NASA Ames Research Center

S. Pete Worden

Center Director
NASA Ames Research Center

NACA Laboratories

NACA

Joseph S. Ames

NASA

Ames

Dryden

Langley

Lewis

1915

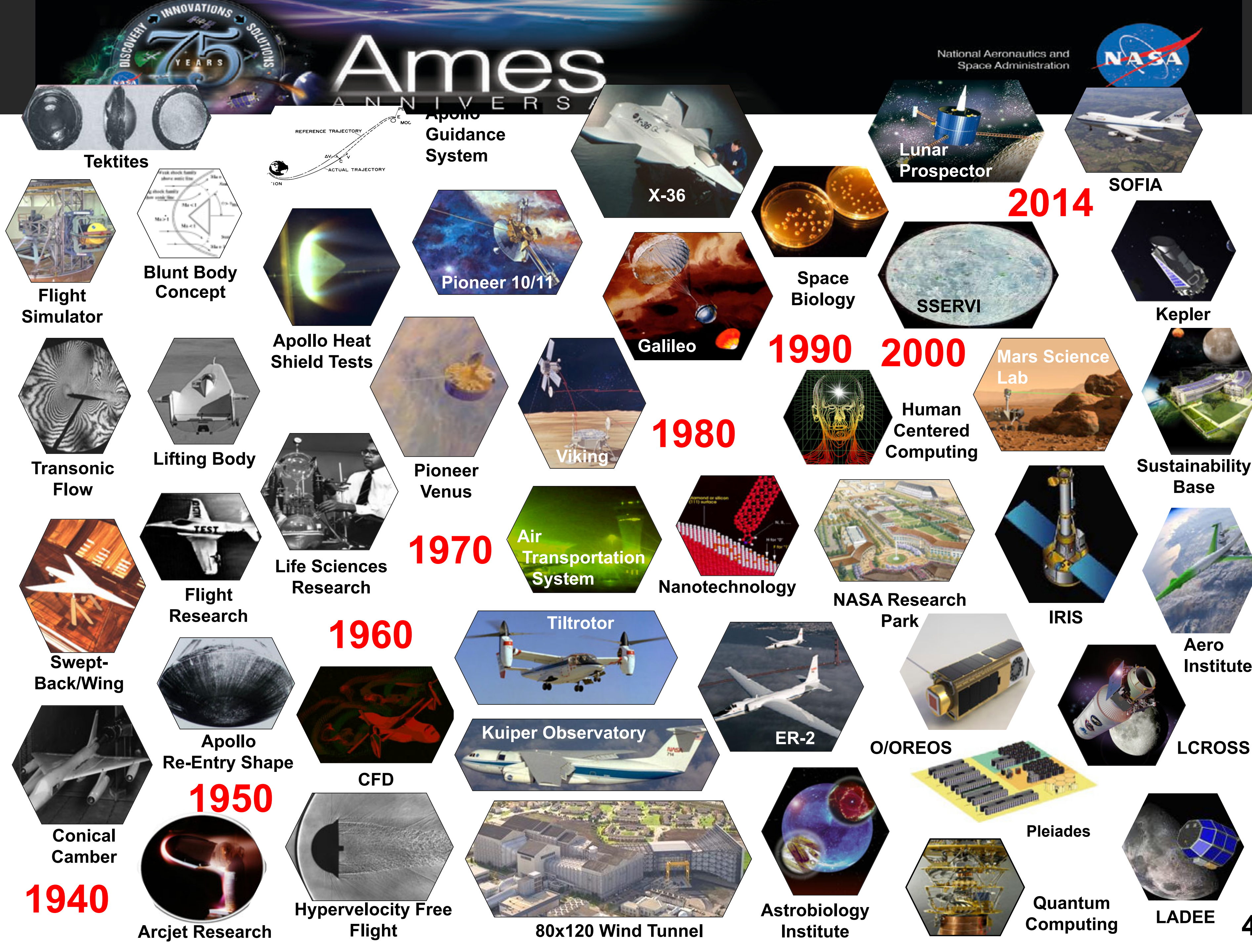
1939

1940

1946

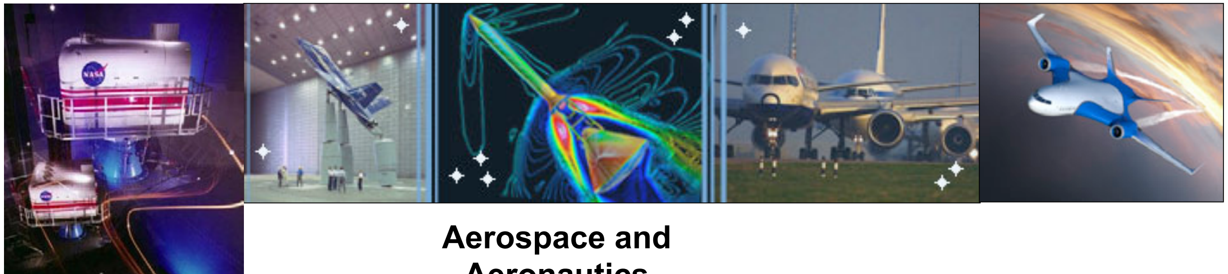
1958

Aerial View of NASA Ames Research Center



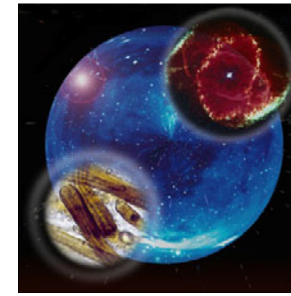
INNOVATIONS
DISCOVERY
SOLUTIONS
75
YEARS
Ames
ANNIVERSARY
National Aeronautics and
Space Administration
NASA
Tektites
Apollo
Guidance
System
REFERENCE TRAJECTORY
ACTUAL TRAJECTORY
X-36
Lunar
Prospector
SOFIA
2014
Flight
Simulator
Blunt Body
Concept
Pioneer 10/11
Galileo
Space
Biology
SSERVI
Kepler
Apollo Heat
Shield Tests
1990
2000
Mars Science
Lab
Transonic
Flow
Lifting Body
Pioneer
Venus
Viking
1980
Human
Centered
Computing
Sustainability
Base
Flight
Research
Life Sciences
Research
1970
Air
Transportation
System
Nanotechnology
NASA Research
Park
IRIS
Swept-
Back/Wing
1960
Tiltrotor
ER-2
O/OREOS
Aero
Institute
Apollo
Re-Entry Shape
CFD
Kuiper Observatory
LCROSS
Conical
Camber
1950
Pleiades
1940
Arcjet Research
Hypervelocity Free
Flight
80x120 Wind Tunnel
Astrobiology
Institute
Quantum
Computing
LADEE

Ames Technology Areas



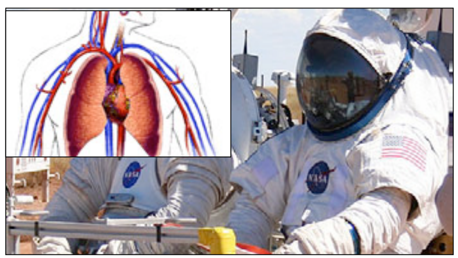
Aerospace and Aeronautics

Integrated Systems Health Management (ISHM)

