2012 Naval Research Advisory Committee Study

How Autonomy Can Transform Naval Operations

Briefing to Hon. Sean Stackley (ASN-RDA)

17 October 2012

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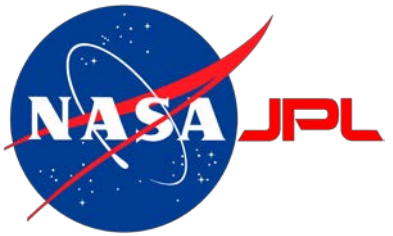
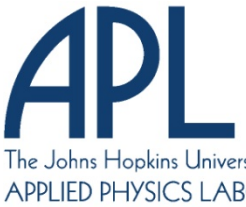
Terms of Reference

- **Examine the state of autonomy technologies and their potential to introduce new capabilities**
- **Identify classes of autonomy technology for Naval applications**
- **Identify critical barriers that impact employment of autonomy in Naval systems**
- **Recommend investments and developments to best leverage the use of autonomous systems**

Who We Met With



Massachusetts Institute of Technology



Bottom Line Up Front

- **Autonomy technologies represent a potentially transformational capability. Effective implementation of this capability will require intentional focus**
- **Build a Naval Autonomy Community**
  - Identify Naval needs and opportunities for autonomy
  - Extract cumulative value from a diverse research base
  - Break down silos to address autonomy challenges
- **Build Trust**
  - Employ Fleet feedback /experimentation /wargaming
  - Address lifecycle support elements in the design phase
  - Address legal, ethical, safety and security issues early

Related Studies

- **Defense Science Board**
  - Create coordinated S&T program, stimulated by realistic challenge problems and that technologists get direct feedback from operators
- **SSG XXVIII**
  - Imperative to rapidly embrace unmanned systems to augment the Fleet in all domains
- **Naval Studies Board**
  - S&T community partner with operational community and monitor the development of critical autonomous vehicle-related technologies
- **Past NRAC Studies (UMDA, Robotics 2003)**
  - Combat potential for the use of UXVs unlimited.

