National Aeronautics and Space Administration

The Challenges of Human-Autonomy Teaming

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RTCA SC 228 Meeting

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Overview

Three Themes

- Not designing autonomous systems to interact with humans increases costs
- At a system level, autonomy coupled with human intelligence will remain superior to either on its own
- Need to consider nominal and off-nominal situations separately

Machine Intelligence

We appear to be at an exciting time with respect intelligent machines (again).

- **Four Related Areas of Development**
  1. Big Data - volume, velocity and variety
  2. Deep Learning
  3. Networked operations and cyber-physical systems
  4. Moore's Law (exponential growth, doubling of components on an integrated circuit every two years): faster, bigger computers driving change with increasing velocity
- **Stephen Hawking, Bill Gates and Elon Musk have all recently warned about the potential dangers of AI.**
- **Also interesting time in terms of self-driving cars and companies with robotic operations/factories like Amazon, Tesla and Toyota**
- **Big Blue, Watson, Pokerbot**
- **Google DeepMind AI Division beats human at GO (Jan 2016)**
- **First AI investment software hits Wall St. (Feb 2016)**

Manpower Reduction: Start with the Human (Not the Technology)

The Autonomy Paradox

(Blackhurst, Gresham & Stone, 2011)

- Autonomy doesn't get rid of humans, it changes their roles
- DoD has shifted from Levels-of-Automation to Cognitive Echelons

As machine intelligence advances, the need for better human interfaces increases

The Littoral Combat Ship

Built to be operated by 45 sailors

Dr. Larry Shattuck, NPS (pg. 13-15)
http://human-factors.arc.nasa.gov/workshop/autonomy/download/presentations/Shaddock%20.pdf

Recent Developments

The Littoral Combat Ship

- New, highly autonomous vehicle

UPDATED: Littoral Combat Ship USS Montgomery Suffers Engineering Casualty, Fifth LCS Casualty Within Last Year

By: Sam LaGrone
September 16, 2016 12:26 PM • Updated: September 16, 2016 10:52 PM

USS Montgomery (LCS-8) during sea trials. Austal USA Photo

In the end, the ship required 60 sailors, all E5 or above

… and they are still encountering major issues

Self-Driving Cars

- About 5 years in
- Companies include: BMW, Bosch, Delphi, Ford, GM, Google, Honda, Nissan, Mercedes-Benz, Tesla, VW, Volvo/Uber, Apple
- Vehicle responsible for own safety. Control Center provides high-level goals when vehicle requires assistance.
- Vehicle control not handed back to human in emergency (“The Nun or the Baby Scenario”)
- Trained safety drivers in vehicles (Tesla and Uber?)
- Low cognitive demand activity (most of the time)
- MB: vehicles like domesticated animals

Car as Guardian: Assisted Driving

Lane keeping

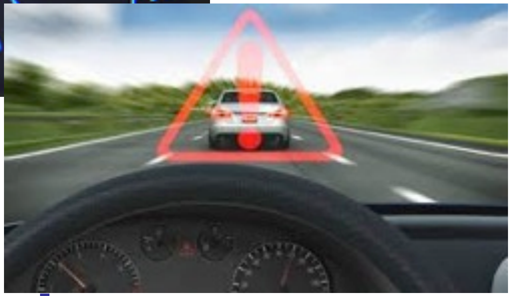
Tight or loose?

Blind-spot monitoring

Adaptive cruise control (speed & spacing)

Automated Emergency Breaking

Forward Collision Warning



Car as Chauffer: Self-Driving

Autosteering (Tesla); DrivePilot (MB)

Ladder of Vehicle Automation

(per SAE International)

	Human Driver Monitors Environment			System Monitors Environment		
	0 No Automation	**1** Driver Assistance	**2** Partial Automation	**3** Conditional Automation	**4** High Automation	**5** Full Automation
	The absence of any assistive features such as adaptive cruise control.	Systems that help drivers maintain speed or stay in lane but leave the driver in control.	The combination of automatic speed and steering control—for example, cruise control and lane keeping.	Automated systems that drive and monitor the environment but rely on a human driver for backup.	Automated systems that do everything—no human backup required—but only in limited circumstances.	The true electronic chauffeur: retains full vehicle control, needs no human backup and drives in all conditions.
Who steers, accelerates and decelerates	Human driver	Human driver and system	System	System	System	System
Who monitors the driving environment	Human driver	Human driver	Human driver	System	System	System
Who takes control when something goes wrong	Human driver	Human driver	Human driver	Human driver	System	System
How much driving, overall, is assisted or automated	None	Some driving modes	Some driving modes	Some driving modes	Some driving modes	All driving modes

Stats

Self-driving cars: 1 critical disengage per 40,000 miles

Humans Drivers:

1.2 fatal accidents per 100,000,000 miles driven

99 injury accidents per 100,000,000 miles driven ~ 1 injury accident per 1,000,000 m

Most (x100) disengagements are on streets (v highway)

