Amendment 0001
Solicitation Number 13-SN-0018
"Robust Adaptive Sensor Filtering / Fusion for Shipboard Autolanding"
28 May 2013

The purpose of Amendment 0001 is the following:

(1) Respond to questions submitted prior to 25 May 2013. Questions received after that date and before the deadline for submissions of questions will be addressed in a subsequent amendment.
(2) Provide the two presentations from the 21 May 2013 webinar. The presentations, entitled "Robust Adaptive Filtering/Fusion for Shipboard Autolanding (RAFSA)", presented by John Kinzer, and "SALRS Virtual Testbed", presented by Dr. David Findlay and Colin Wilkinson, are attached.

1. Questions and Answers are provided as follows:

Q1: Can you give some examples of RF systems per slide 8?

A1: Several generic types are listed, including but not limited to, a very compact radar, an ultra-wide band ranging system, or pseudo- range finders. We don't have specific systems in mind at this time.

Q2: What size of object needs to be detected at what range?

A2: There is nothing specified in the special notice. These would be objects relevant to a safe landing such as a human, a tow bar, or a tool box in the safe landing area. Please do not focus too hard on this. It is not a requirement at this time.

Q3: Can you elaborate on slide 9 "stored template database"?

A3: For example, if you are using an imaging sensor, and there is a stored model of the ship, used for comparison, that would be allowable. This would be permissible for other types of sensors as well.

Q4: Regarding the sensors mentioned on slide 8, are the sensors GFE? Or should proposers include sensor/vendors in their white paper and proposal?

A4: We are not planning to provide any sensors as Government Furnished Equipment (GFE).

Q5: Will the government be providing any simulation or actual sensor data for aircraft landing ?

A5: Initially no, however, the planned sensor testing project will produce sensor models and data, and will be made available as we receive them. We can provide visual ship models, visual aircraft models, the EXHEL model, and the EXFIGHTER aircraft model, as well as ship motion models, and air wake models. They are all packaged with the government flight simulator package Castle.

Q6: Do performers on this BAA have to do their own simulations?

A6: Yes.

Q7: Can we get a list of all the attendees?

A7: No. However, there is a list of interested parties that have agreed to share their contact information. It is available upon request, through the ONR Program Officer, John Kinzer.

Q8: What level of ship motion prediction (e.g. quiescent period) is desired?

A8: At this point, we don't have anything specified. However, from current deck motion algorithms, it is reasonable to expect 5 to 7 seconds. If you have an algorithm you would like to use, feel free to, and we will evaluate it.

Q9: What sensors/models are being tested in "Sensor Performance in Naval Environments" and should the same sensors/models be used for this effort?

A9: Because we are not on the official contract yet with the offeror for that effort, we do not have 100% certainty what those sensors are. However, they do cover EO, IR, RF, Scanning Lidar, and Flash Lidar. We cannot specify the exact ones, at this point. However, once the contract process is complete, we will provide that information.

Q10: Does the Navy have a preference for testing on unmanned versus manned platforms?

A10: No.

Q11: Can you elaborate on the specific additional capabilities of the system over say a standard ILS system?

A11: Please refer back to the performance goals. Most of those cannot be provided by a commercial ILS system, especially on a ship. They are also RF emitters, which are problematic during EMCON conditions.

Q12: Would scaled down aircraft (large RC or UAV) rather than full size aircraft be suitable for flight testing?

A12: Yes

Q13: Has the 10cm SEP been validated in the SALRS sim environment?

A13: No. It is an objective at this time.

Q14: Is it the intent of this proposal requirement to define the process by which these sensors are evaluated for suitability and then the output of the contract will be the selection? Or is the intent of this requirement that the sensors be selected during the proposal phase of this program and the thus-constrained set be evaluated during the contract performance?

A14: The RAFSA white paper / proposal should select the sensors to be used and provide a rationale for that selection. The Government is not defining these. They should be the sensors that can best provide the performance capabilities included in the SN.

Q15: Can multiple PI resumes be submitted to include one for the subcontractor(s) or is only the prime's PI allowed?

A15: Yes, multiple resumes can be included.

Q16: Will program performers be expected to deliver other models besides the sensor fusion algorithms (models); for example, the sensor models used for development?

A16: Yes, the sensor models used for development of the RAFSA architecture, abstraction, filtering, and fusion capabilities should be delivered so that these products can be validated in the Government simulation.

Q17: Will you accept previous publications and or system descriptions of previously designed and delivered capabilities that may not be publicly available in addition to the five pages of text allotted?

A17: These documents may be submitted separately from the white paper, and may or may not be reviewed. All essential information should be included in the white paper.

Q18: System Description and Attributes - Plug and Play capability - Architecture should support the plug-and-play introduction of new sensor hardware and new state-of-the-art

data fusion algorithms. Is the government requesting, in addition to the algorithmic and software design, a hardware (mechanical and electrical) system design?

A18: No. The algorithms and software should be abstracted from hardware.

Q19: Need clarification

a. Program Structure and Tasks - Simulation Phase Tasks - 2. Incorporation of inertial measurement unit (IMU) and at least two other sensors. Demonstrate plug-and-play interchangeability of these sensors with others of the same type.

b. System Description and Attributes - Plug and Play capability - System must be capable of fusing inputs from at least four separate and distinct sensors with scalability to accommodate new and different sensors that may be added.

i. These requirements seem to differ slightly. Is the 4th sensor JPALS?

ii. If so, then the Government is requiring use of an IMU and JPALS and two (2) other sensors of the proposers choosing. Correct?

A19: Yes, correct.