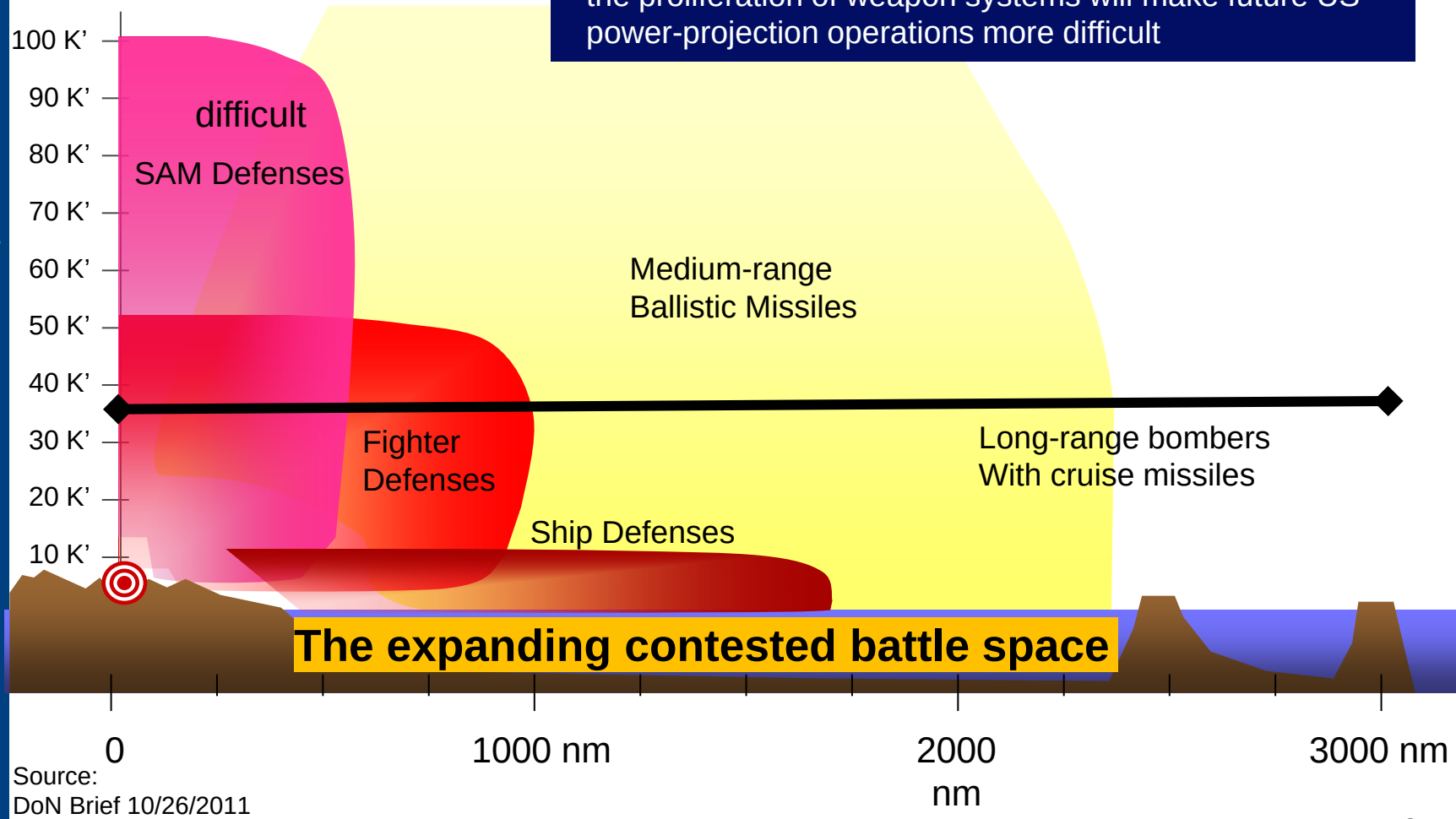
Value of Autonomous Systems

"… the true value of these systems is not to provide a direct human replacement, but rather to extend and complement human capability by providing potentially unlimited persistent capabilities, reducing human exposure to life threatening tasks, and with proper design, reducing the high cognitive load currently placed on operators/supervisors."

Dr. Paul Kaminski
Chairman
Defense Science Board
July 2012

Modern A2AD networks with guided weapons greatly expand the contested zone

- The ability to conduct operational maneuver from strategic distances will stress the US Naval Force
- The appearance of integrated A2AD networks, as well as the proliferation of weapon systems will make future US power-projection operations more difficult



Source:
DoN Brief 10/26/2011

Role of Autonomy in A2AD

- **Unmanned systems required to operate and augment manned Naval capacity (greater numbers), capability**

- **Autonomy is required because of:**
  - Unreliable or contested communications
  - Environmentally driven latency
  - Need for single operator to command, control multiple unmanned platforms
  - High pace and intensity of operations