Disengagements where safety driver takes over dropping slower than disengagements where software hands back control (x5)

Time from software hand-back to human control ~ 1min

Google & Nissan: ~ 1 disengage per 5,000 miles

Tesla; ~ 1 disengage per 3 miles

Tesla's 40% Decrease in accidents after Autosteer Install

Miles include "Autopilot" on and off

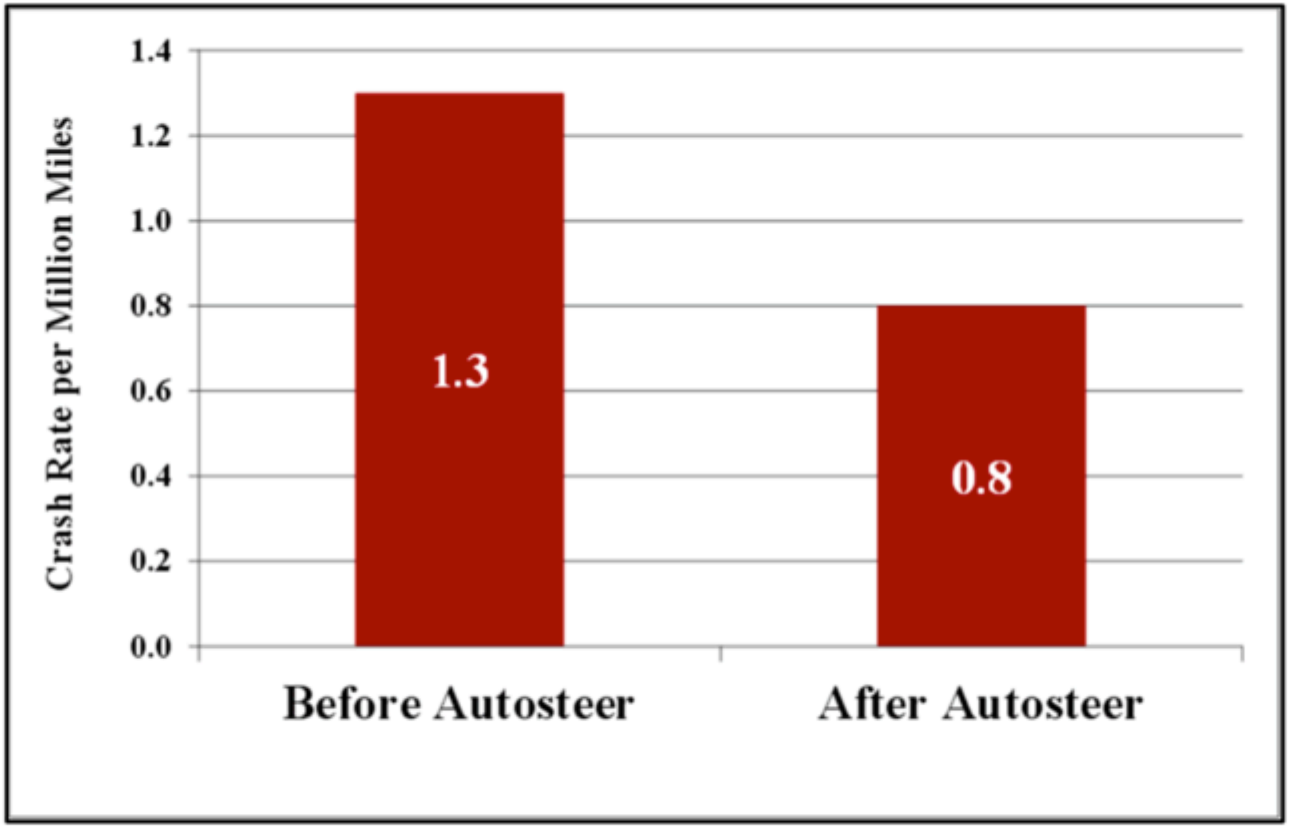


Figure 11. Crash Rates in MY 2014-16 Tesla Model S and 2016 Model X vehicles Before and After Autosteer Installation.