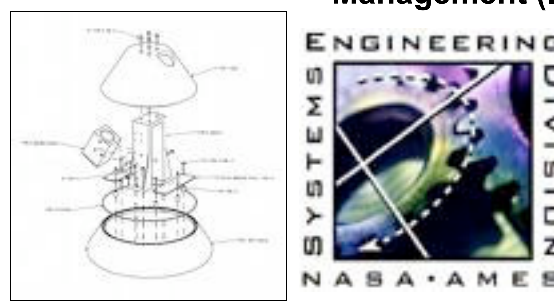


Astrobiology Institute

Small Satellite Systems



BioTech / Biomedical



Systems Engineering

SSERVI

Robotics and Artificial Intelligence

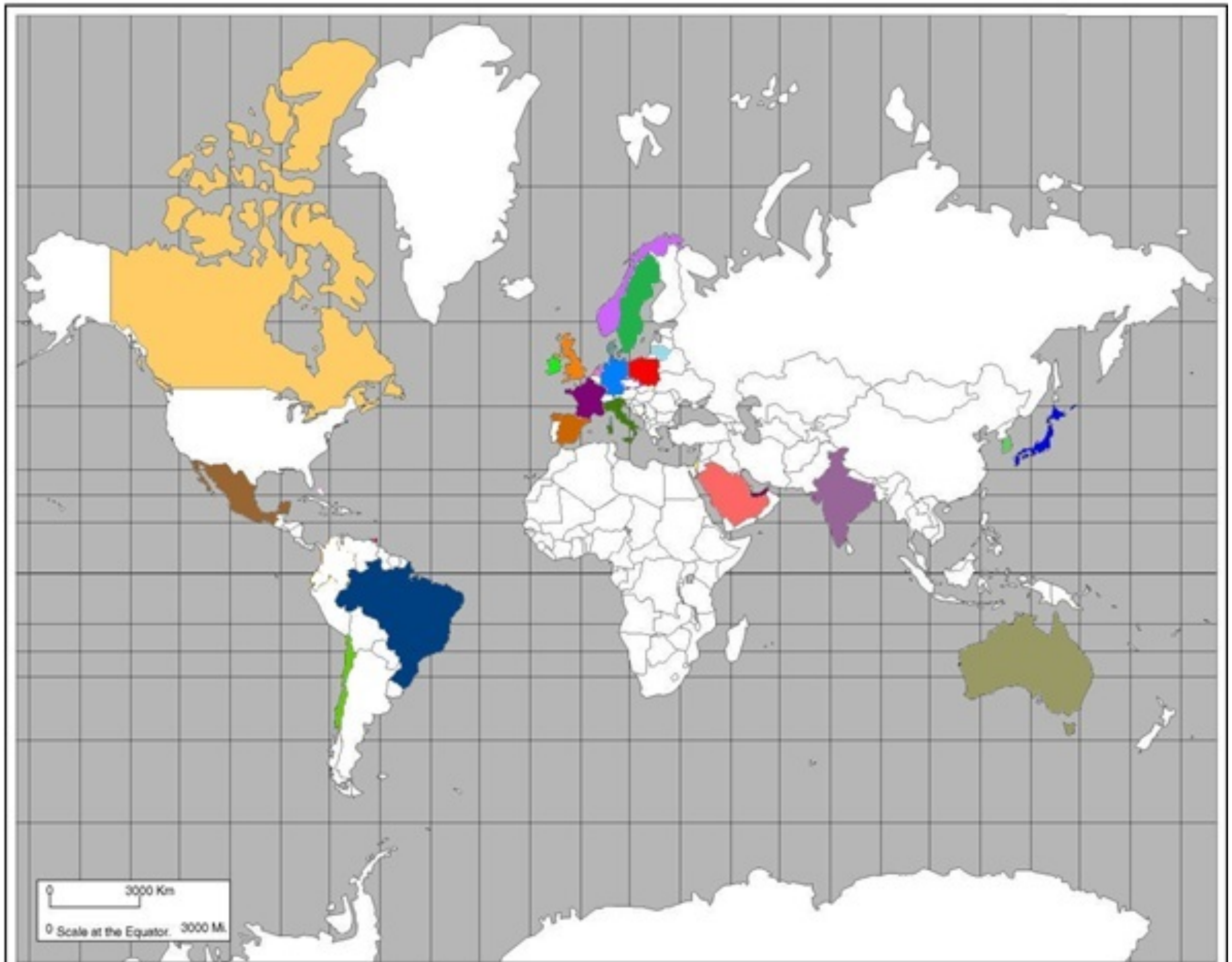
Materials Science and Entry Systems

High-end Computing & Quantum Computing

International Partnerships

Interns & Researchers

1. Australia
2. Brazil
3. Denmark
4. France
5. Japan
6. India
7. Ireland
8. Israel
9. Italy
10. Mexico
11. Norway
12. Poland
13. Spain
14. S. Korea
15. UAE
16. UK



Technical Collaboration

1. Canada
2. Chile
3. France
4. Germany
5. Italy
6. Japan
7. Lithuania
8. Mexico
9. Netherlands
10. Norway
11. Saudi Arabia
12. Sweden
13. Spain
14. Trinidad & Tobago
15. UK

NASA Challenges

- **Managing fleets of autonomous and semi-autonomous vehicles in space, extra-planetary surfaces, and in the National Air Space**
  - Networked vehicles monitored and operated from a control center
  - Semi-autonomous control
  - Human-autonomy teaming
- **Deep-space human missions**
  - Requires increasingly autonomous crew operations
  - Requires autonomy that is reliable, resiliant, and robust
  - Requires effective human-autonomy coordination and collaboration

Common Technologies

Self-Driving Cars

- Diverse human-machine interaction in a structured environment
- GPS & map-based navigation
- Distributed and cloud-based autonomy
- Cyber-security for consumer product
- Etc.

Common Technologies

Autonomy
Advanced Planning & Scheduling Algorithms, etc.

Human-Autonomy Teaming
Robotic Supervision including Human/Robotic Interactions, etc.

Networked Operations
Remote Vehicle Management, etc.

Prognostics and Diagnostics
Including State Management, etc.

Sensor Technologies
Data Processing / Fusion Methodologies, etc.

