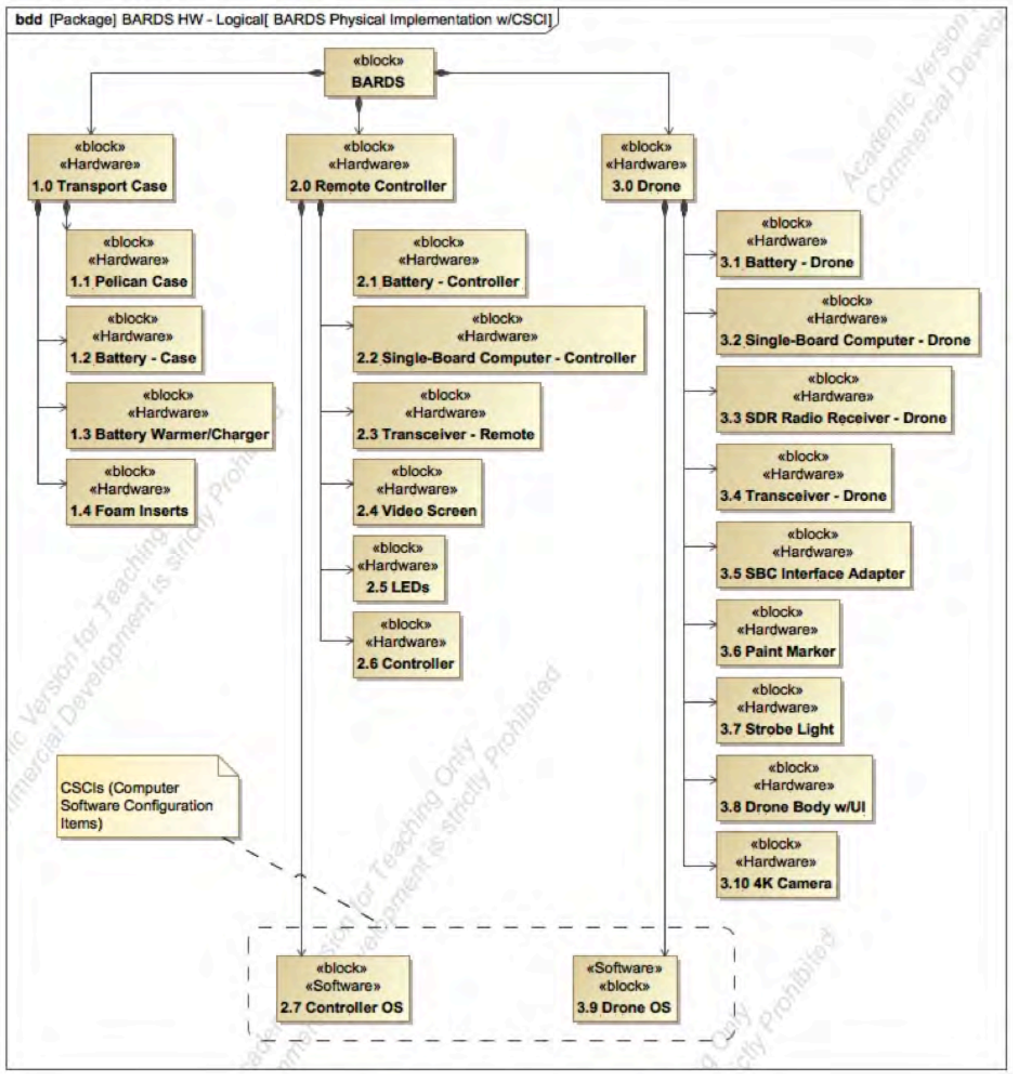


Functions to Requirements – WITHOUT relations – Everything traces

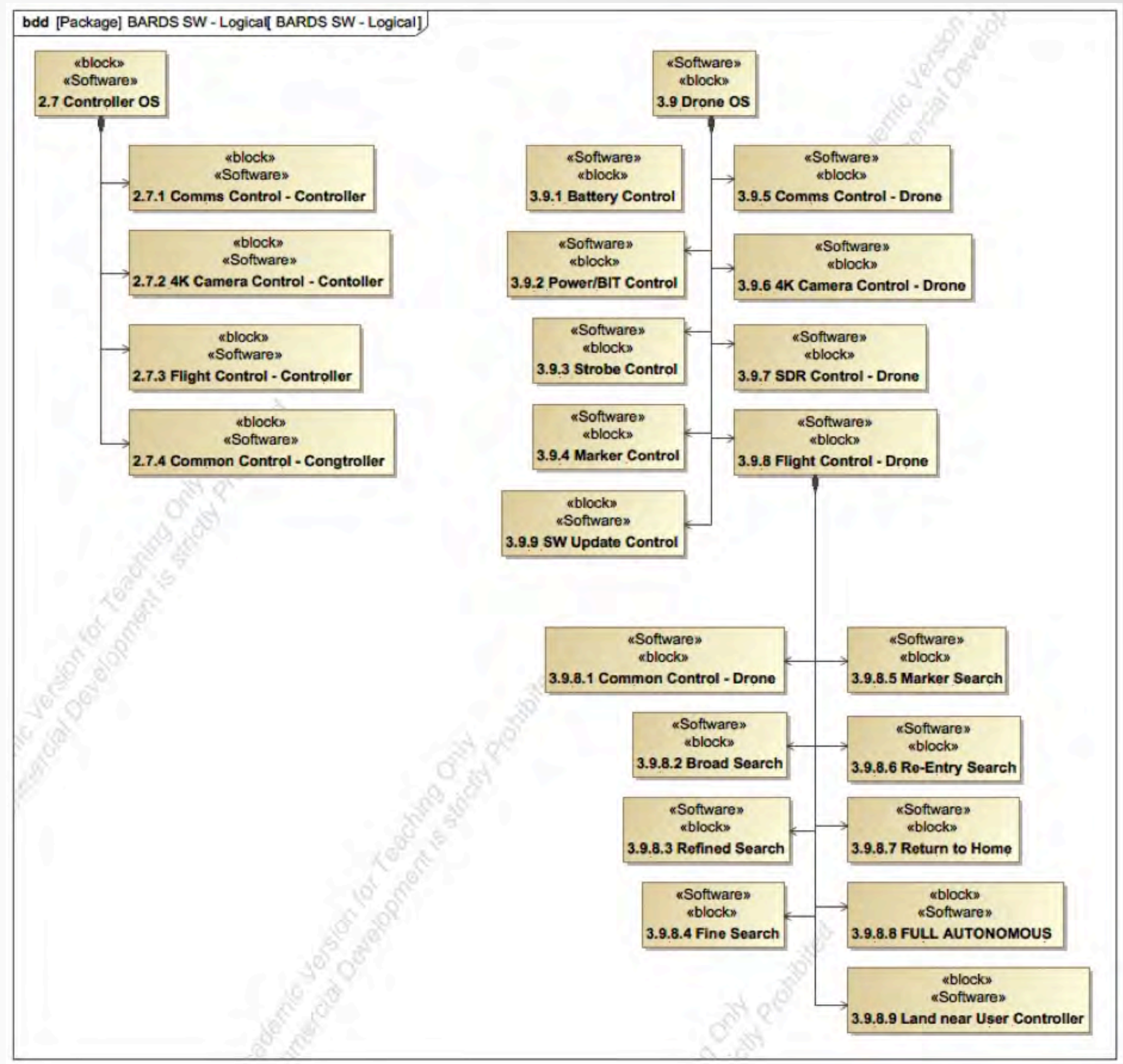


Full Traceability Diagram from (Cameo EA)