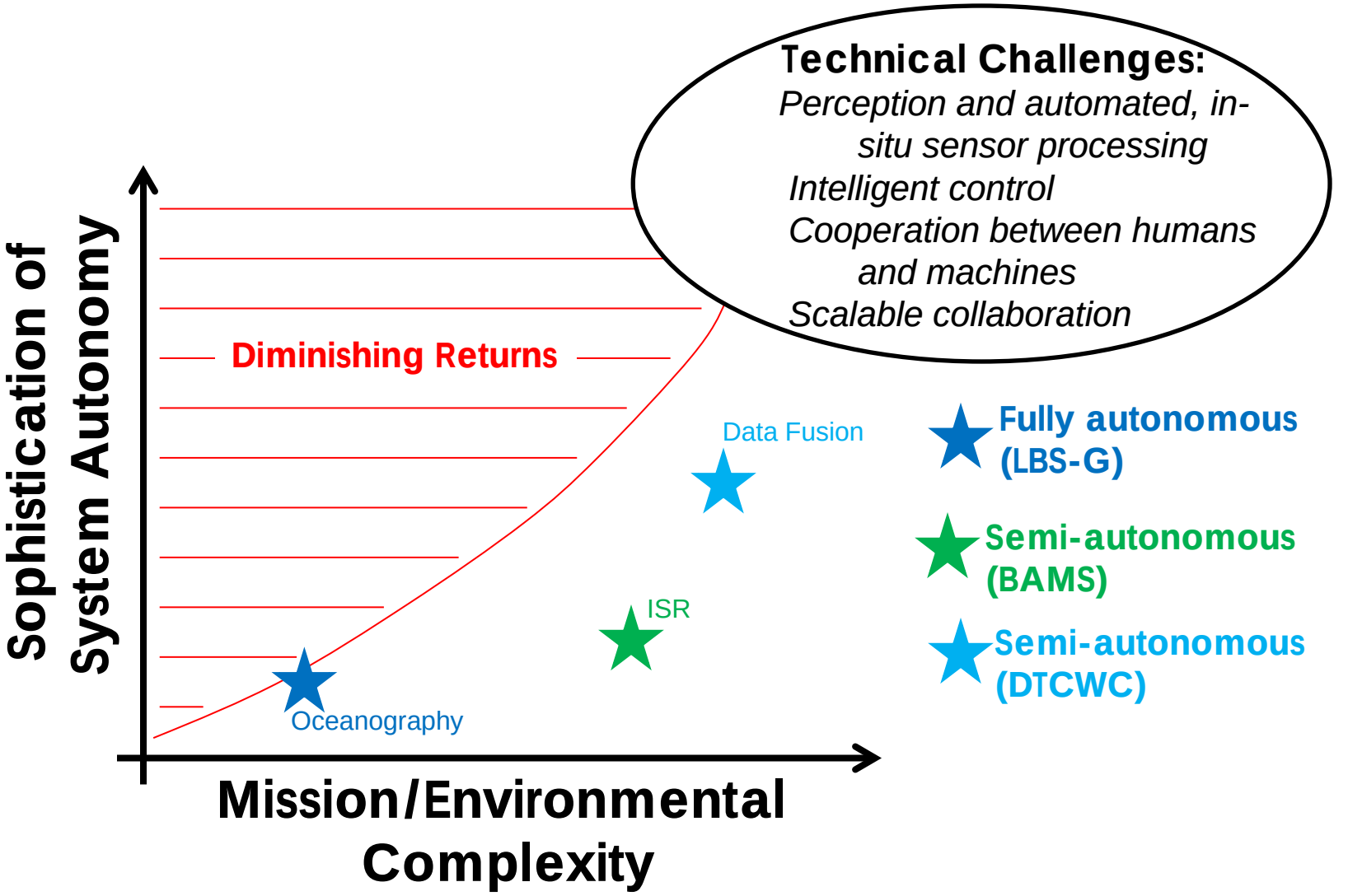
Autonomous Systems will enable increased platform numbers, reach and capabilities to counter A2AD

Setting Expectations

"Improve the reach of today's platforms through … sensors, and unmanned vehicles …"
CNO NAVPLAN 2013-2017

- **There are some things that machines do better than humans**
- **Navy has a problem framing requirements for autonomous systems**
  - Manning requirements not necessarily reduced by use of unmanned systems
  - Divergent expectations by the Navy of what autonomy can do and should do
  - Widely varying definition of autonomy

Matching Naval Autonomy to Mission



Different Views of Autonomy

User View:

Can I give this platform a task, and trust it to accomplish it without constant attention? Can it recognize and deal with unexpected events or ambiguous tasking?