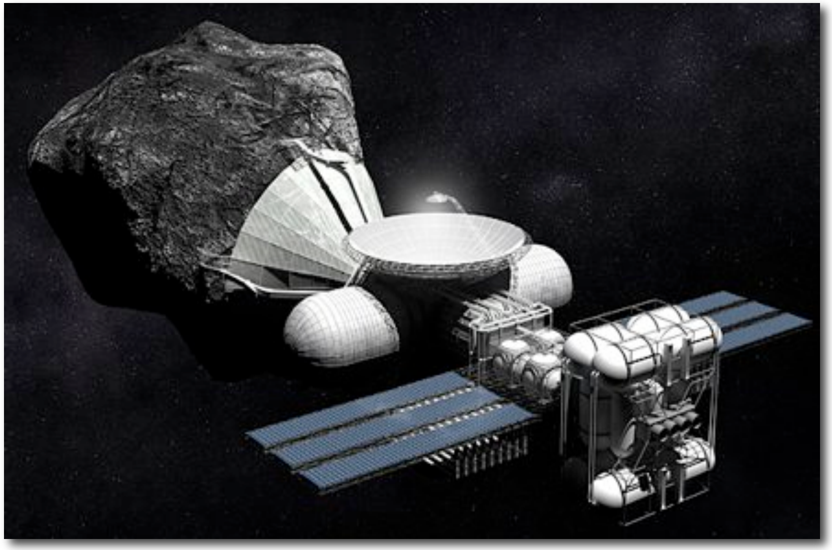
Verification & Validation
Methodologies & Application Experiences, etc.

NASA Missions

- Planned human-machine interaction in natural and time delayed environment
- Space & planetary nav
- Spacecraft autonomy
- Cyber-security for “one-off” systems
- Space environment
- Limited ability to address/recover faults
- Etc.

Autonomy

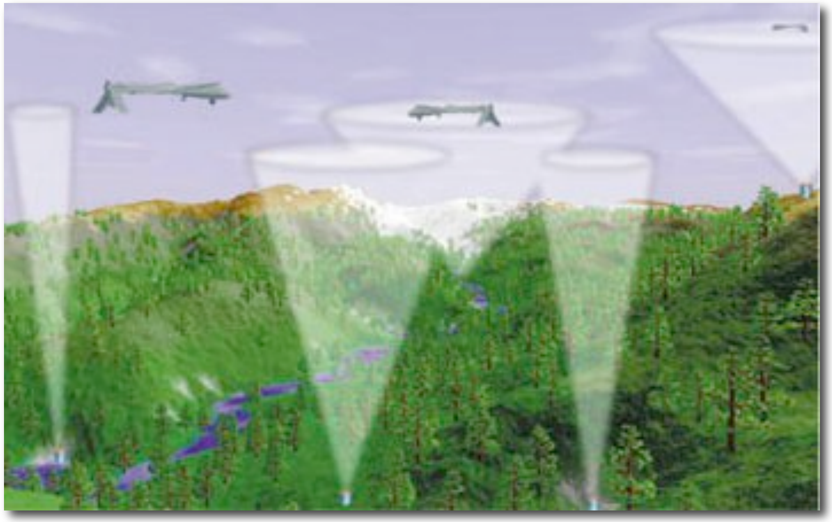
- **Self-driving cars require planning, navigation and coordination**
  - On-board autonomy: automated hazard mapping, obstacle avoidance, local path planning; non-GPS matching terrain to 3D and image data.
  - Off-board autonomy: telemetry monitoring, data archiving, mapping, etc. for remote support

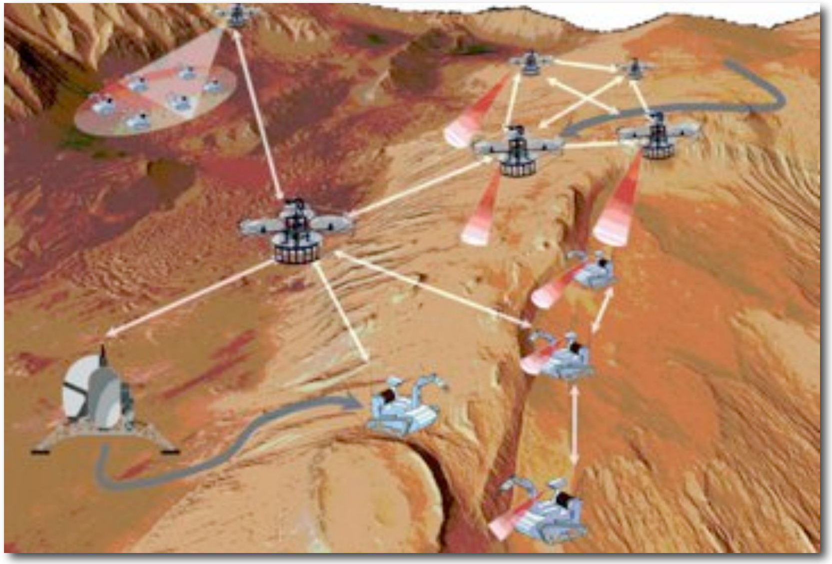


- **New autonomy approaches can be applied to NASA missions**
  - Manned and robotic deep space exploration
  - Unmanned Aerial System Traffic Management (UTM)
  - Safe Autonomous Systems Operations