Q20: Program Structure and Tasks - Simulation Phase Tasks - 4. Conduct and analyze tests in a simulation environment to determine the impact of degraded conditions on the sensor fusion algorithm and precision ship-relative navigation (PS-RN) solution. Degraded conditions include fog, rain, snow, smoke, haze, varied lighting conditions, electromagnetic interference from other ship/aircraft systems, jamming, and thunderstorms.

a. Will the simulation environment with this capability be provided as GFE?

b. If not, then how does the Government intend to define the complexity for integration of the GFE sensor models referenced in item #1 in this section?

A20: No. The GFE sensor models are not defined at this time, so provisions for integration should be estimated.

Q21: Program Structure and Tasks - Simulation Phase Tasks - 4. Conduct and analyze tests in a simulation environment to determine the impact of degraded conditions on the sensor fusion algorithm and precision ship-relative navigation (PS-RN) solution. Degraded conditions include fog, rain, snow, smoke, haze, varied lighting conditions, electromagnetic interference from other ship/aircraft systems, jamming, and thunderstorms.

a. Varied lighting conditions, electromagnetic interference from other ship/aircraft systems, jamming, and thunderstorms were not identified under the performance objective section, yet the Government is asking for analysis testing for these. Please clarify if these are also performance requirements for the PS-RN system.

A21: These should be included as performance objectives, not requirements.

Q22: Program Structure and Tasks - Simulation Phase Tasks - 6. Demonstrate plug and play capability of the multi-sensor precision ship-relative navigation (PS-RN) solution output with simulated air vehicle (rotary wing and fixed wing) flight control systems.

a. **There seems to be an assumption that in addition to a flight simulator for aircraft physics that proposer must also have a flight control system capable of automatic landing. Is this correct?**

A22: The PS-RN output should be designed to support automated landing by an aircraft flight control system. This connection should be defined as a plug and play interface and can be demonstrated in simulation. Actual flight control is not required.

Q23: Program Structure and Tasks - Simulation Phase Tasks - 7. Deliver models, software code, and documentation so that results can be validated using government simulation facilities at Naval Air Warfare Center Aircraft Division, Patuxent River, MD. The documentation should include ICDs (Interface Control Documents) that describe relationships between the sensor filtering / fusion block and the rest of the system blocks such as flight control, aircraft (movement), ship (movement), (degraded) environments of sea, atmosphere and space. All the models, software code and documentation should be based on the open architecture practices mentioned above.

a. **It is not clear what the Government's definition of open architecture practices are. Can the Government provide a clear definition of this?**

A23: Yes. Guidelines can be found in the DoD OPEN SYSTEMS ARCHITECTURE Contract Guidebook for Program Managers v.0.1, December, 2011; Appendix 3, Open Systems Architecture Checklist. This document is available at: https://acc.dau.mil/OSAGuidebook, or you can contact me for a copy.

Q24: Can a proposer propose a separate simulator for 1) evaluation of system performance under degraded conditions and 2) demonstration of system with simulated air vehicle and flight control systems?

A24: Yes

Q25: What level of flight demonstration (manned or unmanned) is required for phase 2 and on what size platform (RC "model" scale, full scale)? Will there be any GFE aircraft available?

A25: The platform does not matter as long as approach profiles representative of fixed wing tactical aircraft and helicopters can be flown.

Q26: Please define real time and is real time fusion necessary for flight testing in phase 2?

A26: Real time means that the capability could support actual flight operations. Real time fusion is necessary in the flight test phase.

Q27: Are there any requirements pertaining to the use of ITAR restricted sensors (e.g., IMU)?

A27: Sensors need to be representative of actual military sensors. If there are non-ITAR sensors available that meet this requirement, that is acceptable.

Q28: Will GFE sensors be provided for Phase 2?

A28: Assume that GFE sensors will not be available. If you know of some that could be used, we will attempt to obtain them, but this can't be guaranteed.

Robust Adaptive Sensor Filtering / Fusion for Shipboard Autolanding (RAFSA)