Challenges to SDV

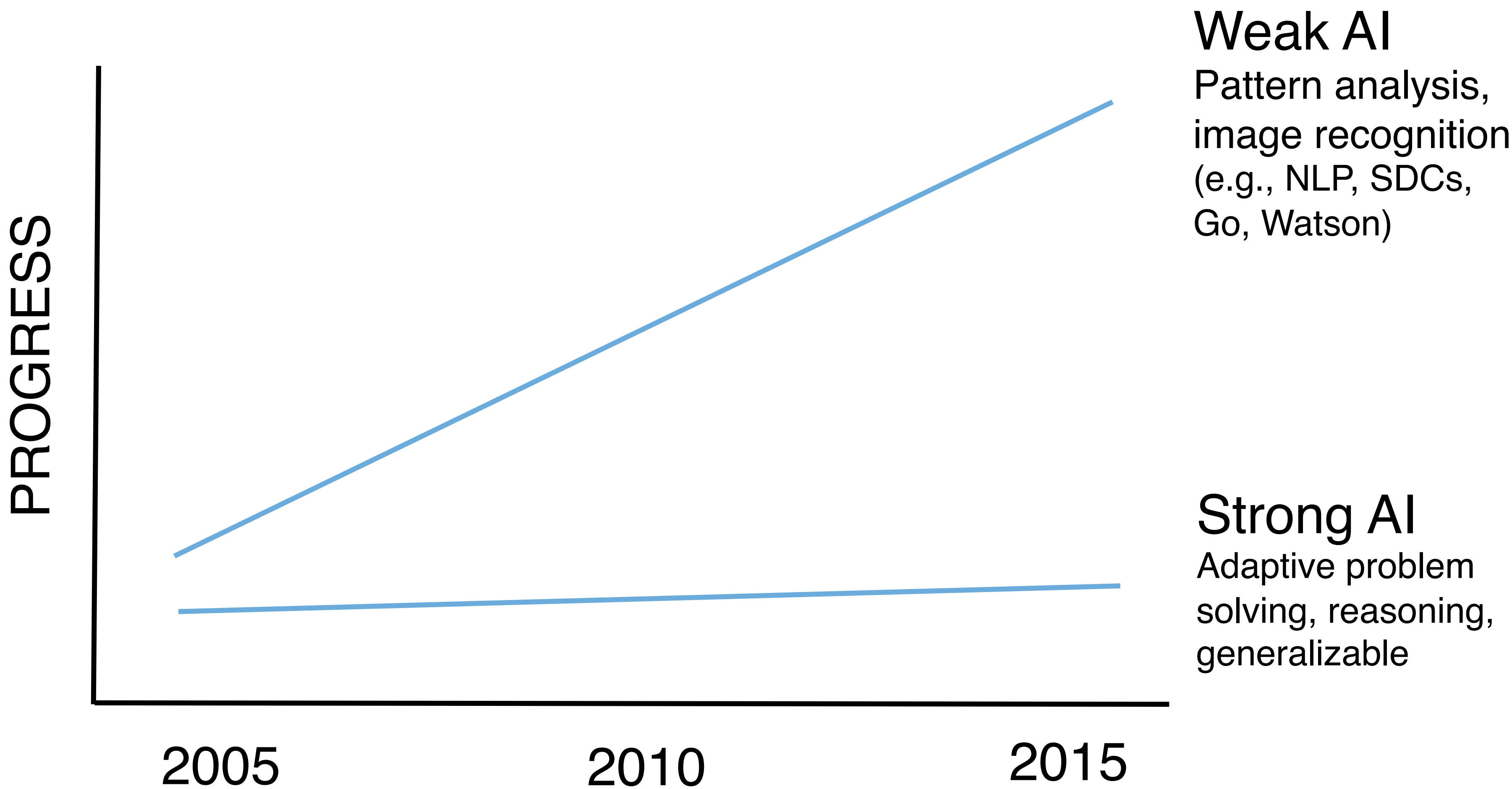
- Software V&V
- Human-systems integration
  - Graceful degradation