Physical Concept – Component Trees

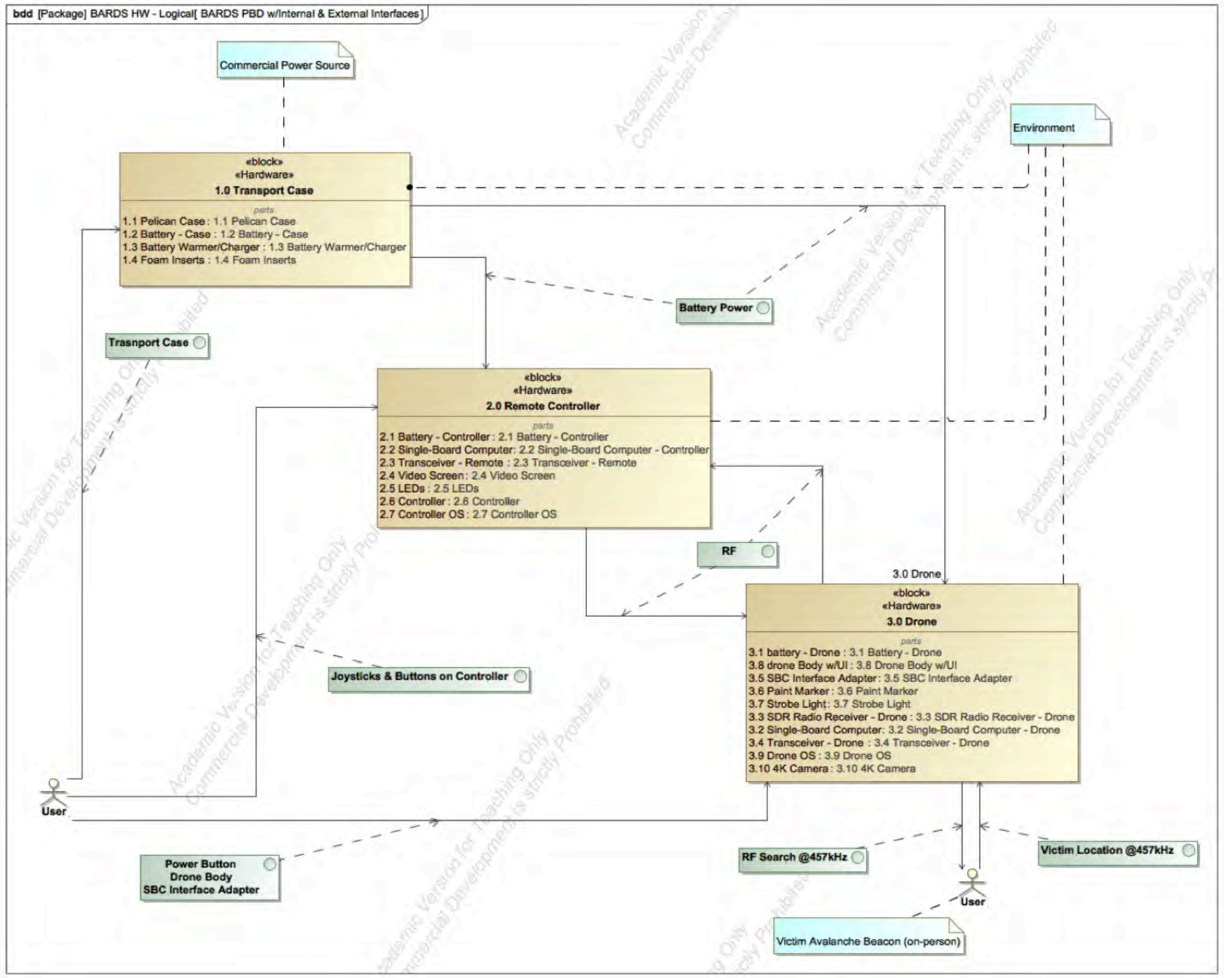


Physical Component Tree – Hardware

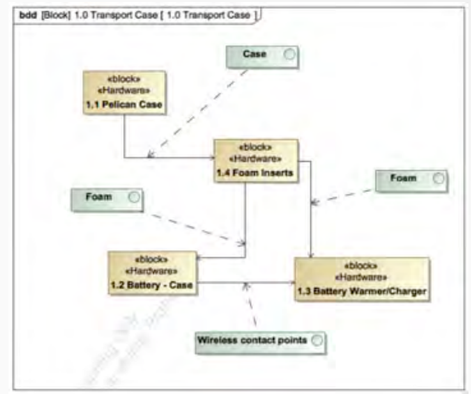


Physical Component Tree – Software

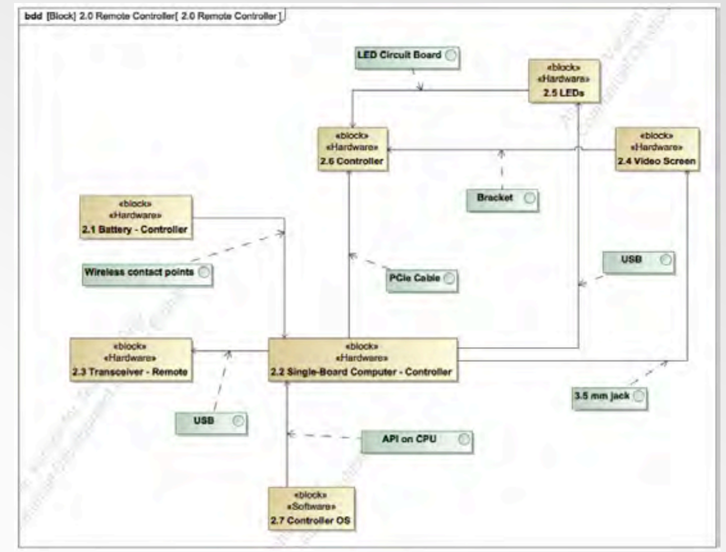
Physical Concept – PBDs and Top-Level DFD



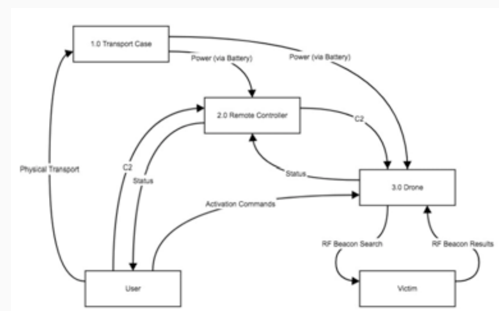
PBD – Top Level



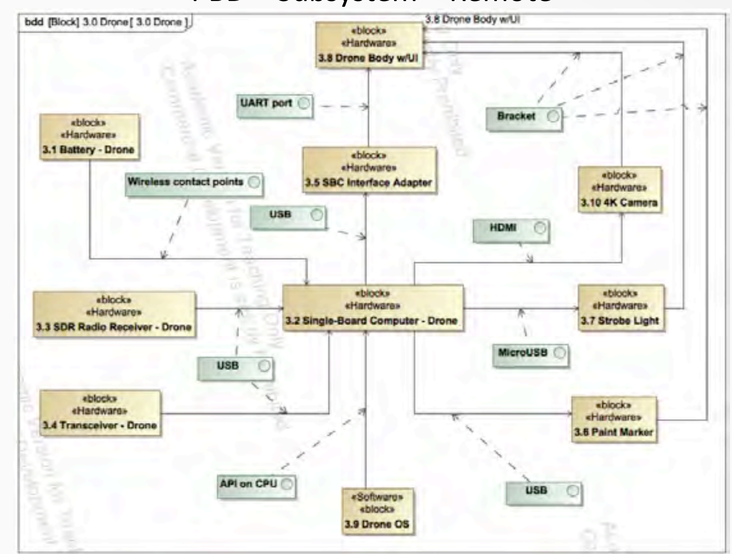
PBD – Subsystem – Case



PBD – Subsystem – Remote



Data Flow – Top Level



PBD – Subsystem – Drone

Let the SE process work… “can I use your transceiver”?