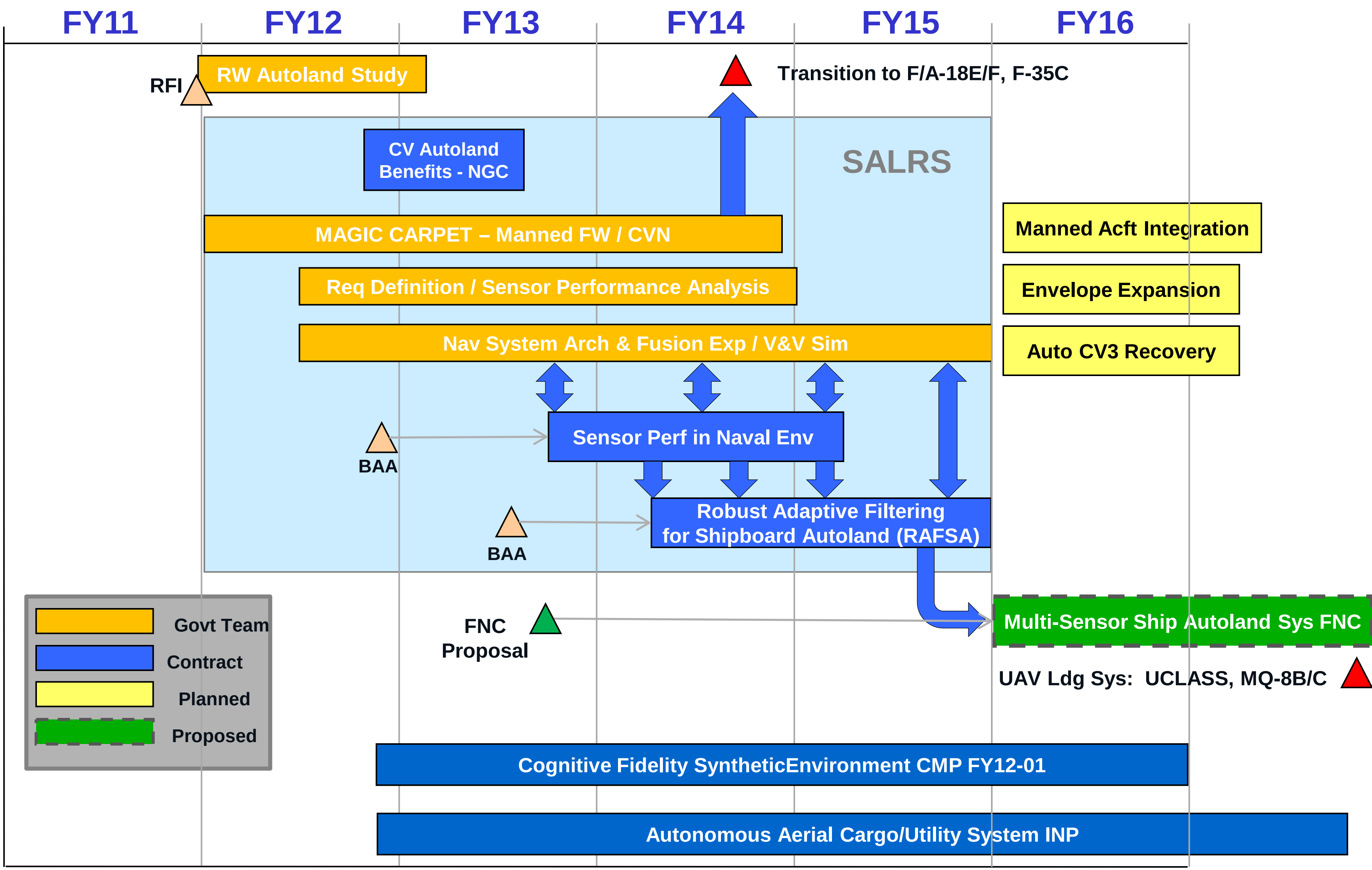
21 May 2013

John Kinzer
Aircraft Technology Program Officer
ONR 351

SALRS Goal and Program Objectives

- Overall goal: develop non-GPS dependent precision ship-relative navigation (PS-RN) capability to support automated aircraft launch and recovery in conditions of degraded weather, high deck motion, and electromagnetic interference
- Program objectives
  1) Characterize and model sensors for use across range of expected sea-based UAV operating conditions
  2) Develop integrated PS-RN system to filter and fuse sensor data and provide accurate, continuous, high integrity input to aircraft flight control system

SALRS Program Plan



Sensor Performance in Naval Environments

- Near-Earth Autonomy selected as performer; contract award is in work
- Expected period of performance: July 2013 – Dec 2014
- Ground and flight testing of relevant sensors
  - Degraded weather conditions
  - Moving deck simulation
  - Representative of both FW and RW approaches
  - Data and models deliverable for use in Robust Adaptive Filtering

Sensor Filtering Research Objective

- Develop
  - Architectures
  - abstraction methods
  - navigation filtering and fusion algorithms to combine inputs from multiple sensors
- Which provide
  - High quality precision ship-relative navigation (PS-RN) solution across the range of demanding naval environments
  - PS-RN solution capable of supporting air vehicle path planning and flight control along the desired approach path to landing
- Not sensor development, but development and demonstration of technology to bring sensor inputs together to produce a high quality navigation solution in a very specific environment

PS-RN Performance Objectives

- Capable of providing final approach guidance for fixed wing aircraft carrier (CVN) based aircraft out to 3 nmi, or rotary wing aircraft out to 1.5 nmi.
  - CVN aircraft approach the ship from the stern
  - Rotary wing aircraft can approach the ship from any direction
  - Sensors for these two different applications may not be the same, but the architectures, abstraction methods, and algorithms should be compatible.
- Navigation system error at touchdown of 10 cm spherical error probable (SEP)
- Compliance with electromagnetic emissions control so that risk of ship detection is not increased during aircraft recovery operations.
- Fully operable with high degree of deck motion, and capable of detecting this motion.
- Fully operable with deck marking degradations experienced during the course of an extended deployment (snow, ice, spilled liquids, wear and tear).
- Fully operable in complete darkness (night, no moon, heavy overcast sky).

PS-RN Performance Objectives, Cont'd

- Compatible with shipboard eye-safety requirements.
- Fully capable, at reduced range, in heavy rain, snow, sleet, smoke, haze and fog.
- Not dependent on GPS
- High reliability: likelihood of aircraft position error at touchdown exceeding 1m is 10E-6.
- High integrity, continuity, and accuracy to account for aircraft performance limitations and safety margins.
- Low impact to aircraft and ship in terms of size, weight, power and cost, even factoring in redundancy needed to meet reliability.
- Capable of integrating data from sensors detecting obstructions to safe landing (i.e. self-determination of landing safety)
- Potential for use in shore-based automated landings
- Potential for landing on unsurveyed ships with no special equipment

Potential PS-RN Sensor Suite

- Aircraft inertial measurement unit, plus:
- At least two of the following
  - Electro-optic (visible wavelength) imager
  - Infrared (short, medium, long wavelengths) imager
  - Scanning LIDAR
  - Flash LIDAR
  - RF system: Very compact radar, Range / Pseudo-range Finder