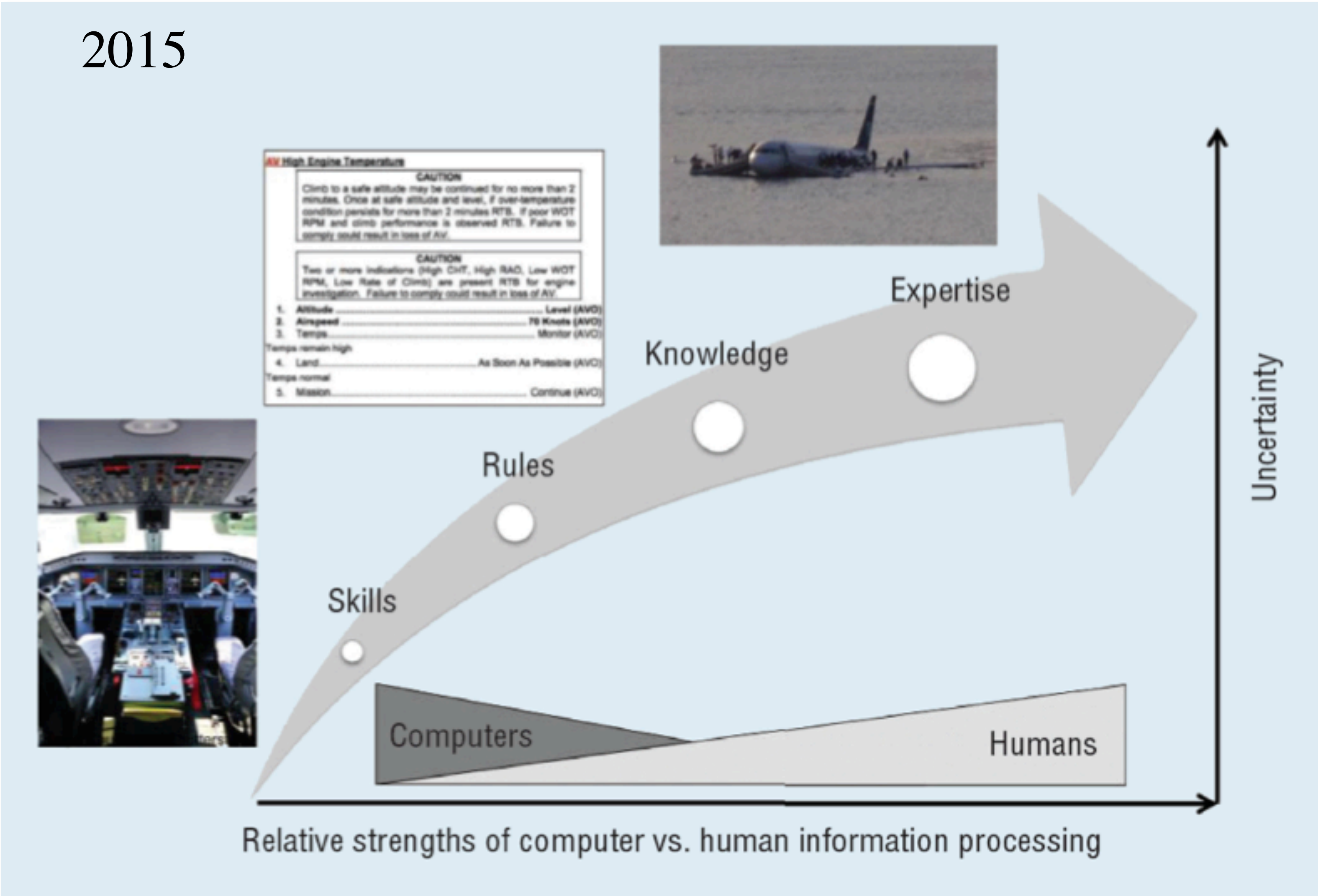
System-Level Approach

- Can't be piecemeal – e.g., Littoral Combat Ship
- Transition of human roles from SMEs (drivers in this case), to autonomy experts.
- What will humans need to do in nominal and off-nominal situations
- Control Centers for off-nominal situations