Physical Concept – N2 Diagrams

Inputs = ↓ Outputs = ←	Commercial power	Environment	Environment
	1.0 Transport Case	Physical Support Battery	Physical Support Battery
Video Screen LEDs	Remote Body	2.0 Remote Controller	RF
Strobe	Drone Body	RF	3.0 Drone

N2 – Top Level

Inputs = ↓ Outputs = ←	Environment	Environment	Environment	Environment	Environment	Environment	Environment	Environment	Environment	Environment
	3.1 Battery - Drone	Wireles Contact Points								
		3.2 SBC-Drone	USB	USB	USB	USB	MicroUSB			HDMI
			3.3 SDR Radio Receiver - Drone							
RF				3.4 Transceiver - Drone						
					3.5 SBC Interface Adapter			UART Port		
						3.6 Paint Marker		Bracket		
							3.7 Strobe Light	Bracket		
User Interface								3.8 Drone Body w/UI		
		API on CPU							3.9 Drone OS	
								Bracket		3.10 4K Camera

N2 – Subsystem – Drone

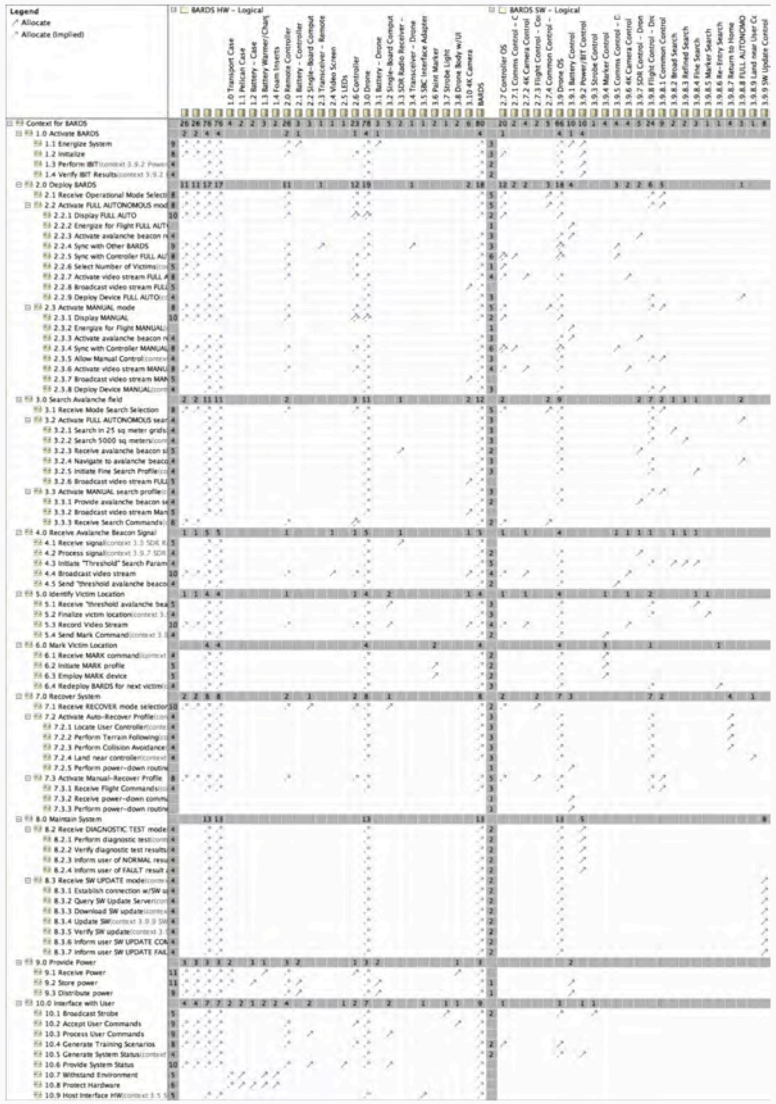
Inputs = ↓ Outputs = ←	Environment	Environment	Environment	Environment	Environment	Environment	Environment
	2.1 Battery	Wireles Contact Points					
		2.2 SBC-Controller	USB		USB		
RF			2.3 Transceiver - Remote	3.5 mm Jack		PCIe Cable	
			Physical Bracket	2.4 Video Screen			
			LED Circuit Board		2.5 LEDs		
User Interface						2.6 Controller Body	
		API on CPU					2.7 Controller OS

N2 – Subsystem – Remote

Inputs = ↓ Outputs = ←	-Environment	-Environment	-Environment	-Environment
User Interface	1.1 Pelican Case			Physical Case
		1.2 Battery - Case	Wireless Contact Points	
Batteries			1.3 Battery Warmer/Charger	
		Foam Support	Foam Support	1.4 Foam Inserts