Networked Operations

- **Self-driving cars provide testbeds of cyber-physical systems**
  - Increasingly autonomous agents communicating with each other to plan and execute coordinated activities
  - Minimal / intermittent human support
  - Field testing of managing set or swarm of autonomous and semi-autonomous systems in real-time
- **Complex multi-vehicle operations**
  - Changing/uncertain environments
  - Information is passed directly from one vehicle to another.
- **Wireless cloud-based architecture continuously tracking constraints and dynamically adjusting routing**



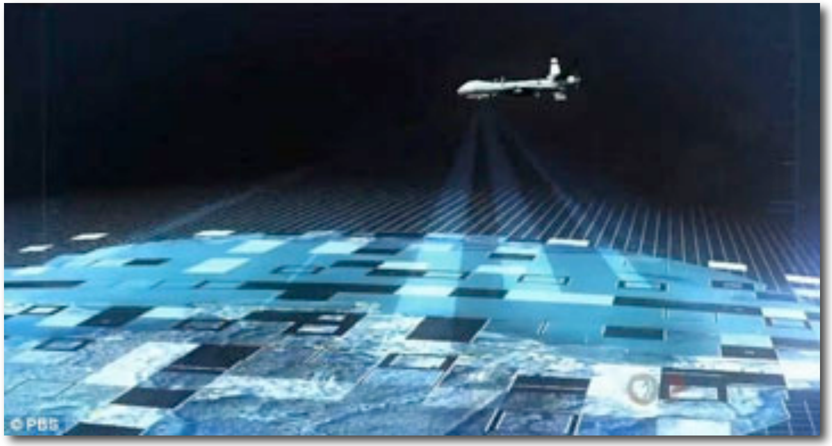


Prognostics and Diagnostics

- **Self-driving cars are an ideal test-bed for maturing advanced vehicle prognostics/diagnostics**
  - Complex interaction with a dynamic environment and situations
  - Large amount of test time.
- **NASA can use these test-beds to develop real-time prognostic and diagnostic methods**
  - Application to a wide range of crewed space vehicles (including but not limited to surface vehicles)
  - Application to unmanned aerial systems, single pilot operations and air traffic management.