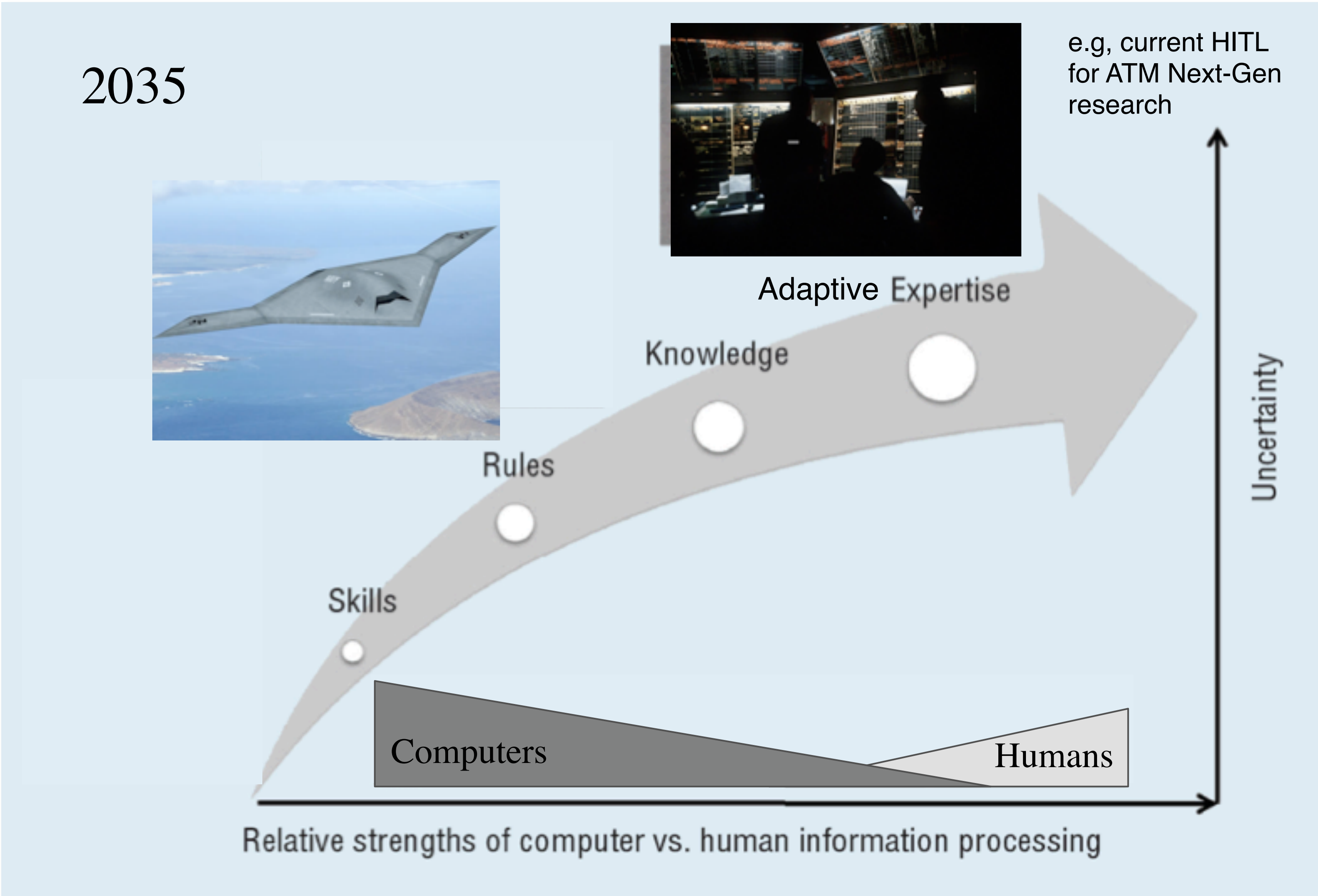
Nissan control center/
console pictures

Progress in Artificial Intelligence





From Cummings, M.L., "Man vs. Machine or Man + Machine?" *IEEE Intelligent Systems*, (2014) 29(5), p. 62-69.



Architecture based on autonomy performing all skill and rule-based roles, as well as most knowledge-based roles. Manpower reduced by two orders of magnitude with remaining expert humans teaming with machine intelligence to solve complex problem solving under uncertainty. Machine intelligence for airspace management evolves from the outset to support teaming with small set of expert humans to support cooperative problem-solving.

What are the Challenges of Working with Autonomy?

- Lack of transparency about intent, state awareness, risk/confidence posture, graceful degradation, etc.
- Part of the challenge is just the reverse though. Given that the Autonomy does not know what the human is trying to do, it is difficult for the system to know to engage in ways that are useful.

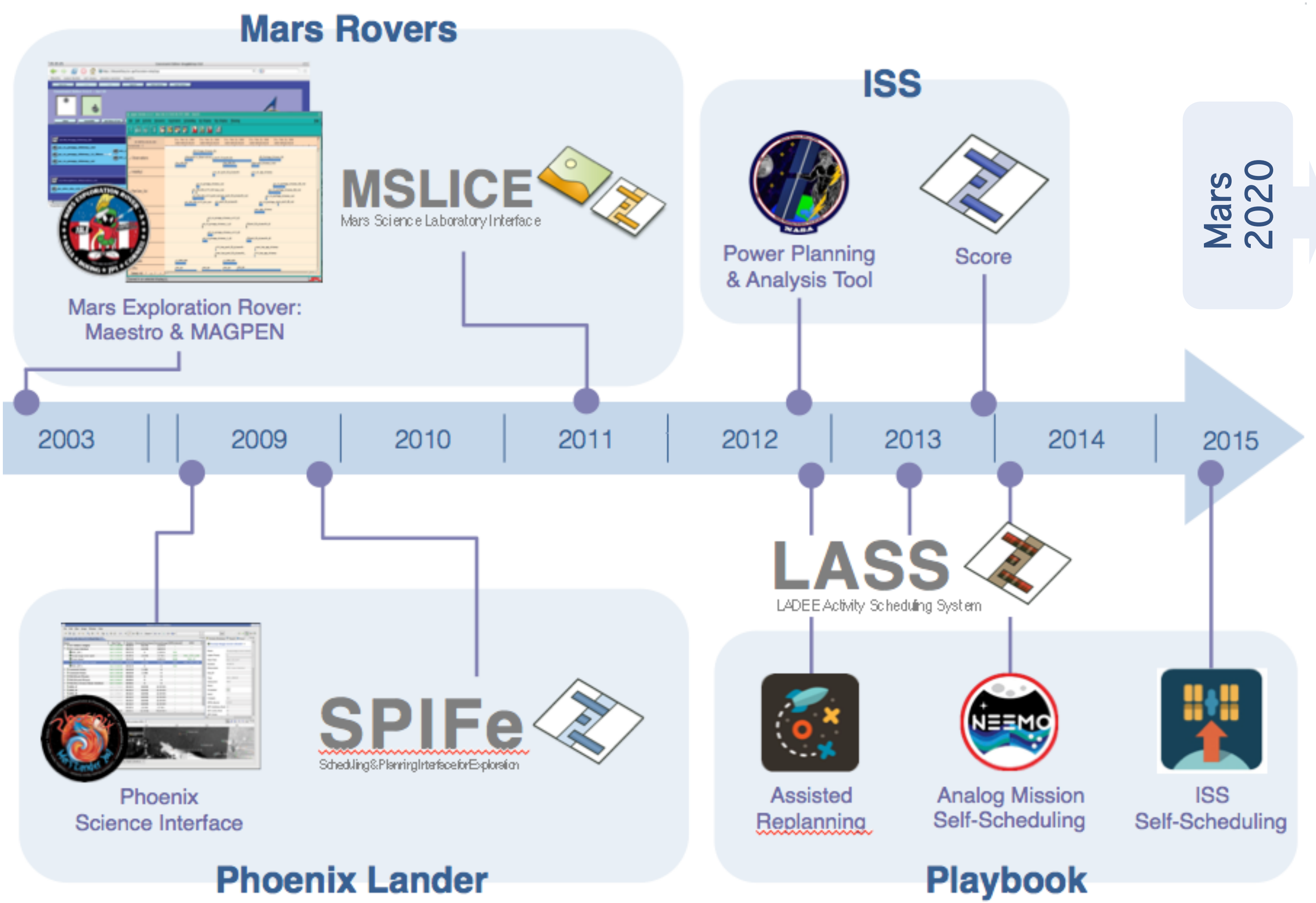
Toward Human-Autonomy Teaming?