N2 – Subsystem – Case

Physical Concept – Traceability and Interfaces



Traceability Functional to Physical from Cameo EA

Int. Number	Int. Name	Description	Component from	Component to	Mapping to Function or function to Interaction	Implementation: -Electrical -Mechanical -Air	What is being Passed
Interface 1	Physical Support Battery	Physial Support for battery and HW	1.0 Transport Case	2.0 Remote Controller	10.7 Withstand Environment	Mechanical	Physical Support
Interface 2	Physical Support Battery	Physial Support for battery and HW	1.0 Transport Case	3.0 Drone	10.8 Protect Hardware	Mechanical	Physical Support
Interface 3	RF	RF Comms	2.0 Remote Controller	3.0 Drone	3.2.6 Broadcast video stream FULL AUTO 3.3.3 Receive Search Commands 10.2 Accept User Commands	Air	C2 and Status
Interface 4	RF	RF Comms	3.0 Drone	2.0 Remote Controller	3.2.6 Broadcast video stream FULL AUTO 3.3.3 Receive Search Commands 10.2 Accept User Commands	Air	C2 and Status
Interface 5	Remote Body	Physical Support	2.0 Remote Controller	1.0 Transport Case	10.7 Withstand Environment 10.8 Protect Hardware	Mechanical	Physical Support
Interface 6	Drone Body	Physical Support	3.0 Drone	1.0 Transport Case	10.7 Withstand Environment 10.8 Protect Hardware	Mechanical	Physical Support
Interface 7	Strobe	Strobe Liight	3.0 Drone	User	10.1 Broadcast Strobe	Mechanical	Location of Drone
Interface 8	Video Screen LEDs	Video Indication	2.0 Remote Controller	User	2.2.1 Display FULL AUTO 2.3.1 Display MANUAL	Electrical	Status of Mode
Interface 9	Physical Case	Hold Foam Inserts	1.1 Pelican Case	1.4 Foam Inserts	10.7 Withstand Environment 10.8 Protect Hardware	Mechanical	Physical Support
Interface 10	Wireless Contact Points	Contact points for battery warmer charger	1.2 Battery - Case	1.3 Battery Warmer/Charger	1.1 Energize System 10.8 Protect Hardware 10.7 Withstand Environment	Electrical	Power to Batteries
Interface 11	Foam Support	Support Battery	1.4 Foam Inserts	1.2 Battery - Case	10.7 Withstand Environment 10.8 Protect Hardware	Mechanical	Physical Support
Interface 12	Foam Support	Protect Batter warmer	1.4 Foam Inserts	1.3 Battery Warmer/Charger	10.7 Withstand Environment 10.8 Protect Hardware	Mechanical	Physical Support
Interface 13	Drone Batteries	System Power	1.3 Battery Warmer/Charger	Batteries	1.1 Energize System	Electrical	Power for Drone
Interface 14	User Interface	Protection of System	1.1 Pelican Case	User	10.7 Withstand Environment 10.8 Protect Hardware	Mechanical	Physical Support
Interface 15	Wireles Contact Points	Contact points for battery warmer charger	2.1 Battery	2.2 SBC-Controller	1.1 Energize System	Electrical	Power for SBC
Interface 16	USB	USB Interface	2.2 SBC-Controller	2.3 Transceiver - Remote	3.1 Receive Mode Search Selection 3.3.3 Receive Search Commands	Electrical	Control Signal for Transceiver
Interface 17	USB	USB Interface	2.2 SBC-Controller	2.5 LEDs	10.6 Provide System Status	Electrical	Status of search
Interface 18	3.5 mm Jack	3.5 mm Jack for video	2.3 Transceiver - Remote	2.4 Video Screen	10.6 Provide System Status	Electrical	Video stream of search field
Interface 19	PCIe Cable	Connection between transceiver and controller body	2.3 Transceiver - Remote	2.6 Controller Body	4.1 Receive signal 5.1 Receive "threshold avalanche beacon" signal obtained 7.3.2 Receive power-down command 7.3.1 Receive Flight Commands	Electrical	C2 and Status
Interface 20	RF	RF Comms between remote and drone	2.3 Transceiver - Remote	3.4 Transceiver - Drone	4.1 Receive signal 5.1 Receive "threshold avalanche beacon" signal obtained 7.3.2 Receive power-down command 7.3.1 Receive Flight Commands	Air	C2 and Status
Interface 21	Physical Bracket	Physical supporr to hold video screen	2.4 Video Screen	2.3 Transceiver - Remote	4.4 Broadcast video stream	Mechanical	Video stream of search field
Interface 22	LED Circuit Board	Mounting point for LEDs	2.5 LEDs	2.3 Transceiver - Remote	10.6 Provide System Status	Electrical	Physical Support
Interface 23	User Interface	Hand-held remote for user interface	2.6 Controller Body	User	10.2 Accept User Commands 10.6 Provide System Status 10.3 Process User Commands	Mechanical	C2 and Status
Interface 24	API on CPU	Application Program Interface on CPU on SBC	2.7 Controller OS	2.2 SBC-Controller	1.2 Initialize 2.2.1 Display FULL AUTO 2.3.1 Display MANUAL	Electrical	C2 and Status
Interface 25	Wireles Contact Points	Contact points for battery	3.1 Battery - Drone	3.2 SBC-Drone	1.1 Energize System	Electrical	Power for SBC
Interface 26	USB	USB Interface	3.2 SBC-Drone	3.3 SDR Radio Receiver - Drone	4.1 Receive signal 4.2 Process signal	Electrical	C2 and Status
Interface 27	USB	USB Interface	3.2 SBC-Drone	3.4 Transceiver - Drone	4.1 Receive signal 4.2 Process signal	Electrical	C2 and Status
Interface 28	USB	USB Interface	3.2 SBC-Drone	3.5 SBC Interface Adapter	10.9 Host Interface HW	Electrical	Physical Support
Interface 29	USB	USB Interface	3.2 SBC-Drone	3.6 Paint Marker	6.2 Initiate MARK profile 6.3 Employ MARK device	Electrical	Initiation and employment of marker
Interface 30	MicroUSB	MicroUSB Interface	3.2 SBC-Drone	3.7 Strobe Light	10.6 Provide System Status	Electrical	C2 and Status
Interface 31	HDMI	HDMI Interface for Video	3.2 SBC-Drone	3.10 4K Camera	10.6 Provide System Status	Electrical	C2 and Status
Interface 32	UART Port	Electrical Connection for SBC to Drone	3.5 SBC Interface Adapter	3.8 Drone Body w/UI	9.1 Receive Power 10.2 Accept User Commands	Electrical	C2 and Status
Interface 33	Bracket	Physical Support	3.6 Paint Marker	3.8 Drone Body w/UI	6.2 Initiate MARK profile 6.3 Employ MARK device	Mechanical	Physical Support
Interface 34	Bracket	Physical Support	3.7 Strobe Light	3.8 Drone Body w/UI	10.1 Broadcast Strobe	Mechanical	Physical Support
Interface 35	API on CPU	Application Program Interface on CPU on SBC - Drone	3.9 Drone OS	3.2 SBC-Drone	1.2 Initialize 2.2.1 Display FULL AUTO 2.3.1 Display MANUAL	Electrical	C2 and Status
Interface 36	Bracket	Physical Support	3.10 4K Camera	3.8 Drone Body w/UI	4.4 Broadcast video stream 5.3 Record Video Stream	Mechanical	Physical Support
Interface 37	RF	RF Comms between remote and drone	3.4 Transceiver - Drone	2.3 Transceiver - Remote	4.1 Receive signal 5.1 Receive "threshold avalanche beacon" signal obtained 7.3.2 Receive power-down command 7.3.1 Receive Flight Commands	Air	C2 and Status
Interface 38	User Interface	Drone Body for user to activate and use	3.8 Drone Body w/UI	User	10.7 Withstand Environment 10.8 Protect Hardware	Mechanical	Physical Support

Interface Description Table

Trade Study

- Numerous informal trade studies
  - Two detailed in report: carrying case and SBC for interface
- Formal trade study
  - Five Drones
    - DJI Phantom 4 Pro V2.0
    - DJI Mavic 2 Pro
    - DJI Mavic Pro Platinum
    - Yuneecx Typhoon H Plus
    - Yuneec Mantis
  - Four criteria / Requirement # trace
    - Flight Time (minutes) / Requirements 22, 110, 105
    - Range (feet) / Requirements 108, 109
    - Altitude (feet) Requirements 108, 109
    - Volume (cubic inches) Requirements 31, 100, 144

Trade Study – Alternatives, Weights, Pairwise

Manufacturer Model	Cost	Flight Time (minutes)	Range (ft)	Altitude (ft)	Volume (cubic inches)
DJI - Phantom 4 Pro V2.0 Quadcopter - White	$1,500.00	30	22966	19685	1159.26
DJI - Mavic 2 Pro Quadcopter with Remote Controller	$1,450.00	31	26246	19685	97.02
DJI - Mavic Pro Platinum Quadcopter with Remote Controller - Platinum	$1,100.00	30	22966	16404	79.872
Yuneec - Typhoon H Plus Hexacopter with Remote Controller - Black	$1,900.00	25	5280	1640	2496.96
Yuneec - Mantis Q Drone with Remote Controller - Black	$500.00	33	4921	262	57.64
Criteria in order of significance	n/a	1	2	3	4

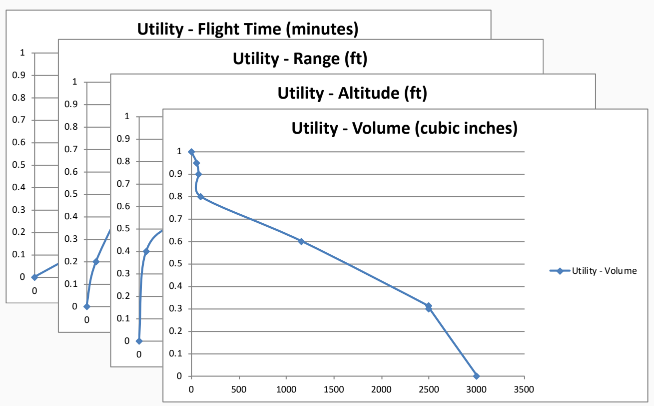
Summary of Alternatives and Criteria Used

Value	Scale	Definition
1	Equal Importance	Both alternatives contribute equally
3	Moderate Importance	Experience and judgement give a slight edge to one alternative
5	Strong Importance	Experience and judgement strangely favor one alternative
7	Very Strong Importance	Actively strongly favored and its dominance is demonstrated in practice
9	Absolute Importance	Evidence favoring one alternative is highest possible

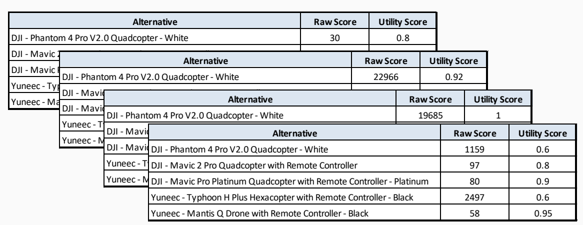
Relative Importance Score of Criteria

Comparison		Stronger	Score
Flight Time	Range	Flight time	5
Flight Time	Altitude	Flight time	5
Flight Time	Cubic Volume	Flight time	7
Range	Altitude	Range	3
Range	Cubic Volume	Range	7
Altitude	Cubic Volume	Altitude	5