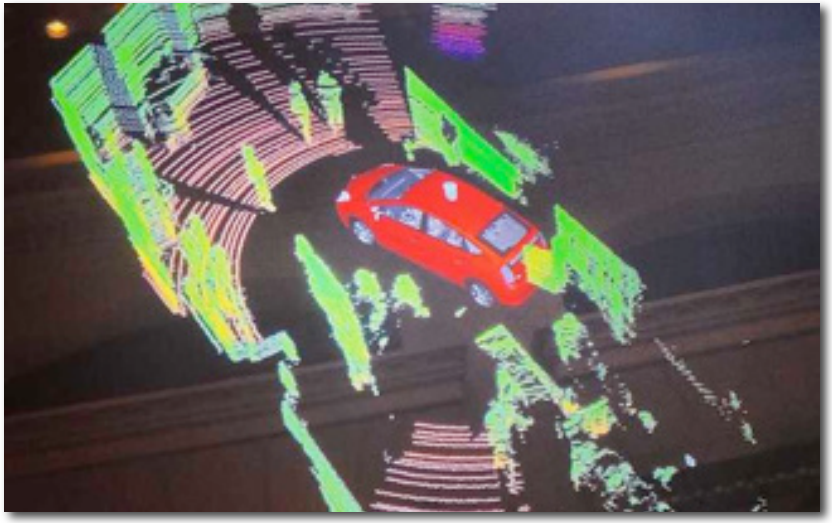
Sensor Technologies

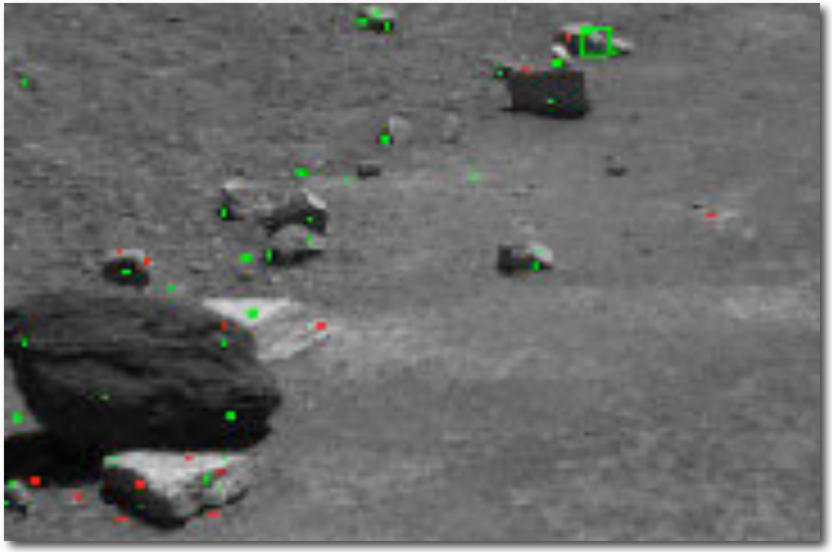
- **Self-driving car companies are developing new, rugged, low-cost, high-performance sensors**
  - Lidar: flash and scanning
  - Radar: high-res narrow angle
  - Real-time stereo vision
- **These sensors are needed for:**
  - Detecting static/dynamic hazards
  - Mapping and positioning (localization)
- **Sensors (and algorithms) can be applied to NASA missions**
  - Robots (Space Station Free-Flyers, planetary rovers, etc.)
  - Unmanned Aerial Systems in the National Air Space



Verification and Validation

- **Self-driving cars represent one of the most challenging applications for V&V due to the unpredictability of the operational environment:**
  - variable lighting / shadows
  - weather
  - human/automation interaction (driver, bystander, cyclist, etc.)
  - dynamic road environment
  - mixed-initiative decision making
- **New V&V methods can be applied to future exploration mission systems, particularly those that involve high reliance on autonomy (e.g., evolvable Mars)**





Human-Autonomy Teaming

- **Variety of approaches**
  - Google and Nissan are developing fully self-driving vehicles
  - BMW, Mercedes Benz, etc are pursuing targeted autonomy (e.g., self-parking, lane changing, etc.)
- **Manned deep space missions will require better human-autonomy teaming than we have today**
- **Increased aviation autonomy**
  - Depends on many factors
  - Control center to help resolve off-nominal situations
  - Requires public trust in autonomous vehicles

Applicability to NASA Goals

+++ Strong Alignment
++ Moderate Alignment
+ Partial Alignment

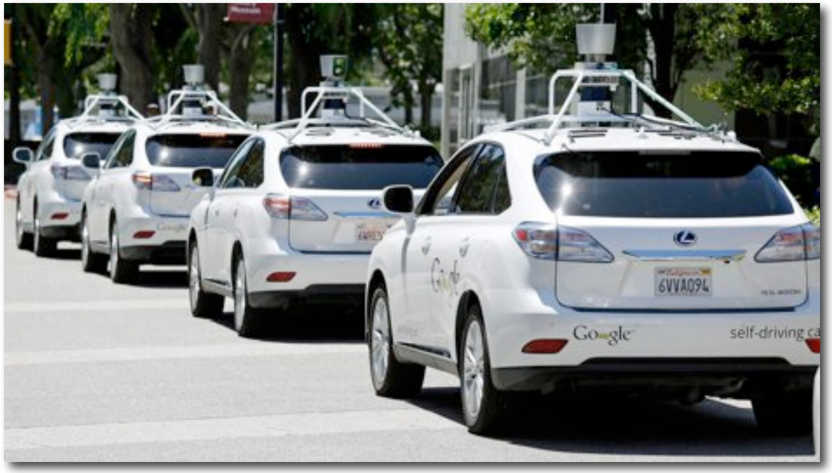
Self-Driving Car Technology Challenges

NASA Challenges

	Autonomy	Networked Operations	Prognostics and Diagostics	Sensor Technology	Verification and Validation	Human-Autonomy Teaming
Manned Deep Space Missions	+++	+	+++	++	+++	+++
Robotic Deep Space Missions	+++	++	+++	+++	++	+++
Single-Pilot Operations	++	++	++	++	+++	+++
Tele-Robotic Operations	+	++	++	+++	++	++
Unmanned Aerial Systems	+++	+++	++	+++	++	+++
Air Traffic Management	+++	+++	+++	++	++	++