Domesticated Robots

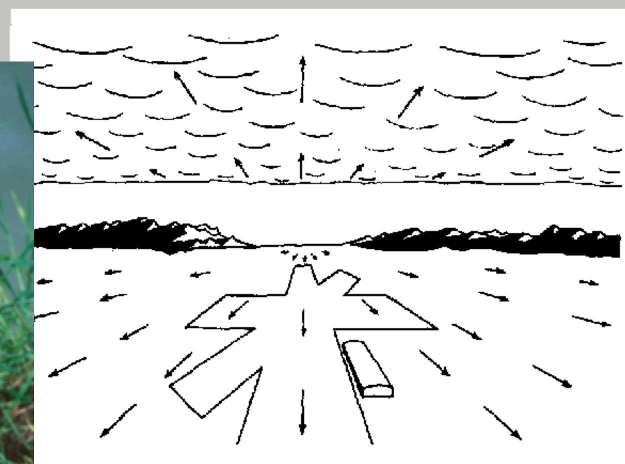
Caged Robots

Designed for Teaming

Path to Collaborative, Human-in-the-Loop Planning Systems

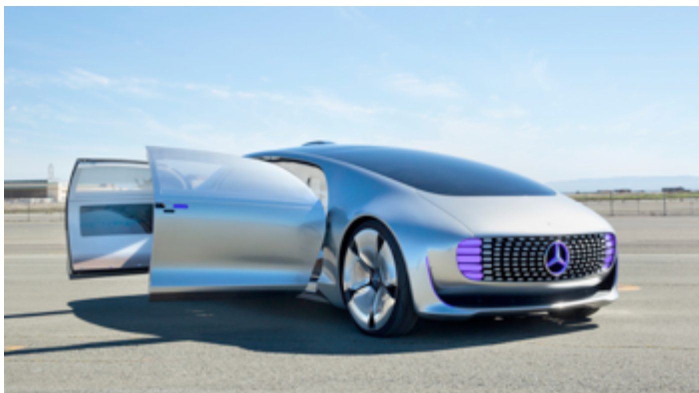


Affordances from the Environment



idealised flowfield (after Gibson, 1950)