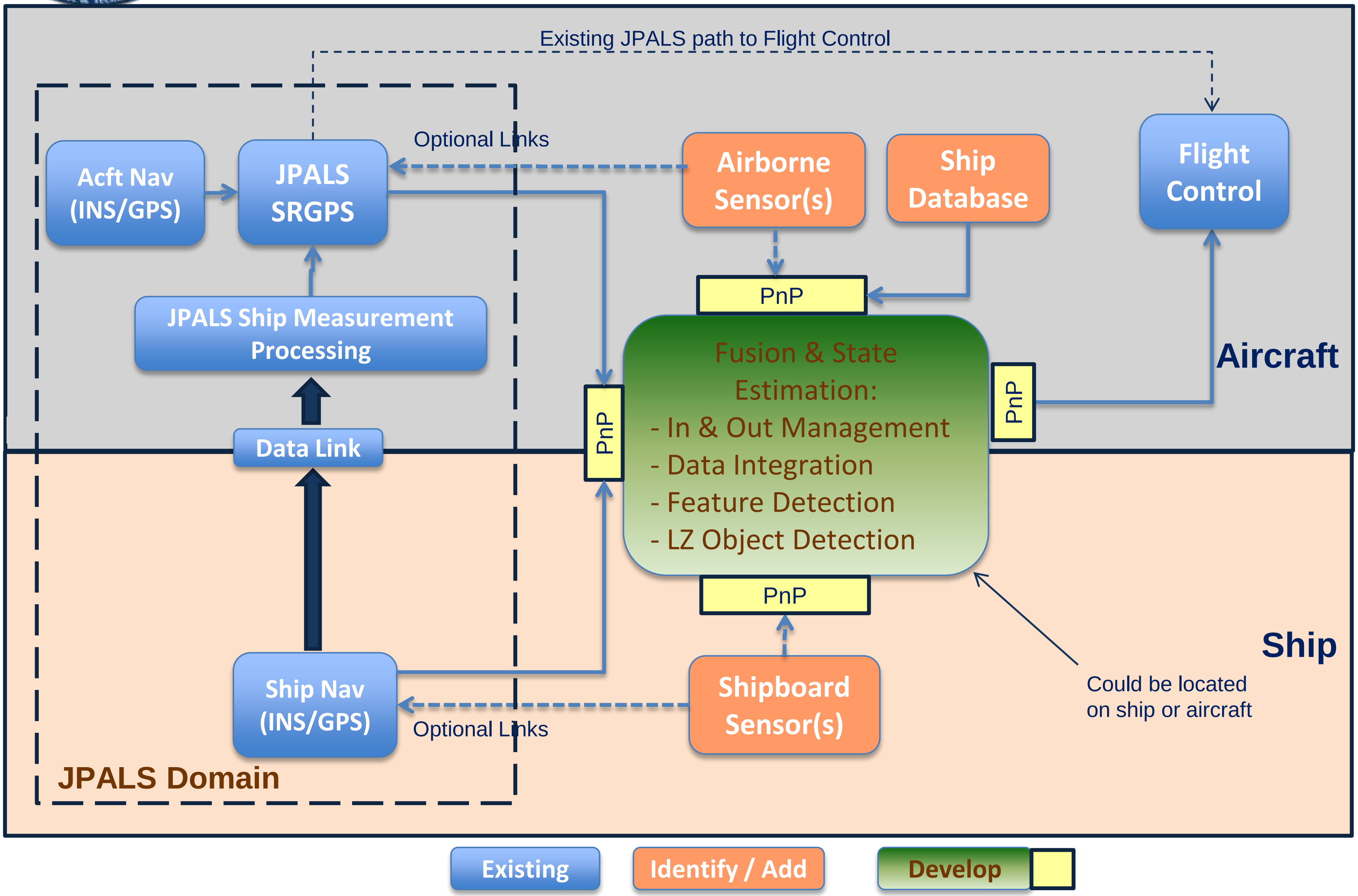
Architecture and Design Considerations

- Architecture
  - Sensors can be suitable for install on either aircraft or ship, and applicable to fixed wing or rotary wing application, or both.
  - Sensor data can originate from either the ship or the aircraft or a combination of both
  - Sensor fusion algorithms should be capable of referencing a stored template database.
  - Architecture should specify (in addition to the data fusion processing functions) the control functions, interfaces, and associated databases
- Fusion Optimization
  - System must be capable of determining when data received from a sensor is no longer valid (corrupted) and subsequently remove it from determining the relative navigation solution.
  - Architecture should provide optimized fusion of sensor data such that the resulting navigation solution is better than would be possible when these sources were used individually.
  - System should adapt in real time to the optimal set of available navigation inputs

Architecture and Design Considerations

- Scalability and Transportability
  - Solutions should follow sound system and software engineering and open architecture practices
  - Architecture, abstraction methods, and algorithms support scalability and transportability across Navy and Marine Corps ships and aircraft with minimal modification, verification and validation
- Plug and Play capability
  - System must be capable of fusing inputs from at least four separate and distinct sensors with scalability to accommodate new and different sensors that may be added.
  - System must allow alternate sensor integration with minimal modification
  - Architecture should support the plug-and-play of new sensor hardware and new state-of-the-art data fusion algorithms
- Joint Precision Approach and Landing System (JPALS) compatibility
  - PS-RN system will provide quality navigation for landing in demanding conditions when GPS inputs are not available or unreliable
  - Architecture, algorithms, and abstraction methods should accommodate integration with JPALS

Autoland System Architecture



Program Plan and Tasks

- Two phases: Simulation and Flight Demonstration.
  - White Papers should describe both phases.
  - Subsequent proposals should include a full cost proposal for the simulation phase, and a priced option for the flight demonstration.
  - Estimated period of performance for simulation phase is 12 months, and 9 months for flight demonstration
  - Two awards may be made; one or both of the options may be exercised