Robotics View:

Can I build a practical robot that does the right thing at the right time? Can I dynamically control, navigate, actuate, and instrument my robot? Can it manage and fuse data?

Machine Learning View:

Can my machine interpret complex sensors? Can it understand spoken language, interpret gestures, or recognize people or objects?

Cognitive View:

Can I make a machine that replicates elements of human intelligence like cognition, inference, and reasoning?

State of Technology

- **Autonomy is widely distributed in both the research and application domain**
  - Cuts across multiple disciplines
  - Lacks a cohesive community working on Naval problems
- **Progressing technical areas transitioned to the engineering practice**
  - Navigation, path planning, articulation, control systems, image processing
- **Ongoing research areas**
  - Machine learning, cognitive architectures, processing at the sensor, system integration and testing, human-machine interfaces, perception, multi-agent coordination, natural language understanding

Autonomy Architectures

- **Architectures partition functionality of software components, define component interfaces, and sometimes specify the algorithmic methodologies:**
  - Many organizations have proprietary architectures
  - Open robot architectures include MIT's MOOS-IVP and the Robot Operating System championed by Willow Garage. A consortium has developed MOAA for Naval robotics.
  - Cognitive community approaches include ACT-R (CMU, models human cognition) and Soar (uses include intelligent agents)
  - Hybrid architectures (CARACaS, developed at JPL)
- **Architectures that support portability will allow leverage of rapidly advancing research results.**
- **Interfaces and data ontologies need to be platform independent to support algorithm portability.**

Examples of Autonomy in the Market

- **Commercial and other government applications exist in all relevant domains but not all development is suitable for Naval use**

Domain	Application	Company / Agency	Technology / Vehicle
Undersea	Oil and Gas	SeeByte	SeeTrack CoPilot
Undersea	Oceanography	Teledyne	Ocean Glider
Surface	Oceanography	Liquid Robotics	Wave Glider
Land	Transportation	Google	Driverless car
Land	Domestic	iRobot	Roomba
Air	Atmospheric Science	NOAA	Global Hawk
Space	Exploration	NASA	Planetary Rovers
Information	Productivity	Apple	SIRI

International Landscape

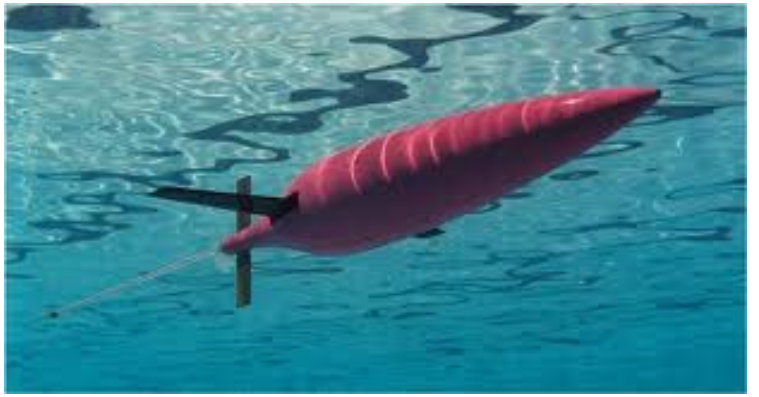
- **US currently leads in Navy-relevant areas, but position is extremely tenuous**
  - Evidence suggests adversaries are very interested in these technologies and are devoting significant resources to close the technology gap
  - US leads in basic research, but in application domain the advantage is less pronounced
    - Manufacturing (worldwide)
    - Human helper robots (Asia)
    - Agricultural applications (Europe)
    - Mining (Australia)
  - Limited-capability applications becoming increasingly inexpensive and easy via COTS products, and open source on-line software. This makes it impossible for DoN to drive the market