Using Affordances



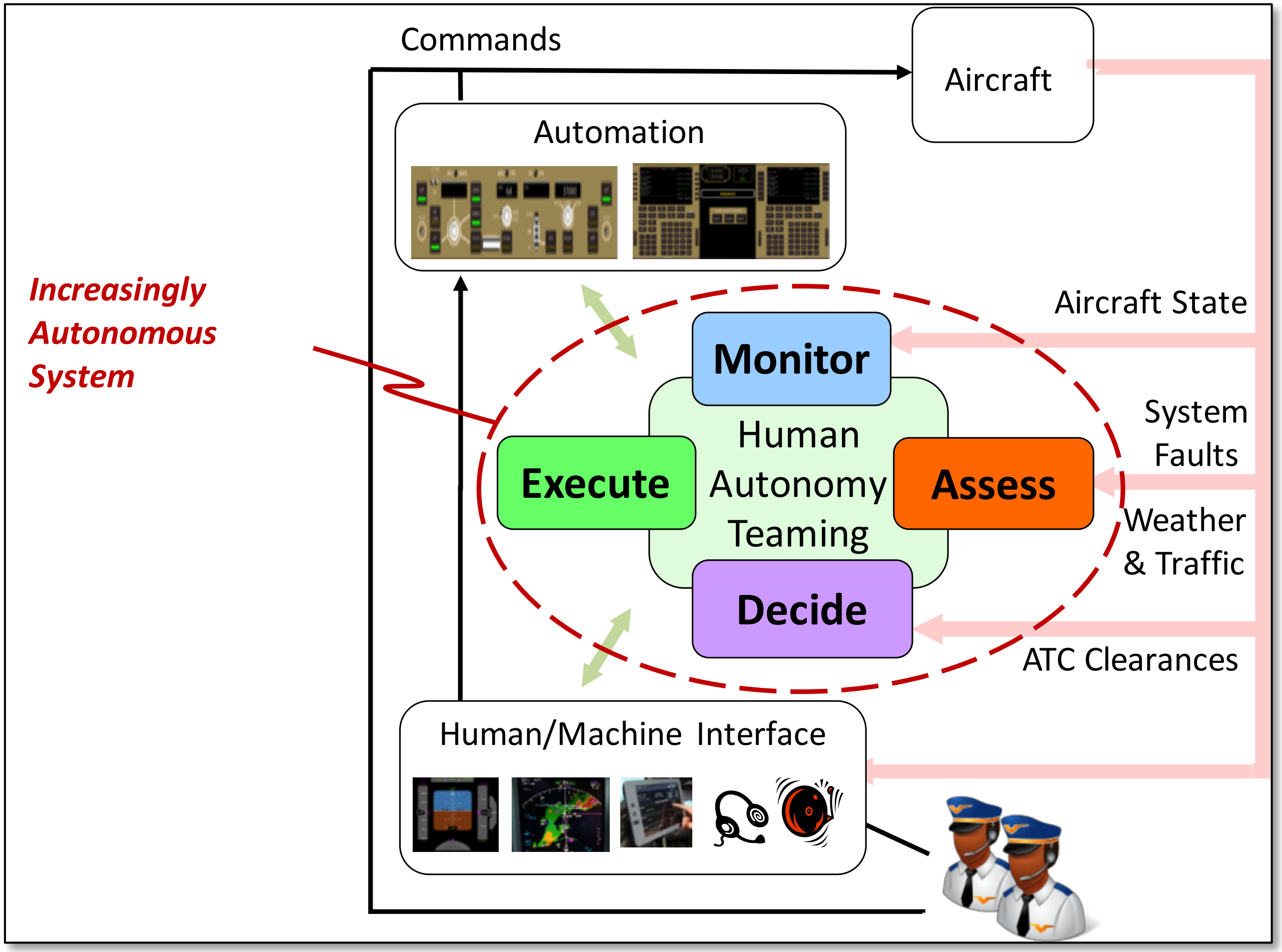
- **Application of Gibsons' Ecological Psychology**
  - Alternatives to using human central attention resource
  - A car more like a horse

Apple Research on Teaming of IISs with Humans

- Characterizing calorie burn during swimming and using learning algorithms to tune the functionality to individual differences
- Developed novel experimental hardware and tested on 700 swimmers
- To develop a feature on one app for the new iWatch

http://www.cultofmac.com/444551/why-apple-is-the-new-nasa/?&tc=em

System-Level Design



From SECAT briefing package, Aponsonet al., 09/2016

- **Airspace is a complex system and complexity will only continue to increase**
- **Humans are both limiting and enabling parts of system (pilots have to address unexpected safety issues on 20% if flights*)**
- **DoD → $3B on H/A Teaming in FY17**

** From NTSB Asiana 214 Docket*

The Economics of Human-Centered Automation

- **For lower costs, higher efficiencies and overall improved system performance:**
  - Characterize nature of human roles (skills, rules, knowledge, expertise) and tasks (e.g., proportion of hard and soft constraints)
  - Wrap autonomy around remaining human roles from the beginning

Critical to shape the autonomy industry

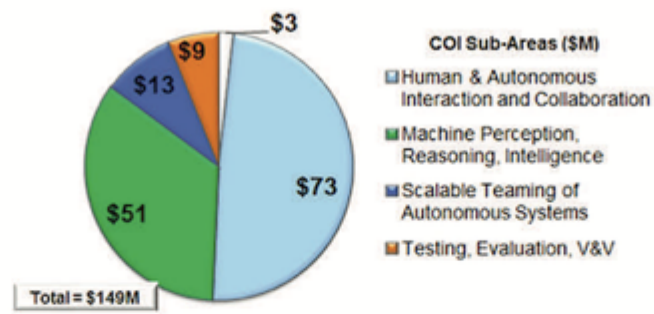
- e.g., Apple v. Littoral Combat Ship

Purpose

Advancement of autonomous systems, and identification of potential investments to advance or initiate critical enabling technology development.

What's driving Autonomy S&T?