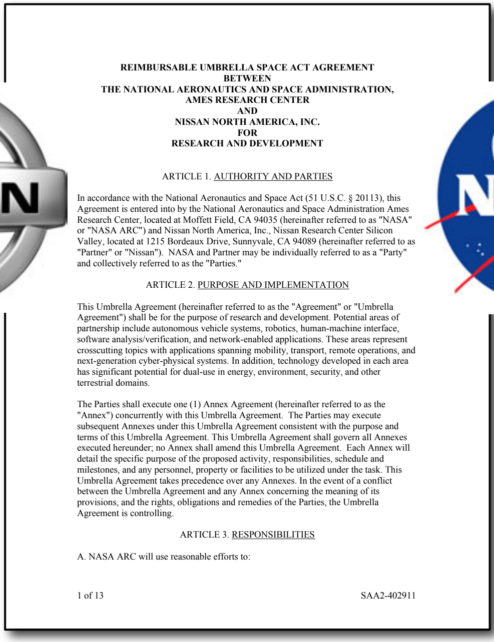
Self-Driving Cars at NASA Ames

- **Aligned with NASA autonomy development priorities**
- **Enables NASA to gain valuable knowledge and lessons learned from extensive real-world testing**
- **Enables joint development and demonstration of high-impact vehicle applications**
  - Mobility, transport, remote ops, and cyber-physical systems
- **Facilitates spin-off of NASA technologies to the private sector**
  - Robot navigation, perception, user interface, etc.
  - Dual-use in energy, environment, security, and other terrestrial domains.



Nissan-NASA Partnership

- **R&D agreement (5 year term)**
  - Autonomous vehicle systems
  - Human-machine interface
  - Network-enabled applications
  - Software analysis and verification
  - Vehicle testing at NASA Ames
- **Initial focus: Tele-robotics technologies**
  - Application of NASA algorithms and concepts
  - Joint development, testing, and assessment
  - Demonstration: fleet management of multiple autonomous vehicles


REIMBURSABLE UMBRELLA SPACE ACT AGREEMENT
BETWEEN
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,
AMES RESEARCH CENTER
AND
NISSAN NORTH AMERICA, INC.
FOR
RESEARCH AND DEVELOPMENT

ARTICLE 1. AUTHORITY AND PARTIES

In accordance with the National Aeronautics and Space Act (51 U.S.C. § 20113), this Agreement is entered into by the National Aeronautics and Space Administration Ames Research Center, located at Moffett Field, CA 94035 (hereinafter referred to as "NASA" or "NASA ARC") and Nissan North America, Inc., Nissan Research Center Silicon Valley, located at 1215 Bordeaux Drive, Sunnyvale, CA 94089 (hereinafter referred to as "Partner" or "Nissan"). NASA and Partner may be individually referred to as a "Party" and collectively referred to as the "Parties."

ARTICLE 2. PURPOSE AND IMPLEMENTATION

This Umbrella Agreement (hereinafter referred to as the "Agreement" or "Umbrella Agreement") shall be for the purpose of research and development. Potential areas of partnership include autonomous vehicle systems, robotics, human-machine interface, software analysis/verification, and network-enabled applications. These areas represent crosscutting topics with applications spanning mobility, transport, remote operations, and next-generation cyber-physical systems. In addition, technology developed in each area has significant potential for dual-use in energy, environment, security, and other terrestrial domains.

The Parties shall execute one (1) Annex Agreement (hereinafter referred to as the "Annex") concurrently with this Umbrella Agreement. The Parties may execute subsequent Annexes under this Umbrella Agreement consistent with the purpose and terms of this Umbrella Agreement. This Umbrella Agreement shall govern all Annexes executed hereunder; no Annex shall amend this Umbrella Agreement. Each Annex will detail the specific purpose of the proposed activity, responsibilities, schedule and milestones, and any personnel, property or facilities to be utilized under the task. This Umbrella Agreement takes precedence over any Annexes. In the event of a conflict between the Umbrella Agreement and any Annex concerning the meaning of its provisions, and the rights, obligations and remedies of the Parties, the Umbrella Agreement is controlling.