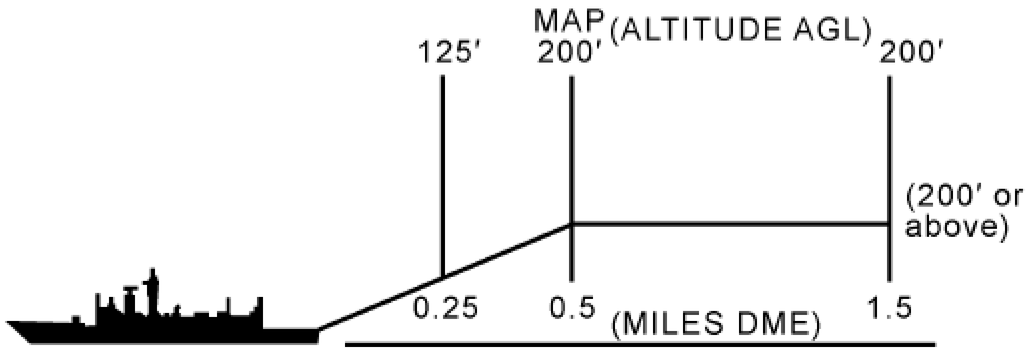
Simulation Phase Tasks

1) Use highest available fidelity sensor models
   - Represent sensor use for shipboard approach and landing in varying weather and lighting conditions
   - ONR is planning parallel effort to test actual sensors in conditions representing shipboard landing in degraded conditions. The models developed in this effort will be provided when available.
2) Incorporate IMU and at least two other sensors. Demonstrate plug-and-play interchangeability of these sensors.
3) Characterization of fused PS-RN sensor performance in demanding conditions representative of the Naval operating environment.
   - Develop data that show how fused sensor performance varies with the magnitude of the obscuring and deck motion condition, and with range from zero to 1.5 nmi for helicopter systems and 3 nmi for fixed wing systems.
4) Conduct and analyze tests to determine impact of varying sensor signal propagation across a range of degraded conditions on sensor fusion algorithm and precision ship-relative navigation (PS-RN) solution.
   - Degraded conditions include fog, rain, snow, smoke, haze, varied lighting conditions, electromagnetic interference from other ship/aircraft systems, jamming, and thunderstorms

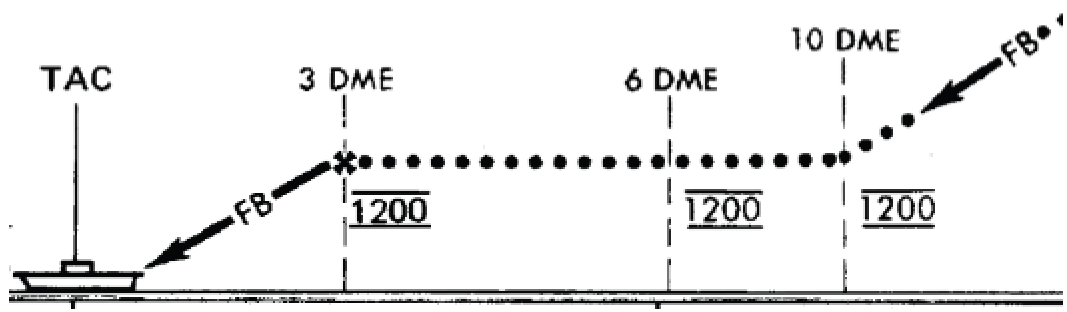
Simulation Phase Tasks

5) Determine system accuracy, integrity, and continuity under different combinations of sensors and operating conditions. Describe and justify any necessary assumptions.
6) Demonstrate plug and play capability of the multi-sensor precision ship-relative navigation (PS-RN) solution output with simulated air vehicle (rotary wing and fixed wing) flight control systems.
7) Deliver models, software code, and documentation so that results can be validated using government simulation facilities at Naval Air Warfare Center Aircraft Division, Patuxent River, MD
   - » Documention should include ICDs (Interface Control Documents) that describe relationships between the sensor filtering block and the rest of the system blocks such as flight control, aircraft (movement), ship (movement), (degraded) environments of sea, atmosphere and space
   - » All models, software code and documentation should be based on the open architecture practices mentioned above
8) Provide recommendations, supported by the simulation tasks and analysis, as to what GPS-denied precision ship-relative navigation system would be best suited for FW-CVN and RW-small deck ship use
9) Fusion with JPALS. Govt will provide JPALS model

Nominal Approach Profiles



Helicopter approach to Air Capable Ship



Jet / Turboprop approach to carrier

Flight Demonstration Tasks

- Validate the simulation results in flight, to the maximum extent possible
- Flight Demonstration of capabilities developed in Simulation Phase
  - Real time
  - Suitable airborne platform
  - Simulated ship landing area
  - Available weather conditions
- Update models, software code, documentation, and system recommendations provided in the simulation phase to reflect the results of flight demonstration

Special Notice Overview

- Special Notice 13-SN-0018, "Robust Adaptive Filtering for Shipboard Autolanding"
- Not a standalone solicitation in itself – all white papers and proposals to be submitted under ONR Long Range Broad Agency Announcement for Navy and Marine Corps S&T (BAA 13-001)
  - SN takes precedence if conflicting
- Nominal award
  - Two awards for Simulation Phase plus Flight Demonstration Option; 1 or 2 options for Flight Demonstration will be exercised
  - Estimated period of performance
    - » Simulation Phase: 12 months
    - » Flight Demonstration: 9 months
  - Estimated funding
    - » Simulation Phase: $1M each award
    - » Flight Demonstration: $1M each
  - Flexibility on all the above – will use white papers to evaluate best approach, schedule and budget can be adjusted to some extent