Pairwise Comparison Scores



Utility Curves



Alternative	Raw Score	Utility Score
DJI - Phantom 4 Pro V2.0 Quadcopter - White	1159	0.6
DJI - Mavic 2 Pro Quadcopter with Remote Controller	97	0.8
DJI - Mavic Pro Platinum Quadcopter with Remote Controller - Platinum	80	0.9
Yuneec - Typhoon H Plus Hexacopter with Remote Controller - Black	2497	0.6
Yuneec - Mantis Q Drone with Remote Controller - Black	58	0.95

Utility Scores

Criteria		Scale	
A	Flight Time	1	Equal
B	Range	3	Moderate Importance
C	Altitude	5	Strong Importance
D	Cubic Volume	7	Very Strong Importance
		9	Absolute Importance

Nth Root

	A	B	C	D	Sums	Nth Rooth Weights	N-zed Weighting Factors
A	1	5	5	7	175.00	3.64	**0.598**
B	0.20	1	3	7	4.20	1.43	**0.235**
C	0.20	0.33	1	5	0.3333	0.76	**0.125**
D	0.14	0.14	0.20	1	0.0041	0.25	**0.042**
						6.081	1.00

Values from Pairwise w/Nth Root

Trade Study – Results

	Weight	DJI - Phantom 4 Pro V2.0			DJI - Mavic 2 Pro Quad			DJI - Mavic Pro Platinum			Yuneec - Typhoon H Plus			Yuneec - Mantis Q		
		Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value
Flight Time (minutes)	59.809%	30	0.8	0.478	31	0.9	0.538	30	0.8	0.478	25	0.6	0.359	33	0.96	0.574
Range (ft)	23.541%	22966	0.92	0.217	26246	0.96	0.226	22966	0.92	0.217	5280	0.61	0.144	4921	0.55	0.129
Altitude (ft)	12.495%	19685	1	0.125	19685	1	0.125	16404	1	0.125	1640	0.55	0.069	262	0.4	0.050
Volume (cubic inches)	4.156%	1159.26	0.6	0.025	97.02	0.8	0.033	79.872	0.9	0.037	2496.96	0.6	0.025	57.64	0.95	0.039
Weighted Sum		0.84			0.922			0.857			0.596			0.793		
Cost		$1,500.00			$1,450.00			$1,100.00			$1,900.00			$500.00		
Costs Effectiveness Selection Function		0.00056			0.00064			0.00078			0.00031			0.00159		

Legend

Alternative 1	**DJI - Phantom 4 Pro V2.0 Quadcopter - White**
Alternative 2	**DJI - Mavic 2 Pro Quadcopter with Remote Controller**
Alternative 3	**DJI - Mavic Pro Platinum Quadcopter with Remote Controller - Platinum**
Alternative 4	**Yuneec - Typhoon H Plus Hexacopter with Remote Controller - Black**
Alternative 5	**Yuneec - Mantis Q Drone with Remote Controller - Black**

Raw and weights scores, with cost

Winner – Yuneec Mantis Q

	Weight	DJI - Phantom 4 Pro V2.0			DJI - Mavic 2 Pro Quad			DJI - Mavic Pro Platinum Quad			Yuneec - Typhoon H Plus			Yuneec - Mantis Q		
		Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value
Flight Time (minutes)	0.000%	30	0.8	0.000	31	0.9	0.000	30	0.8	0.000	25	0.6	0.000	33	0.96	0.000
Range (ft)	23.541%	22966	0.92	0.217	26246	0.96	0.226	22966	0.92	0.217	5280	0.61	0.144	4921	0.55	0.129
Altitude (ft)	12.495%	19685	1	0.125	19685	1	0.125	16404	1	0.125	1640	0.55	0.069	262	0.4	0.050
Volume (cubic inches)	4.156%	1159.26	0.6	0.025	97.02	0.8	0.033	79.872	0.9	0.037	2496.96	0.6	0.025	57.64	0.95	0.039
Weighted Sum		0.37			0.384			0.379			0.237			0.219		
Cost		$1,500.00			$1,450.00			$1,100.00			$1,900.00			$500.00		
Costs Effectiveness Selection Function		0.00024			0.00026			0.00034			0.00012			0.00044		

	Weight	DJI - Phantom 4 Pro V2.0			DJI - Mavic 2 Pro Quad			DJI - Mavic Pro Platinum Quad			Yuneec - Typhoon H Plus			Yuneec - Mantis Q		
		Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value
Flight Time (minutes)	59.809%	30	0.8	0.478	31	0.9	0.538	30	0.8	0.478	25	0.6	0.359	33	0.96	0.574
Range (ft)	0.000%	22966	0.92	0.000	26246	0.96	0.000	22966	0.92	0.000	5280	0.61	0.000	4921	0.55	0.000
Altitude (ft)	12.495%	19685	1	0.125	19685	1	0.125	16404	1	0.125	1640	0.55	0.069	262	0.4	0.050
Volume (cubic inches)	4.156%	1159.26	0.6	0.025	97.02	0.8	0.033	79.872	0.9	0.037	2496.96	0.6	0.025	57.64	0.95	0.039
Weighted Sum		0.63			0.696			0.641			0.453			0.664		
Cost		$1,500.00			$1,450.00			$1,100.00			$1,900.00			$500.00		
Costs Effectiveness Selection Function		0.00042			0.00048			0.00058			0.00024			0.00133		

	Weight	DJI - Phantom 4 Pro V2.0			DJI - Mavic 2 Pro Quad			DJI - Mavic Pro Platinum Quad			Yuneec - Typhoon H Plus			Yuneec - Mantis Q		
		Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value
Flight Time (minutes)	59.809%	30	0.8	0.478	31	0.9	0.538	30	0.8	0.478	25	0.6	0.359	33	0.96	0.574
Range (ft)	23.541%	22966	0.92	0.217	26246	0.96	0.226	22966	0.92	0.217	5280	0.61	0.144	4921	0.55	0.129
Altitude (ft)	0.000%	19685	1	0.000	19685	1	0.000	16404	1	0.000	1640	0.55	0.000	262	0.4	0.000
Volume (cubic inches)	4.156%	1159.26	0.6	0.025	97.02	0.8	0.033	79.872	0.9	0.037	2496.96	0.6	0.025	57.64	0.95	0.039
Weighted Sum		0.72			0.798			0.732			0.527			0.743		
Cost		$1,500.00			$1,450.00			$1,100.00			$1,900.00			$500.00		
Costs Effectiveness Selection Function		0.00048			0.00055			0.00067			0.00028			0.00149		

	Weight	DJI - Phantom 4 Pro V2.0			DJI - Mavic 2 Pro Quad			DJI - Mavic Pro Platinum Quad			Yuneec - Typhoon H Plus			Yuneec - Mantis Q		
		Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value	Raw Score	Utility Score	Weighted Utility Value
Flight Time (minutes)	59.809%	30	0.8	0.478	31	0.9	0.538	30	0.8	0.478	25	0.6	0.359	33	0.96	0.574
Range (ft)	23.541%	22966	0.92	0.217	26246	0.96	0.226	22966	0.92	0.217	5280	0.61	0.144	4921	0.55	0.129
Altitude (ft)	12.495%	19685	1	0.125	19685	1	0.125	16404	1	0.125	1640	0.55	0.069	262	0.4	0.050
Volume (cubic inches)	0.000%	1159.26	0.6	0.000	97.02	0.8	0.000	79.872	0.9	0.000	2496.96	0.6	0.000	57.64	0.95	0.000
Weighted Sum		0.82			0.889			0.820			0.571			0.754		
Cost		$1,500.00			$1,450.00			$1,100.00			$1,900.00			$500.00		
Costs Effectiveness Selection Function		0.00055			0.00061			0.00075			0.00030			0.00151		