ARTICLE 3. RESPONSIBILITIES

A. NASA ARC will use reasonable efforts to:

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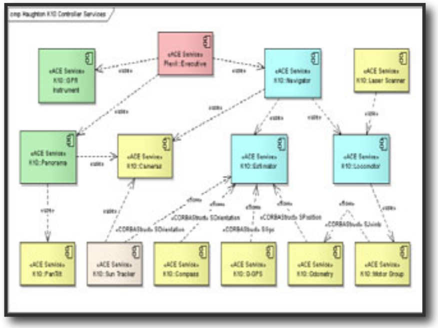
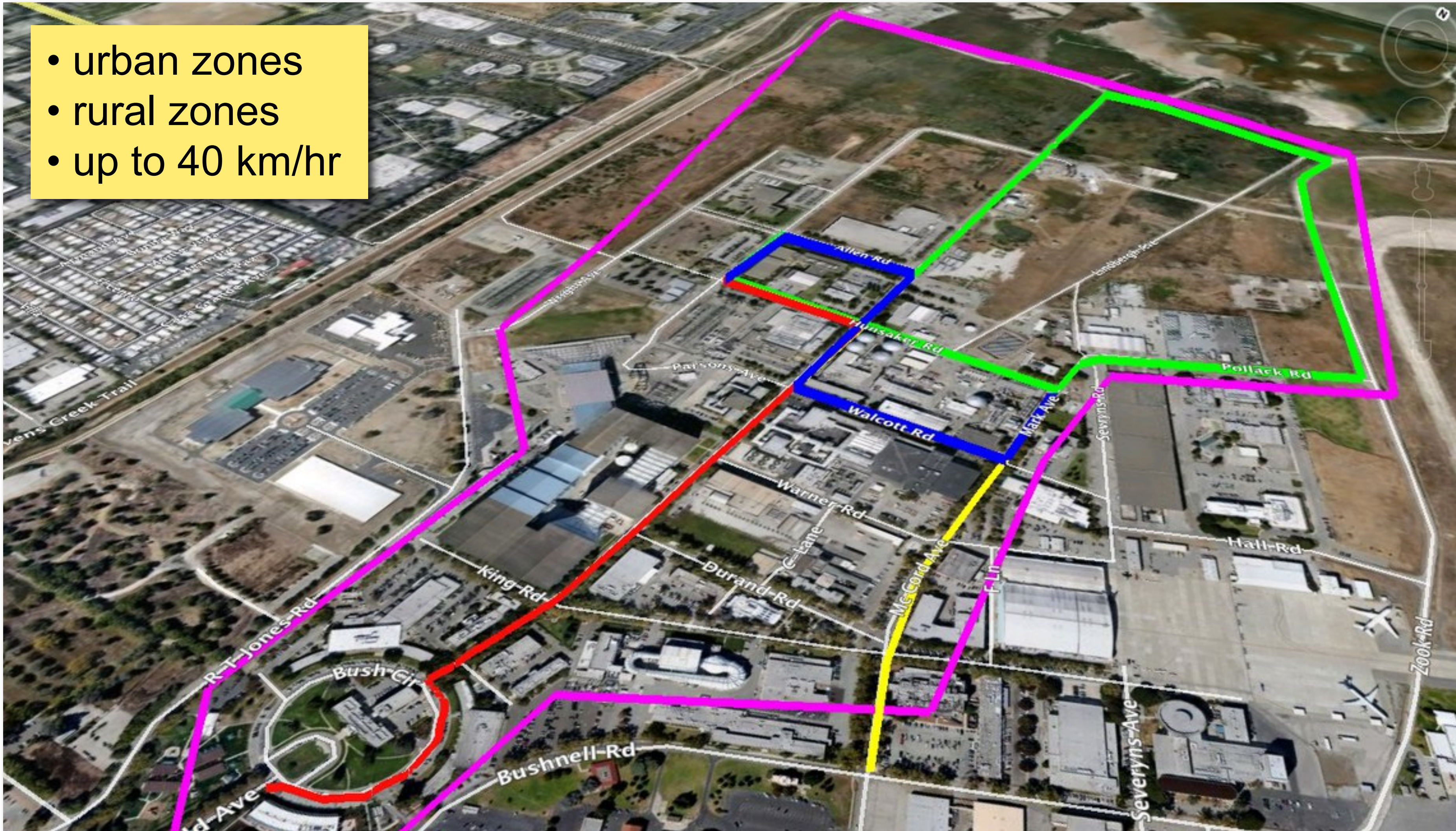


Candidate Test Routes at NASA Ames

- urban zones
- rural zones
- up to 40 km/hr



Nissan-Ames 2015

- **Develop Fleet Management**
  - Focus on remote monitoring for transport (taxi service, goods delivery)
  - Adapt and enhance NASA robot operator interfaces to Nissan vehicles
  - Demonstrate proof-of-concept using NRC-SV simulator

- **Key 2015 activities**
  - March — Digital street map of NASA Ames for NRC-SV simulator
  - April — Integrate 3D model of Nissan Leaf in NASA user interface
  - Sept. — Dynamic map updates to from simulator to interface
  - Dec — Demo remote monitoring of single vehicle in NRC-SV simulator from NASA Ames

Nissan-Ames 2016

- **Test Fleet Management Concept**
  - Extend monitoring from single vehicle to multiple vehicles
  - Add technology for remote intervention (diagnose and handle contingency situations)
  - Test with NRC-SV simulator and Nissan vehicle at NASA Ames

- **Key 2016 activities**
  - March — Fleet management test with NRC-SV simulator
  - June — Complete implementation of multi-vehicle monitoring
  - Sept. — Demo #1 of Nissan Leaf at NASA Ames
  - Dec — Demo #2 of Nissan Leaf at NASA Ames