Opportunities for Naval Autonomy

- There are potential near-term applications that will provide practical benefit and build trust
  - Ocean monitoring
  - ISR
  - MCM
  - Signature collection
  - Damage control
  - Force protection
  - Infrastructure Protection
  - Hull inspection
  - Logistics
- There are long-term opportunities for autonomy to augment existing forces
  - Capacity to operate in A2AD environment
  - Mine clearing
  - ASW
  - *In situ* ISR data processing to reduce analyst load

Latency, communication, and decision cycle times all drive an autonomous requirement

State of Fielded Systems



- **Vehicles**
  - Most fielded systems require a high level of human interaction
  - Autonomy most advanced in environments limited by communications (ocean gliders)
- **Information**
  - Current approach is centralized post-processing of data
  - Automated, in situ processing required to deal with explosive growth of ISR data

Example Programs

	Air	Ground	Surface	Undersea	Information
ASW			ACTUV (S&T)	PLUS (Fleet Exp.)	
Expeditionary	Shadow	AEODRS **(PoR)**	UISS **(PoR)**	Knifefish **(PoR)**	
ISR	BAMS **(PoR)**	PackBot **(PoR)**	MUSCL (Fleet Exp.)		DTCWC **(PoR)**
Environmental Monitoring			SHARC	LBS Glider **(PoR)**	
Logistics, Inspection, Test Platforms	AACUS (S&T)		USSV (S&T)	LDUUV (test platform)	

Fundamental autonomy technologies cut across domains

Manual MCM

Program

Navigate/ Sense

Recover

Analyze/Detect

Autonomous MCM

Task

Real-time Mine ID

Communicate (optional!)

Act/Coordinate

Technical Opportunities

- **Perception and automated, in-situ sensor processing**
  - Sensors (miniaturization, power efficiency, sensitivity, cost)
  - Software for processing and interpretation
- **Intelligent control**
  - Independent, mission-focused action
  - Adaptive behaviors
- **Cooperation between humans and machines**
  - Natural interaction (language, gesture, etc.)
  - Understanding with high levels of abstraction
  - Interpreting commander's intent
- **Scalable collaboration**
  - Collective behaviors
  - Decentralized control

Trusting Autonomous Systems

- Systems with a high degree of autonomy <u>will be different</u> from legacy systems
  - Interaction with human supervisor
  - Not rule-based
  - Systems will perceive and understand the environment and reason (e.g., new anti-torpedo torpedo)
  - Self-supervised learning
  - Multiple coordinated systems – i.e., swarms
- Challenge – How to test these systems to establish trust?

Testing Autonomous Systems

- Testing must:
  - Build the trust required for effective operational employment
  - Verify system meets legal and ethical requirements and is accepted by military and civilian communities
- Trust-based testing protocols need to be developed:
  - Require capable facilities
  - Simulation plus actual field testing
  - Safety as well as proving mission competence is essential (e.g., optionally operated systems)

A trust-based testing philosophy requires an extension of current testing techniques

Value Added from Testing

- Trust-based testing will constantly evolve as operator gains confidence in the system and the system performance improves
- This testing results in transferable, validated algorithms which are exercised against and “tuned” to real world data for implementation in system
- These trusted algorithms and the accumulated data become the “secret sauce” that will provide the US its technological edge

Autonomous Systems Lifecycle Support Chain

- Need early development of doctrine and CONOPS and coherent articulation of fleet support mechanisms
- Challenge in Fleet introduction of autonomous systems includes
  - Ensuring adequate manning
  - Developing and executing a robust logistics management plan
  - Executing DOTMLPF responsibilities in a manner that reflects manning plans and logistics support

Legal and Ethical Issues

- Legal and ethical considerations will effect system design and CONOPS development
- Implications in an operational context require early Navy leadership
- No universal definition of the status of “autonomous systems” exists
  - There are consequences to the definition
  - Autonomous ships/vessels, UAVs, and weapons (e.g., CAPTOR) are in different states of definition
  - Size and degree of automation are factors
  - Immunity and salvage rules governed by international acceptance of definitions
- Greater emphasis must be given to ethical issues early – a departure from historic practice
- Using legal/ethical benchmarks in the technology development process protects against capital investment missteps