- **Manpower efficiencies**
  reduce human footprint and personnel cost
- **Rapid response and 24/7 presence**
  timely, persistent, enduring
- **Harsh environments**
  day, night, hot, cold, weather, rubble
- **New mission requirements**
  increasing competence, new capabilities
- **Advanced medical applications**
  critical response, end-to-end critical care
- **Logistical support**
  reduce logistics burden



Dr. Jon Bornstein, DoD Autonomy Roadmap Autonomy Community of Interest
http://www.defenseinnovationmarketplace.mil/resources/AutonomyCOI_NDIA_Briefing20150319.pdf

Teaming of Human and Machine Intelligence

- **Even as computers get very "intelligent", it is very likely that the nature of the their intelligence will be different than that of humans (unless they become omniscient or we program them to function just like humans)**
- **Humans are particularly good at adaptive problem-solving and discovery, areas where there has been little machine intelligence progress**
- **Successful efforts going forward will be those that wrap new machine intelligence capabilities around human competencies in order to get the most out of each**

Goal: Design the human into the process. Focus on how the system will communicate it's state to the human so that the human can help in un-anticipated situations, *and vice versa.*

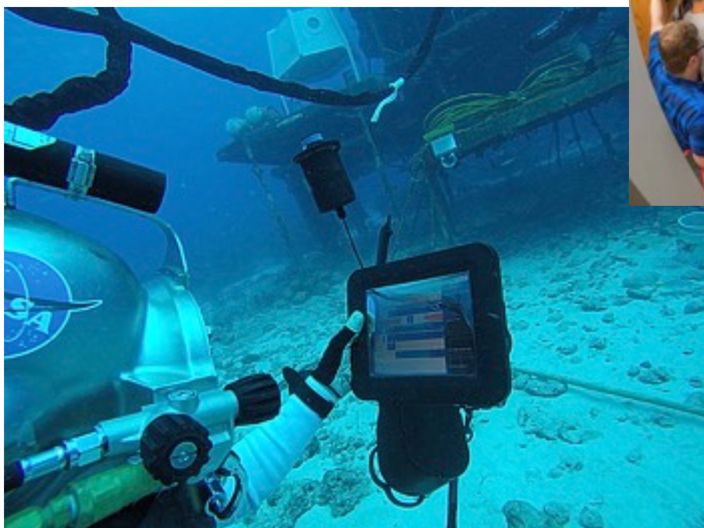
What data and how it is presented to each agent such that each can bring its unique capabilities to bear on it.

Final Thoughts

- **Humans will remain important components of complex systems**
- **Use human adaptive expertise as much as possible**
- **Use human cognitive & perceptual system as much as possible in interactions**
- **Robotics progressing faster than AI**
- **Be aware of areas where you don’t have big data**
  - Not all problems are associative in nature
- **Don’t assume pattern association and search will solve all problems**

Thank you

NEEMO



Crew at Splashdown

7/21/2015 http://www.nasa.gov/mission_pages/NEEMO/ 2

Daily Status: Mission Day 1

Playbook

For this mission, our plan execution tool is Playbook, which is developed by NASA Ames Research Center and specifically designed for use by crew to support mission operations. It is mobile, web-based, and designed to be flexible enough to work on a tablet device or in a traditional web browser. Used as the primary mission operations tool, Playbook allows controllers and crew to see the mission plan and schedule changes in real-time or through fully simulated time-delay. New features under evaluation include one that makes it very easy for the crew to collaboratively self-schedule flexible tasks, create new tasks, add groups of tasks to the timeline and keep the ground informed as they do so. We have a number of objectives related to crew self-scheduling we will be looking at, and crew feedback will continue to make this tool even more capable. There is also a new feature giving the ability to search all messages in real time, to allow mission control and the crew to easily refer back to past messages or to see all messages in a related thread.

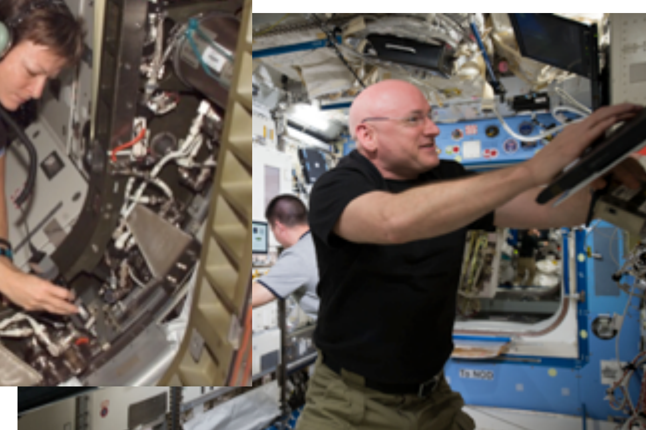
Playbook previously flew on ISS as an objective of the IRISS mission of Andreas Mogensen in Sept., 2015. It will be flying again during Increment 50/51 as a technology demonstration task list objective for Peggy Whitson under the name CAST, Crew Autonomous Scheduling Test. You can view the high level mission timeline at: https://neemo.nasaplaybook.com.

NASA Extreme Environments Mission Operations (NEEMO): Underwater laboratory off of the coast of Key Largo, Florida.

International Space Station

CAST – Crew Autonomous Scheduling Test:

- Playbook Check-Out by Scott Kelly on Station in August 2015.
- Astronaut Peggy Whitson trained on Playbook in July 2016.
- Astronaut self-scheduling study on ISS on Mission Increment 50/51 Nov 2016.



ISS Mission Control

- Three integrated planning systems: Power, Attitude Control and Crew Activity
- Crew activity includes ESA JAXA and Payloads