White Papers

- Expected NLT June 14, 2013
- See BAA 13-001 and 13-SN-0018 for detailed requirements
- 5 pages or less (excluding cover page and PI resume)
- White paper content (note: different from BAA)
  1) Principal Investigator;
  2) Technical approach that will be pursued to meet the technical objectives
  3) Listing of sensors to be used in the fusion process and rationale for selection.
  4) Program Plan and Schedule
  5) Brief description of ongoing or prior programs that will be leveraged
  6) A funding plan showing requested funding per fiscal year

Selection Process

- Submissions evaluated against BAA objectives
- Criteria:
    1) Scientific and technical merits
    2) Potential Naval relevance
    3) Offeror capabilities, experience, facilities, techniques
    4) Qualifications, capabilities, experience of PI and team
    5) Cost realism and funds availability

  Criteria 1-4 of equal value, significantly greater than Criterion 5
- Evaluations by Navy and other Government Subject Matter Experts

Full Proposal and Award

- **Selected white papers will be invited to full proposal:**
  - Based on white paper
  - Does not ensure award (will plan for paper:award ratio of approx 1.5-2 to 1
  - See BAA 13-001 and 13-SN-0018 for detailed requirements
  - Expected NLT August 16, 2013 (estimated)
- **Evaluation process same as white papers**
- **Selection notification September 13, 2013 (estimated)**
- **Award estimated – Feb 2014**

Questions?

SALRS Virtual Testbed

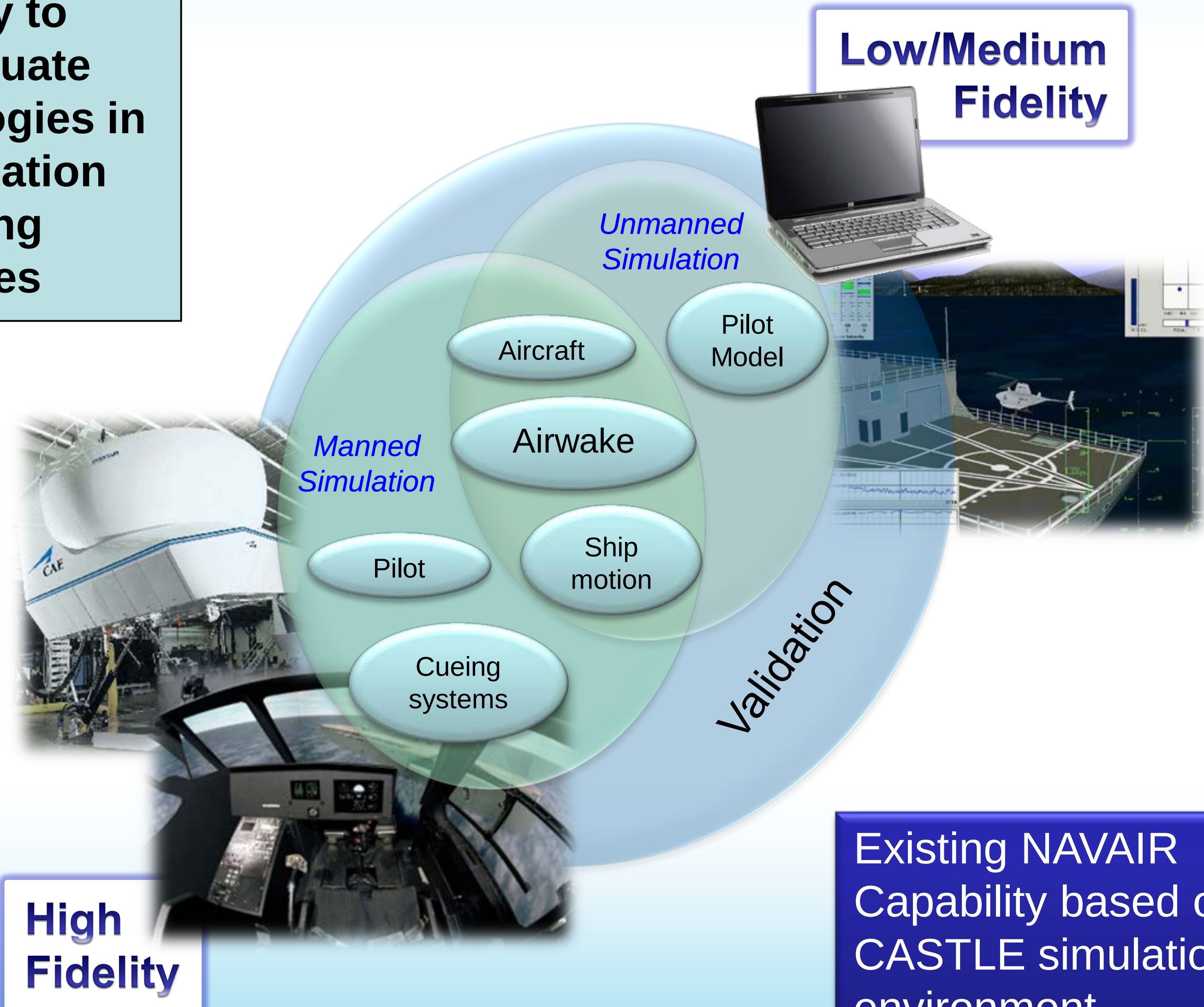
SALRS Team Lead
Dr David Findlay
NAVAIR Patuxent River
301-342-8548
david.findlay@navy.mil

Virtual Testbed Team Lead
Colin Wilkinson
NAVAIR Patuxent River
301-342-9016
colin.wilkinson@navy.mil

SALRS Virtual Testbed

Develop capability to integrate and evaluate autoland technologies in closed-loop simulation building on existing NAVAIR capabilities

- *Evaluate & compare sensor concepts*
- *Develop & validate requirements*
- *Explore sensor fusion techniques*
- *Select and test sensor system prior to flight*