Indeterminate status of answers to issues involved suggests the need for more focused attention

Safety and Security

Safety

- UAS operations
  - UAS operation in civilian airspace
    - Current inability to comply with FAA sense and avoid rules without ground observer or chase aircraft
    - Challenges: UAS C3 and sense and avoid
    - Cultural acceptance of mixed use of airspace
- USV and UUV operations
  - Collision regulations at sea (COLREGS)
  - Discussions began this year on regs for USVs and UUVs
  - Today small unmanned systems considered debris

Security

- Protection from deception and loss of comms
- Protection of the asset
- Protection of the technology

Trust Building

- Trust building is essential to timely, productive introduction of autonomy into the Fleet
- Acceptance is enabled by Fleet participation with the Autonomy Community and experimentation
- Legal, ethical, safety and security issues are trailing technology, but becoming highly visible

Findings and Recommendations (1)

Findings:

- With the expansion of the contested fleet operational zone, autonomy is the best opportunity to transform Naval Operation by enhancing capacity.
- The widely distributed state of the technology, breadth of applications and diversity of expectations make fielding autonomy a complex challenge
- Previous examples of Naval transformation demonstrate that community orientation and senior leadership are required for success

Recommendation:

Establish an Autonomy Community – led by a senior champion – composed of technical, acquisition, requirements, and operational experts to focus on autonomy for Naval needs **(Action: SECNAV/CNO)**

Building an Autonomy Community

Increased Levels of Integration

Technology and Operational Communities

Naval S&T Community, DARPA & Other DoD Components, NWDC, Academia, US & Global Autonomy R&D

