Task Force on the Role of Autonomy in the DoD Systems

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Terms of Reference

- Review relevant technologies to evaluate readiness for introduction into DoD
- Review current Service plans for integrating autonomy into near-term and next generation systems to identify missed opportunities
- Assess training and force structure impacts of autonomy improvements with a focus on reducing weapon system cost and personnel forward footprint
- Identify new opportunities for more aggressive application of autonomy and the associated benefits
- Comment on potential value of autonomy to both symmetric and asymmetric adversaries and where possible provide a net assessment
- Anticipate new vulnerabilities from reliance on pervasive autonomy and explore the value of autonomy as a hedge against weaknesses of net-centricity
- Identify systemic barriers to realizing full potential of autonomous systems
- Define special needs for testing and modeling & simulation for evaluating autonomous systems and their CONOPS
- Anticipate operational difficulties associated with rapid introduction of autonomous systems capabilities
Panel Members

- Brent Appleby
- Adele Howe
- Ken Israel, MG USAF (ret)
- Alexis Livanos
- James McCarthy, Gen USAF (ret)
- Ray Mooney
- Robin Murphy (co-chair)
- John Nathman, Adm USN (ret)
- Kevin Parker
- James Shields (co-chair)
- Robert Tenney
- David Woods
Impact

- Unmanned systems are having a worldwide impact (offensive and defensive) across the DoD, but we are operating in relatively benign conditions and at the initial stages of innovation for autonomy
  - Uses are primarily in air and ground applications to date
  - Marine systems have not achieved widespread usage
  - Space system benefits are primarily ground-based staff reduction and enhanced mission flexibility

- Main benefits of autonomous UxS* are to extend and complement human performance, not provide a direct replacement of humans
  - Extend human reach: perception, action, speed, persistence, size, scale, fatigue
  - Permit delegation and reduction of cognitive load – if explicitly designed to do so
  - Expand the adaptive capacity of the warfighter (e.g., more options, more flexibility)
  - Synchronize activities of UxS, software, and warfighter over wider scopes and ranges

- Consequence of these systems include:
  - New forms of data overload
  - Gaps between responsibility and authority
  - Challenges in coordinating joint activity that may require more people or investment

* Unmanned ___X___ System, where X designates the domain – air, ground…
About Autonomy

- Common misperceptions
  - Autonomy is misunderstood as providing independent thought and action when in fact they are “self-governing”
  - Action is bounded by its programmed capability
  - Autonomy is a capability (or a set of capabilities) not a “black box”

- Challenges of autonomous systems
  - For the commander, the design space and trade-offs for incorporating autonomy into a mission are not well understood and the result is new operational consequences
  - For the operator, must address human-machine collaboration, which often is overlooked during design
  - For the developer, autonomy is primarily software and presents challenges to hardware-oriented, vehicle-centric development and acquisition processes
Recommendations

Technology

- Abandon efforts to define levels of autonomy and develop an autonomous system reference framework that
  - Focuses on how autonomy supports specific capabilities
  - Identifies cognitive functional responsibilities to be delegated to the human or the computer
  - Makes visible the systems level trades inherent in the design of autonomous capabilities
Autonomous System Reference Framework

**Framework for the Design and Evaluation of Autonomous Systems**

**Cognitive Echelon View**
As component agent and roles increase in autonomy, critical issues shift to relationships and coordination across roles and echelons.

**Complex System Trades Space View**
whether explicitly made or not, system level performance trades result from design.

**Mission Dynamics View**
where cognitive functions can assist

**Scope of Control**
- MISSION
- SECTION
- VEHICLE

**INITIATION**
Plan, including delegation and bounds

**IMPLEMENTATION**
Action failures, Obsolete portions of plans

**TERMINATION**
Mission Complete

**Responsibility: Short-Term vs. Long-Term Goals**

**Perspectives: Local vs. Global Views**

**Impact: Centralized vs. Distributed**

**Plans: Efficiency vs. Thoroughness**

**Fitness: Optimality vs. Resilience**

Performance

Variation from nominal conditions
Each cognitive function is performed by a mix of humans and/or computers.

Shifting a function from a human to a computer affects system performance, cost, and man power requirements.
# System Level Trades

<table>
<thead>
<tr>
<th>Trade Space</th>
<th>Trades</th>
<th>Benefits</th>
<th>Unintended Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fitness</td>
<td>Optimality vs. resilience</td>
<td>More precise results for understood situations</td>
<td>Increased brittleness</td>
</tr>
<tr>
<td>Plans</td>
<td>Efficiency vs. thoroughness</td>
<td>Balanced use of computational resources</td>
<td>Locked into wrong plan/difficulty revising plan</td>
</tr>
<tr>
<td>Impact</td>
<td>Centralized vs. distributed</td>
<td>Ability to tailor actions to appropriate echelon</td>
<td>High cost of coordination</td>
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<tr>
<td>Perspectives</td>
<td>Local vs. global views</td>
<td>Ability to balance scale/area of action with resolution</td>
<td>Data overload; reduced speed of decision making</td>
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<tr>
<td>Responsibility</td>
<td>Short-term vs. long-term goals</td>
<td>Builds trust tailoring risk management to goals, priorities, context</td>
<td>Break down in collaboration and coordination</td>
</tr>
</tbody>
</table>
Recommendations