Sensitivity Analysis

Risk Management – Summary

ID	Type	Title	Updated	Initial L/C	Final L/C
001	T	Insufficient Drone power	RR	3/5	1/5
002	T	SW Interface between Transceiver & Drone	RR	3/5	1/5
003	T	Inadequate Drone Payload Capacity	RR	3/5	1/5
004	T	Atmospheric effects on system	TS; CDR, TR, RR	3/5	1/5
005	P	Completion of Capstone in One Term	TS, TR, RR	3/3	1/3
006	T	Integrated Single-Board Computer (SBC) & Software Defined Radio (SDR)	CDR, RR	3/5	1/5

Risk Summary

Risk Management – Detailed

Risk Title	004 – Atmospheric effects on system	
Description:	**If** the atmosphere is too extreme, including weather, temperature and/or altitude, **then** BARDS may not function properly	
Initial Assessment:	Initial Likelihood:	3
	Initial Consequences:	5
	Description of Consequences if realized	Operation is cold weather would seriously degrade the performance of the system
Mitigation Plan: Perform trade study to conduct environments analysis and drone and avalanche transceiver performance in those environments		

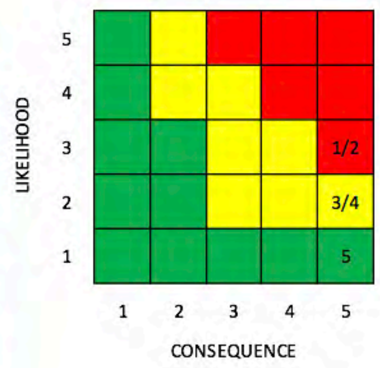
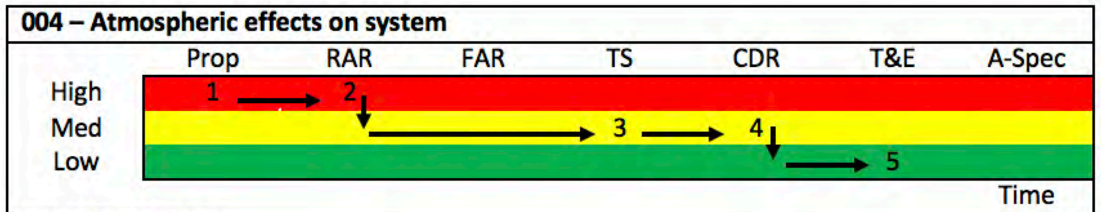


Figure 3-7. Risk Table and Cube – 004



Event/Mitigation

1 – Initial Understanding
2 – Evaluate requirements for performance parameters; study alternatives
3 – Perform trade study to ensure candidates will perform as expected
4 – Implement design solution with battery warmer in transport case
5 – Perform T&E to prove out HW and procedures mitigation

Figure 3-8. Risk Waterfall Chart – 004

Narrative:

Research for the RAR revealed that operational procedures would be needed to ensure system performance. The trade study revealed options for implementation. The CDR specified HW implementation (battery warmer). The T&E proved out the functionality by testing both the physical implementation of a battery warmer, and the operational procedures of hovering the drone in a stationary mode for three minutes prior to full employment.

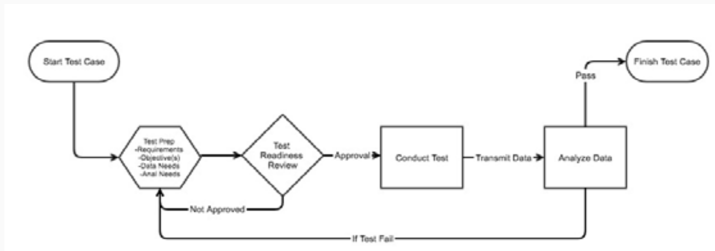
Estimated Risk at End of Course: 1/5

Test Plan – Drone Subsystem

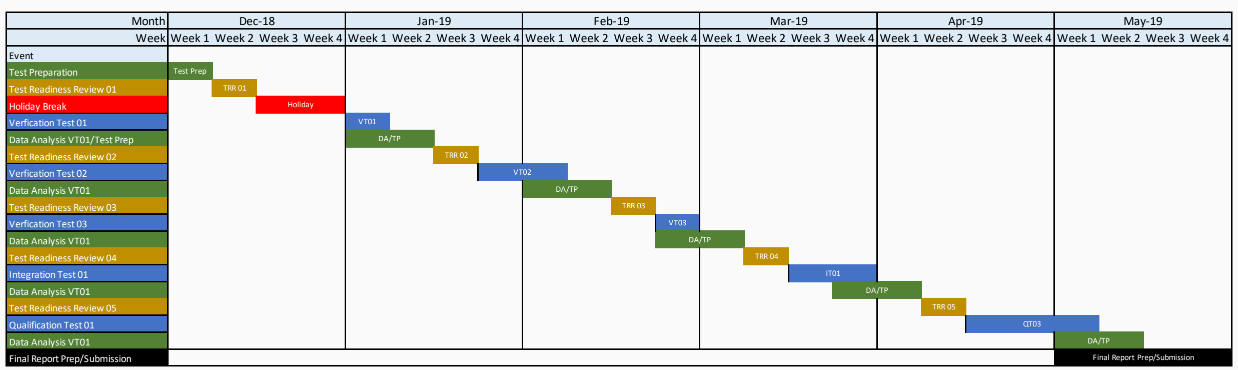
Objective from Office Hours 08	Apply to this Report?	Success Criteria
1. Verify existing performance or capability requirements	Yes. Key to this test plan.	If all requirements both quantitative and binary, are successfully achieved.
2. Identify and collect [additional] requirements	Yes. It will also refine existing requirements.	It is believed additional requirements will be generated.
3. Reduce Risk	Yes. Specifically, we are looking to understand if Risk 004 (Atmospheric Effects on System) will be addressed.	The if/then statement is as follows: ***If** the atmosphere is too extreme, including weather, temperature and/or altitude, **then** BARDS may not function properly.* Tests in representative environmental conditions will verify appropriate requirements and lead to risk reduction.
4. Verify environmental constraints	Yes – Risk 004.	See above
5. Demonstrate technology readiness (similar to risk reduction)	Yes. It will inform the user that a modified COTS drone can be used to meet their mission needs.	The current implementation of the systems is a hybrid approach with a COTS drone and custom software specifically written for necessary functionality.
6. Analyze [and compete] design alternatives	Not in this academic exercise.	NOTE: if this were the real world, alternatives would have been tested DURING the trade study—so it's arguable that formal testing in this phase could address alternative selection
7. Verify Milestone completion	No	N/A
8. Train operators	No. The SE and discipline engineers will perform the tests with consultation from rescue experts.	N/A
9. Validate the system meets user's needs	Yes, for SOME of the user's needs.	We won't demonstrate the transportability, maintenance, troubleshooting, or reliability/availability/maintainability

Objectives, Application and Success Criteria

Verification Test 01
Verification Test 02
Verification Test 03
Integration Test 01
Qualification Test 01