Requirements Community

Fleet and Domain Enterprises

Programmatic Community

Navy PMOs, Other Government PMOs, Defense & Commercial Industry

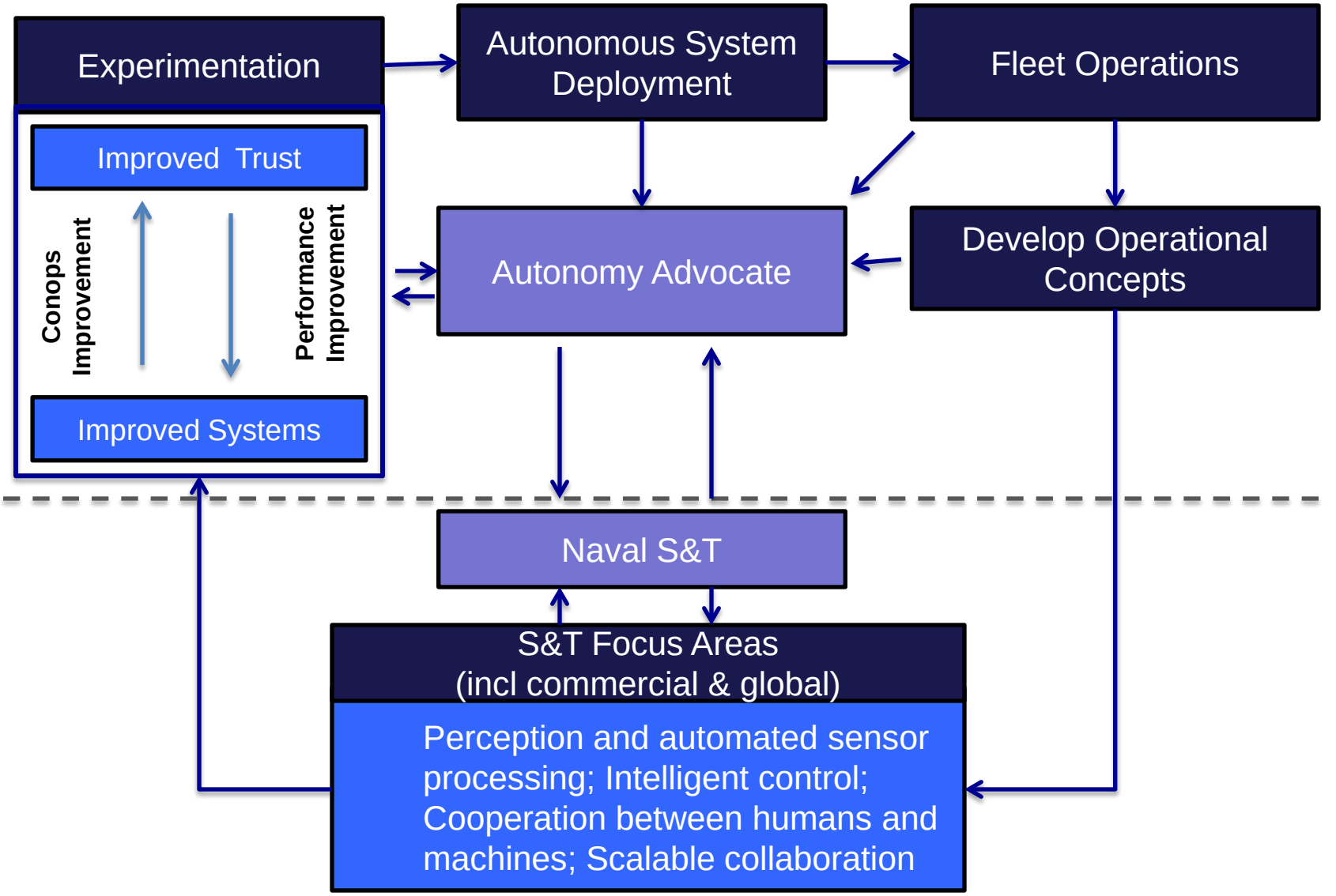
Focus and Advocacy

Special Projects Office

Focused Autonomy Technology Resources

An Autonomy Community is required to align government needs & efforts with commercial advances

Potential S&T Process to Support Naval Autonomy Development



Findings and Recommendations (2)

Findings:

- There is an interrelationship between Naval opportunities for autonomy with commercial and other government applications
- Given the widely distributed developments ongoing, there is a need for a systematic examination of autonomy technology developments both domestic and international

Recommendation:

Periodically commission an outside market survey to access, analyze and assess global autonomy markets that may be relevant to its efforts **(Action: CNR**)

Findings and Recommendations (3)

Findings:

- Navy has divergent expectations of what autonomy can and should do
- Navy is exploring a variety of programs which necessitate the need to build trust in the user community
- A key element in developing this trust is to ensure that attention and resources are focused on implementation and support in a balanced and strategic manner

Recommendation:

Ensure resource allocation reflects the urgency of introducing this capability to address Naval needs in key enabling technology areas **(Action: CNO N8 lead, CNO N2/N6 and CNO N9 support)**

- Perception and automated, in-situ sensor processing
- Intelligent control
- Cooperation between humans and machines
- Scalable collaboration

Findings and Recommendations (4)

Finding:

- To build trust, autonomous systems must appropriately reflect a range of issues such as legal, ethical, safety and security considerations
- Testing is central to achieving operational user acceptance.
- Autonomous systems differ from legacy systems and require new test methodologies as well as adequate facilities

Recommendations:

Develop protocols and enhance facilities as necessary to support autonomous systems testing and “trust building” **(Action: CNO N84)**

Take Aways

- **Autonomous Systems represent a transformational capability for Naval Operations in all domains**
- **A sense of urgency is required to create a focused, cross-domain Naval Autonomy Community**
- **Continuous experimentation with the fleet will be essential in generating and maintaining the trust that will be required**
- **Validated algorithms and data generated by these experiments will provide DoN with a sustaining technological and operational advantage.**

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