**Technology**

- Abandon efforts to define levels of autonomy and develop an autonomous system reference framework that
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- ASD(R&D) should work with Services to develop a coordinated S&T to strengthen autonomy technology with emphasis on
  - Natural user interfaces and trusted human-system collaboration
  - Perception and situation awareness to operate in a complex battle space
  - Large-scale teaming of manned and unmanned systems
  - Test and evaluation of autonomous systems

- Stimulate the S&T program with challenge problems motivated by operational experience and evolving mission requirements
  - Create focused on-site collaborations across academia, government/NFP labs and industry

- Strengthen the government technical workforce for autonomy by attracting AI and software engineering experts and establishing career paths and promotion opportunities that will retain them
Missed Opportunities, Needed Technology Developments

Under-utilized existing capability
Open technical challenges needing investment

Mission Commander, Executive Officer, Intel Analyst, Support Staff
Reach into World
Scope of Control

Scenario Planning & Decision Making
Scenario Assessment & Understanding
Information/Network Management
Contingency Management

Mission Planning & Decision Making
Failure Anticipation and Replanning
Multi-agent, Communication, Collaboration

GN&C
Failure Detection & Vehicle Health Management
Situational Awareness
Communications

Section Leader, Team Lead, Team Members
Pilot, Sensor Operator

Communications
Fault Detection & Vehicle Health Management
Situational Awareness

Adaptive Capacity
Recommendations

Acquisition

- USD(AT&L) and Services to use reference framework in developing and evaluating new autonomous system designs
  - Direct that system designs explicitly address human-system interaction and delegation of decisions within the mission context
  - Separate autonomy (especially operator control and human supervision subsystems) development programmatically from vehicle development
  - Accelerate DoD and Service efforts to develop common, open software operator control systems leveraging proven human factors principles

- Joint Staff and Services should improve the requirements process to develop a mission capability pull for autonomous systems
  - Use autonomy framework to identify missed opportunities and future system capability, especially over echelons and timelines
  - Explicitly feed back operational experience with current unmanned/autonomous systems to develop future requirements
  - Create new methods for quantifying design trades, cost of coordination, and resilience and new T&E techniques for complex systems with non-deterministic behavior

- Each Service should initiate at least one open software design project for an existing or planned UxS platform that decouples autonomy from the vehicle and deploys proven technology to reduce manpower, increase capability and adapt to future missions
  - Strengthen government technical and acquisition capability by leveraging academia, not-for-profit laboratories and industry
  - Recognize that programming for autonomous systems is different than traditional software development
Recommendations

Operations/Culture

- Services should improve understanding of the role and benefits of autonomous systems
  - Develop short courses on autonomy for inclusion in professional military education
  - Include UxS concepts in war games
  - Ensure that lessons learned from use of unmanned systems in the current conflict are broadly disseminated
  - Develop operation training techniques that explicitly build trust in the autonomous system

- USD(AT&L) establish developmental and operational T&E techniques that focus on the unique challenges of autonomy
  - Coping with the difficulty of enumerating all conditions and non-deterministic responses
  - Basis for system decisions often not apparent to user
  - Measuring trust that the autonomous system will interact with its human supervisor as intended
  - Expanding the test environment to include direct and indirect users (human supervisors, higher level command, etc.)
  - Leverage the benefits of robust simulation
Recommendations

Avoid Capability Surprise

- Task DIA and the Intelligence Community to develop threat assessments for adversaries relative to the unmanned/autonomous systems capability
- Include adversary use of unmanned/autonomous systems in war games, training, simulations and exercises. Do not be constrained by U.S. system concepts and rules of engagement
- Services to develop tactics, techniques and procedures for countering adversary unmanned capabilities
- Task acquisition programs to assess vulnerabilities of U.S. systems to physical, jamming and cyber attacks
- Red team adversary responses to U.S. systems and actions
Summary

- Unmanned systems are having a worldwide impact (offensive and defensive) across the DoD, but we are operating in relatively benign conditions and at the initial stages of innovation of autonomy.
- Main benefits of UxS* are to extend and complement human performance, not provide a direct replacement of humans.
- Principal recommendation for capturing additional benefits of autonomous systems include:
  - Abandon definitions of levels of autonomy and replace with the autonomous systems reference framework. Use the framework to shape technology programs and to make key decisions for the design of future systems.
  - ASD(R&E) should work with Services to establish a coordinated S&T program guided by feedback from operational experience and evolving mission requirements.
  - Joint Staff and Services should improve the requirements process to develop a mission capability pull for autonomous systems.
  - USD(AT&L) to create developmental and operational T&E techniques that focus on the unique challenges of autonomy.
  - DIA and Intelligence Community to track adversary capabilities for autonomous systems. Include these threats in war games, training, simulations and exercises.