Test Process



Test Schedule

REQ ID/Name	Text	Verifcation Method	Metric	Pass
Test Objective 001 - Power				
29 Power Sufficiency	The system shall have sufficient power to facilitate geolocation for 10 victims	Test	Number	Geolocate and mark no less than 10 victims in one sortie (no battery change required)
102 Power Initiation	The system shall be powered-up within 45 seconds of recognized need	Test	Seconds	Power initiated on drone no less than 45 seconds from "Need" (a "go" command)
104 Auto Off	The system shall have auto-off feature if not in use for 10 minutes	Test	Minutes	Drone powers down after 10 mintues of idle time
105 Onboard Power	The system shall have onboard power for 15 minutes of operation	Test	Minutes	Drone operates in search mode for at least 15 minutes
107 READY in 30 seconds	The system shall achieve READY FOR DEPLOYMENT state within 30 seconds of power initiation	Test	Seconds	READY indications no less than 30 seconds of power initiated
142 Power Down	The system shall accept manual POWER down command	Demonstration	Binary - Drone operations - verification	Drone powers down when manually commanded
Test Objective 002 - Flying				
25 Manual and Autonomous Modes	The system shall enable manual and autonomous modes of operation	Demonstration	Operational Modes	Engineer able to operate drone in both manual and autnomous modes
97 Avoidance Maneuvers	The system shall perform avoidance maneuvers with other BARDS systems	Demonstration	Binary - Drone operations - verification	Observers evaluate two BARDS drones avoiding each other
135 Obstacle avoidance	The system shall avoid both natural and man-made obstacles	Test	Binary - Drone operations - verification	Drone navigates through a man-made obstacle course; then into natural environment
153 Headless Mode	The drone subsystem shall have "Headless" mode	Demonstration	Binary - Drone operations - verification	Drone syncs with controller and orientation of operator
154 Return Home Mode	The drone subsystem shall have "Return Home" mode	Demonstration	Binary - Drone operations - verification	Drone successfully executes return to hand-held controller
Test Objective 003 - Victim Geolocation				
22 Victim recovery time	The system shall achieve avalanche victim recovery in < 5 minutes	Test	Minutes	Geolocate and mark all test victims in no more than five minutes
23 Victim geo-location accuracy	The system shall enable victim geolocation to within 1 meter	Test	Meters	Geolocate and mark all test victims in no less than 1 square meter
26 Find up to 10 avalanche victims	The system shall geo-locate < = 10 avalanche victims	Test	Number	Geolocate and mark no less than 10 victims
93 FIX - Disregard Previously Identified Victim Location	The system shall disregard victim locations after initial geolocation and marking in order to search for new	Demonstration	Binary - Drone operations - verification	Observers witness Drone marking, then moving to next victim
98 Additional Beacon Search	The system shall search for additionial victim beacon transmissions, while in autonomous mode, after victim	Demonstration	Binary - Drone operations - verification	Observers witness drone searching for other victims
108 Grid Pattern 25 square meters	The sysem shall search in a grid pattern in 25 square meters per grid	Test	Meters	Observers measure drone on test grid pattern
109 Search 500 square meters	The system shall search 500 square meters square in less than one minuted	Test	Minutes	Observers measure drone on test grid pattern
110 Victim Recovery within five minutes	The system shall achieve victim recovery within five minutes from BARDS deployment after READY state	Test	Minutes	System completes victim recovery actions in no more than five minutes
111 Geolocation in Priority Order	The system shall geolocate victims in prioity order based on beacon signal strength	Demonstration	Binary - Drone operations - verification	System ignores previously marked victim locations
Test Objective 004 - Marking Victim Location				
27 Mark victim location(s)	The system shall mark victim location(s)	Test	Paint	Activate paint marker at victim location
103 Mark Location 1 square meter	The system shall mark victim location to within 1 square meter	Test	Meters	Paint maker designates victim location within limits
116 User operation - victim marking	The system shall interface with avalanche debris field with marking mechanism	Test	Binary - Drone operations - verification	Drone able to navigate in debris field
141 Provide 4K Video Stream	The system shall stream 4K video of the search location	Demonstration	Binary - Drone operations - verification	Drone transmits 4K video as measured against signal analyzer
Test Objective 005 - Landing				
95 Hover	The system shall be able to hover during RECOVERY mode for easy user "catching"	Demonstration	Binary - Drone operations - verification	Operator able to "catch" drone with hand
96 Land Autonomously	The system shall be able to land autonomously	Demonstration	Binary - Drone operations - verification	Observers witness drone landing autonomously
Test Objective 006- Drone Visual Identification				
138 Identifcation Beacon	The system shall provide visible indication of location.	Demonstration	Binary - Drone operations - verification	Engineers visually see strobe
158 Strobe Ligth visibility	The Drone subsystem shall be visible from no less than 3 statue miles	Test	Light meter and distance in statute miles	Engineers can see stobe from no less than 3 statue miles
Test Objective 007 - Environment Stress				
128 Extreme environment operation	The system shall operate in temperatures between -4F and 113F	Demonstration	Farenheit Temp	System operation through multiple victim recovery sequence
129 Water resistance	The system shall operate in relative humidity range of 20% to 75%	Demonstration	Humidity	System operation through multiple victim recovery sequence

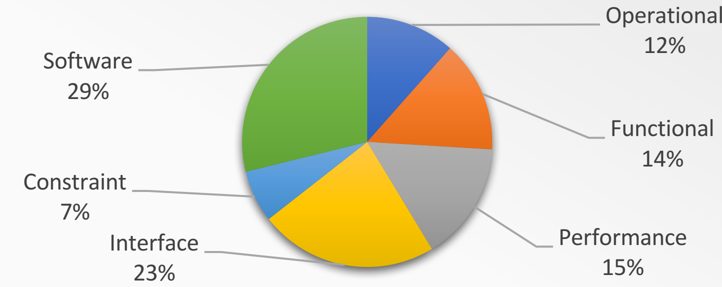
Desired Results and Metrics

System Specification

Report	Type	Total	Q	%	B	S
Requirements Analysis Report	*MNS = 22 = Not counted in Requirements*					
	OPER	18	5	28%	13	0
	FUNC	33	0	0	33	0
	PERF	10	9	90%	1	0
	INT	14	5	35%	9	0
	CONS	12	12	100%	0	0
	Total	87	31	35%	56	0
Report	**Type**	**Total**	**Q**	**%**	**B**	**S**
Functional Analysis Report	*MNS = 22 = Not counted in Requirements*					
	OPER	16	8	50%	8	0
	FUNC	16	1	1	15	0
	PERF	11	9	82	2	0
	INT	12	12	100%	0	0
	CONS	11	11	100%	0	0
	Total	66	41	68%	25	0
Report	**Type**	**Total**	**Q**	**%**	**B**	**S**
Trade Study Report						
	OPER	17	9	53%	8	0
	FUNC	16	1	1	16	0
	PERF	16	9	82	2	0
	INT	19	15	79%	4	0
	CONS	11	11	100%	0	0
	Total	79	45	68%	30	0
Report	**Type**	**Total**	**Q**	**%**	**B**	**S**
Conceptual Design Report	NO CHANGES					
Report	**Type**	**Total**	**Q**	**%**	**B**	**S**
Test Plan Report	*MNS = 22 = Not counted in Requirements*					
	OPER	17	8	47%	9	0
	FUNC	16	10	63%	6	0
	PERF	18	15	83%	3	0
	INT	19	6	32%	13	0
	CONS	14	4	29%	10	0
	Total	84	43	51%	41	0
Report	**Type**	**Total**	**Q**	**%**	**B**	**S**
A-Spec Report	*MNS = 22 = Not counted in Requirements*					
	OPER	17	12	71%	5	0
	FUNC	17	15	88%	2	0
	PERF	18	16	89%	2	0
	INT	27	24	89%	3	0
	CONS	14	7	50%	7	0
	SW	30	30	100%	0	0
	Total	123	104	85%	19	0

Requirements Maturity Through Capstone

Requirements Types – Final



Type	# Reqs at RAR	Change at other modules	Added at A-Spec	Total Quant	Total Binary	Total Subj	Total Overall	Percent Quant
Operational	18	-1	0	12	5	0	17	71%
Functional	33	-17	1	15	2	0	17	88%
Performance	10	8	0	16	2	0	18	89%
Interface	14	5	8	24	3	0	27	89%
Constraint	12	2	0	7	7	0	14	50%
Software	0	0	30	30	0	0	30	100%
Total	87	-3	39	104	19	0	123	85%

Total Quantitative Requirements = 85%
Growth from RAR to A-Spec = 36 (87-3+39)
Percentage increase from RAR to A-Spec = 41% (36/87)