Existing NAVAIR Capability based on CASTLE simulation environment

SALRS Virtual Testbed

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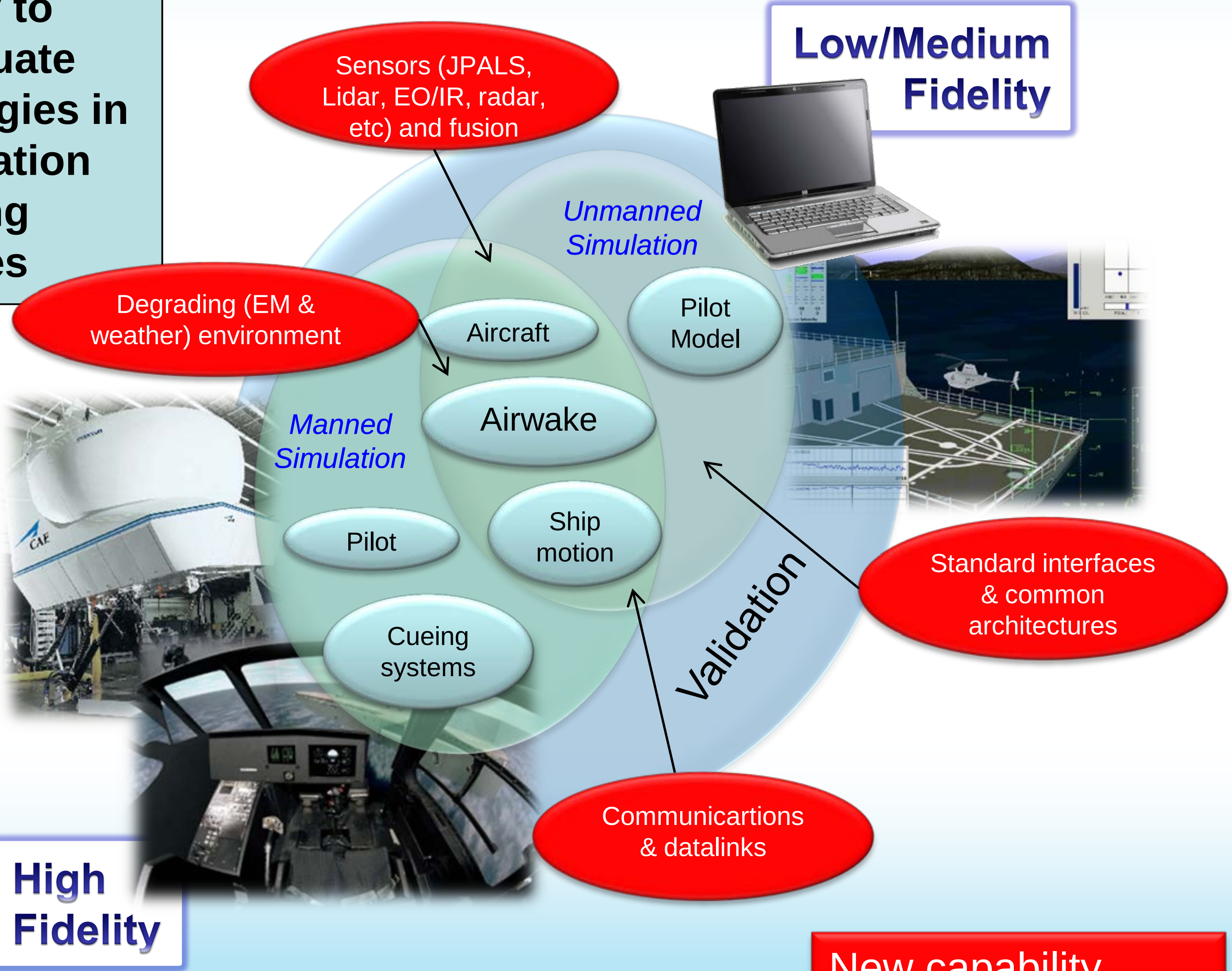
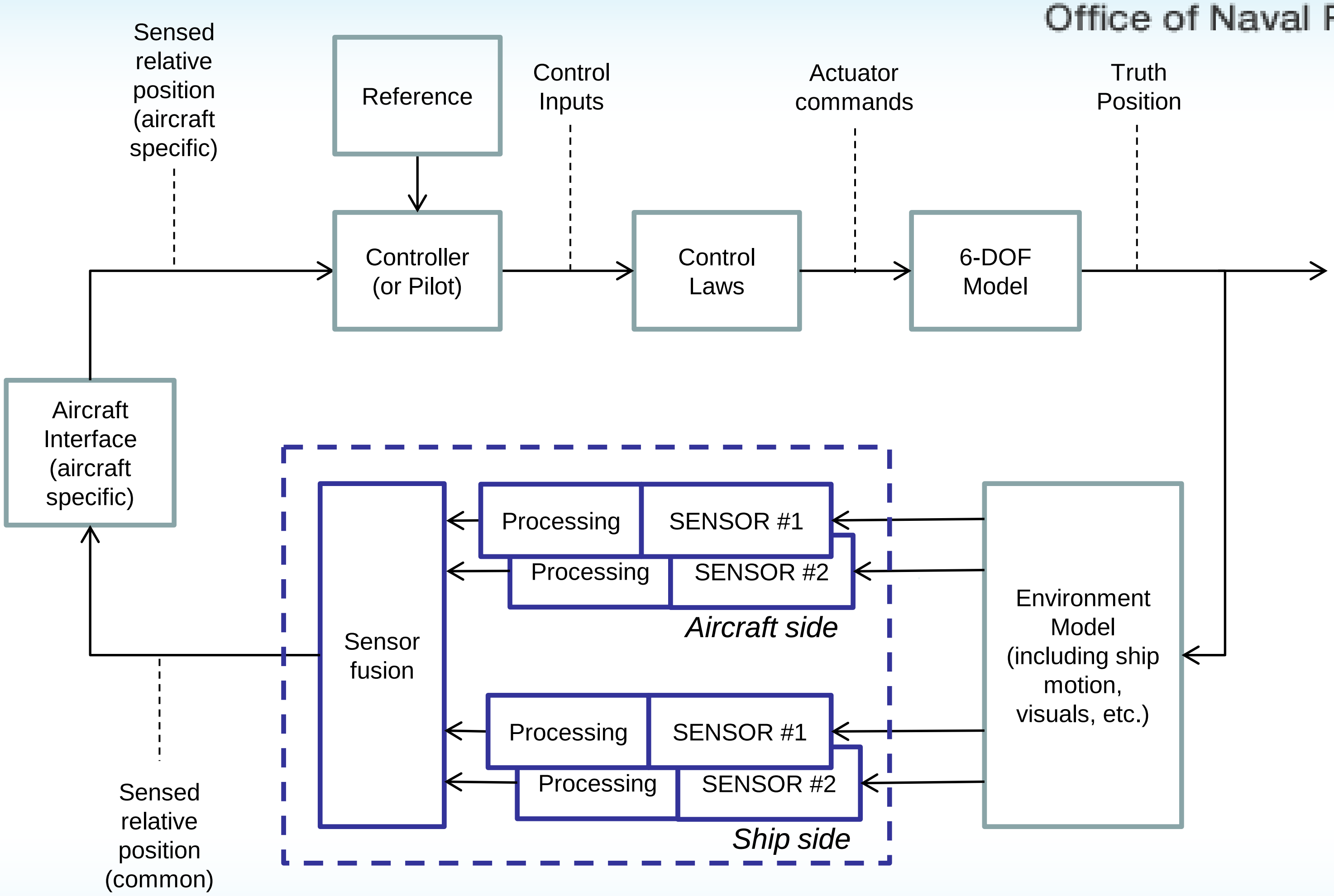