Summary of Requirements Work – Final

Key Performance Parameters

ID	KPP Title	KPP Statement
22	Efficacy	The system shall achieve avalanche victim recovery within 5 (T) / 3 (O) minutes
107	Speed	The system shall achieve On-Operational state within 30 (T) / 20 (O) seconds of power initiation
109	Coverage	The system shall search 500 meters square in less than one minute (T) / 45 seconds (O)
23	Precision	The system shall enable victim geolocation to within 1 (T) / .5 (O) square meter
26	Operation	The system shall geolocate at least 10 (T) / 15 (O) avalanche victims
27	Victim Location Marking	The system shall mark victim location(s) to within 1 square meter
102	Power up	The system shall enter into On-Initialize state in less than 5 seconds of power initiation
105	Power	The system shall have sufficient power to facilitate at least 15 (T) / 20 (O) minutes of search

Final KPPs

…must be met, or customer can reject the system

Summary of Final Concept and Further Work

- Multiple SMEs and colleagues made this possible (22 at last count)
- Working Capstone in $85B acquisition program big key to success
- "THAT is COOL" response every time it was discussed
  - Autonomous drone, quickly deployable, and highly effective – here in Utah
- But BARDS still needs work…Two options:
  - Approach drone manufacturer and pitch a new use case and payload option
    - Will lose idea
  - Develop organically
    - Technical
      - Additional engineering clarity and component development (e.g., SBC/SDR payload)
      - SW development, either organically or through DJI SDK
      - Detailed integration and testing
    - Market
      - Consumer market is individual users; perhaps rescue organizations
      - Will require additional investment of money and time
    - Operational
      - Test of use cases
      - Develop procedures for use (these are not too hard…)

Lessons Learned

Task Name	Duration	Start	Update	Finish	Update	Roll Up	Estimated Hours	Actual Hours
SE Capstone	*120 days*	*Mon 6/25/18*		*Fri 12/7/18*		307		
System Proposal Development	**13 days**	**Thu 6/28/18**		**Sun 7/15/18**		33	33	33
Devlop Candidates	3 days	Thu 6/28/18		Mon 7/2/18			10	2
Draft/Finalize/Submit Proposal	4 days	Fri 6/29/18		**Wed 7/4/18**			20	30
Feedback/Review w/Mentor	2 days	Mon 7/9/18		Tue 7/10/18			2	-
Submit for Instructor Review	5 days	Tue 7/10/18		Sun 7/15/18			1	1
Develop RAR/CONOPS	**16 days**	**Mon 7/16/18**		**Sun 8/5/18**		50	50	48
Stakeholder Interview	5 days	Mon 7/16/18		Fri 7/20/18			5	7
Draft CONOPS/Diagram/Use Cases	5 days	Mon 7/16/18		Fri 7/20/18			15	5
Develop Initial Requirements	8 days	Mon 7/16/18		Wed 7/25/18			20	24
Duaghter's Wedding (28 July)	4 days	Thu 7/26/18		Tue 7/31/18			--	--
Draft/Finalize/Submit Report	4 days	Wed 8/1/18		~~Sun 8/5/18~~	Tue 8/7/18		10	12
Develop Functional Analysis Report	**11 days**	**Mon 8/6/18**		**Sun 8/19/18**		40	40	45
Generate Functional Diagrams	11 days	Mon 8/6/18		Sun 8/19/18			15	22
Trace Function to Requirements	11 days	Mon 8/6/18		Sun 8/19/18			15	15
Travel for Aging Parents	3 days	Thu 8/9/18		Mon 8/13/18			--	
Draft/Finalize/Submit Report	6 days	~~Mon 8/13/18~~	Tue 8/7/18	~~Sun 8/19/18~~	Sun 8/26/18		10	8
Develop Trade Study	**11 days**	**Mon 8/20/18**		**Sun 9/2/18**		28	28	30
ID Candidates	8 days	Mon 8/20/18		Wed 8/29/18			3	5
Perform Studies	8 days	Mon 8/20/18		Wed 8/29/18			15	14
Draft/Finalize/Submit Report	4 days	~~Wed 8/29/18~~	Mon 8/27/18	~~Sun 9/2/18~~	Sun 9/9/18		10	11
Conceptual Design Report	**11 days**	**Mon 9/3/18**		**Sun 9/16/18**		35	35	33
Generate Diagrams	8 days	Mon 9/3/18		Wed 9/12/18			20	18
Perform Traceability	8 days	Mon 9/3/18		Wed 9/12/18			5	3
Draft/Finalize/Submit Report	4 days	~~Wed 9/12/18~~	Mon 9/10/18	~~Sun 9/16/18~~	Mon 9/24/18		10	12
T & E Report	**11 days**	**Mon 10/1/18**		**Sun 10/14/18**		30	30	20
ID Test Requirements	8 days	Mon 10/1/18		Wed 10/10/18			5	5
Generate Test Plan	8 days	Mon 10/1/18		Wed 10/10/18			15	8
Draft/Finalize/Submit Report	4 days	~~Wed 10/10/18~~	Mon 10/8/18	~~Sun 10/14/18~~	Sun 10/7/18		10	7
Risk Management Report	**76 days**	**Mon 7/16/18**		**Sun 10/28/18**		26	26	16
ID Risks	71 days	Mon 7/16/18		Mon 10/22/18			4	6
Develop Risk Cubes	71 days	Mon 7/16/18		Mon 10/22/18			12	4
Draft/Finalize/Submit Report	6 days	~~Mon 10/22/18~~	Mon 10/22/18	~~Sun 10/28/18~~	Sun 10/21/18		10	6
System Spec (A-Spec)	**11 days**	**Mon 9/17/18**		**Sun 9/30/18**		30	30	25
A Spec Draft 1	8 days	Mon 9/17/18		Wed 9/26/18			15	12
A Spec Draft 2	8 days	Mon 9/17/18		Wed 9/26/18			5	5
Draft/Finalize/Submit Report	5 days	~~Tue 9/25/18~~	Mon 9/24/18	~~Sun 9/30/18~~	Sun 11/4/18		10	8
Final Report	**16 days**	**Mon 10/22/18**		**Sun 11/11/18**		16	15	12
Draft/Review	11 days	Mon 10/22/18		Mon 11/5/18			15	11
Submit Report	1 day	~~Sun 11/11/18~~	Mon 11/5/18	Sun 11/11/18			1	1
Oral Presentation	**20 days**	**Mon 10/22/18**		**Fri 11/16/18**		19	19	12
Draft/Review Presentation	11 days	Mon 10/22/18		Mon 11/5/18			15	6
Review Presentation	16 days	Mon 10/22/18		Mon 11/12/18			1	4
Present Presentation	1 day	Fri 11/16/18		Fri 11/16/18			3	2
TOTAL HOURS						307		274

Author captured fourteen *key learning points* in modules 2-9; also in A-Spec. Highlights are as follows:

- Systems Engineering … let it work
  - Iteration – must design, develop, evaluate, repeat
  - Collaboration – requires many SMEs
  - Automation for integration – must use MBSE (see next point)
- Systems engineering activities in academic environment really help in real-world DoD acquisitions, but there are differences
- MBSE is the key to future systems development
  - Has already reduced design cycles (e.g. $6B / $12B savings in lifecycle costs)
- My 6-month approach kept my sanity (too much for single term)
  - Started in June / finished in November … Job, life, etc.

Solid Systems Engineering: Academics + OJT + Experience = Success

Recommendations

- Amount of work is too much – need two weeks each for RAR, FAR, CDR
  - Encourage students to spends two weeks on RAR, FAR and CDR
  - Encourage students to execute Capstone on a 6-month timeline
  - Consider elimination of a course module
- Must inculcate MBSE into core curriculum NOW – two options:
  - Mandatory class (645.621.3VL) (seventh core class); early or late in sequence?
  - Hybrid approach – insert modules into each core class
- Need examples that start at *Intro to SE* and build through curriculum
  - Examples need to be complex but understandable; must be current
- Consider JHU EP "Tools Repository" (with configuration management)
  - Templates, math formulas, utility curves, QFD, etc.
- Evaluate all classes for efficacy, ISD, and consistency
  - Some BRILLIANT instructors; some AWESOME classes

Questions?