New capability

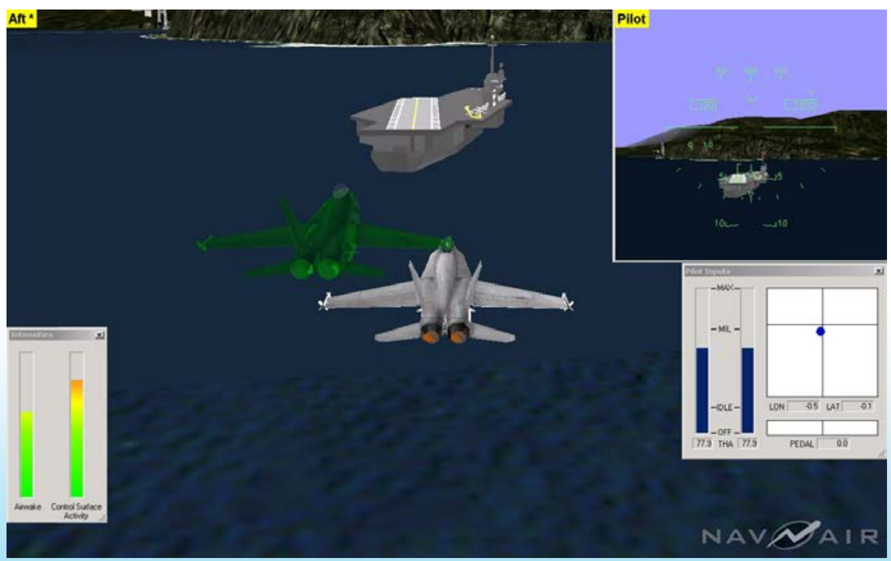


- Simulation architecture based on CASTLE
- Models include: atmosphere, targets, equations of motion, terrain
  CFD airwake, turbulence/gusts, wind profile, ship, inc. ship motion

Phase 1 Accomplishments

(Completed Jan 13)

- Created ‘generic’ closed-loop autoland simulation
  - Fixed wing (F/A-18 to CVN) and rotary wing (H-60 to DDG) operations
  - Outer-loop controller pilots the aircraft through approach and landing in realistic shipboard environment (airwake, 6 dof ship motion, etc)
  - Surrogate sensor model modulates relative position signal with noise, sample and hold, bias, etc.
  - Simulation implemented on desktop for non-real-time analysis and in real-time lab for demonstration



Phase 2
(CY13/14)

- Extend the generic SALRS simulation into a specific shipboard autoland simulation
  - Physics-based sensors delivered by Sensors in Degraded Environments BAA
  - Sensor fusion algorithms delivered by Sensor Filtering BAA
  - Air vehicle models:
    - FW : F/A-18 and/or ExFighter (Year 1) / UCLASS (Year 2)
    - RW : ExHel (Year 1) / Fire Scout (Year 2)
- Facilitate integration of multiple types of sensors (GPS, electro-optic, radar, ladar, etc.) and sensor fusion techniques
- Implement and verify existing landing system models (e.g. JPALS, UCARS)
- Employ SALRS Virtual testbed to evaluate:
  - performance of sensors in perfect and degraded conditions
  - sensor fusion techniques for the shipboard task
  - procedural issues associated with shipboard autoland
- Support integrated Govt/Contractor technical teaming to develop common interface definitions, validation methods and effective simulation methodologies

Phase 2

(CY13/14)

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- Support integrated Govt/Contractor technical tear interface definitions, validation methods and effec

Define common interfaces to enable integration of multiple sensor types and maximize compatibility with potential sensor fusion algorithms

SALRS Software Model Interface

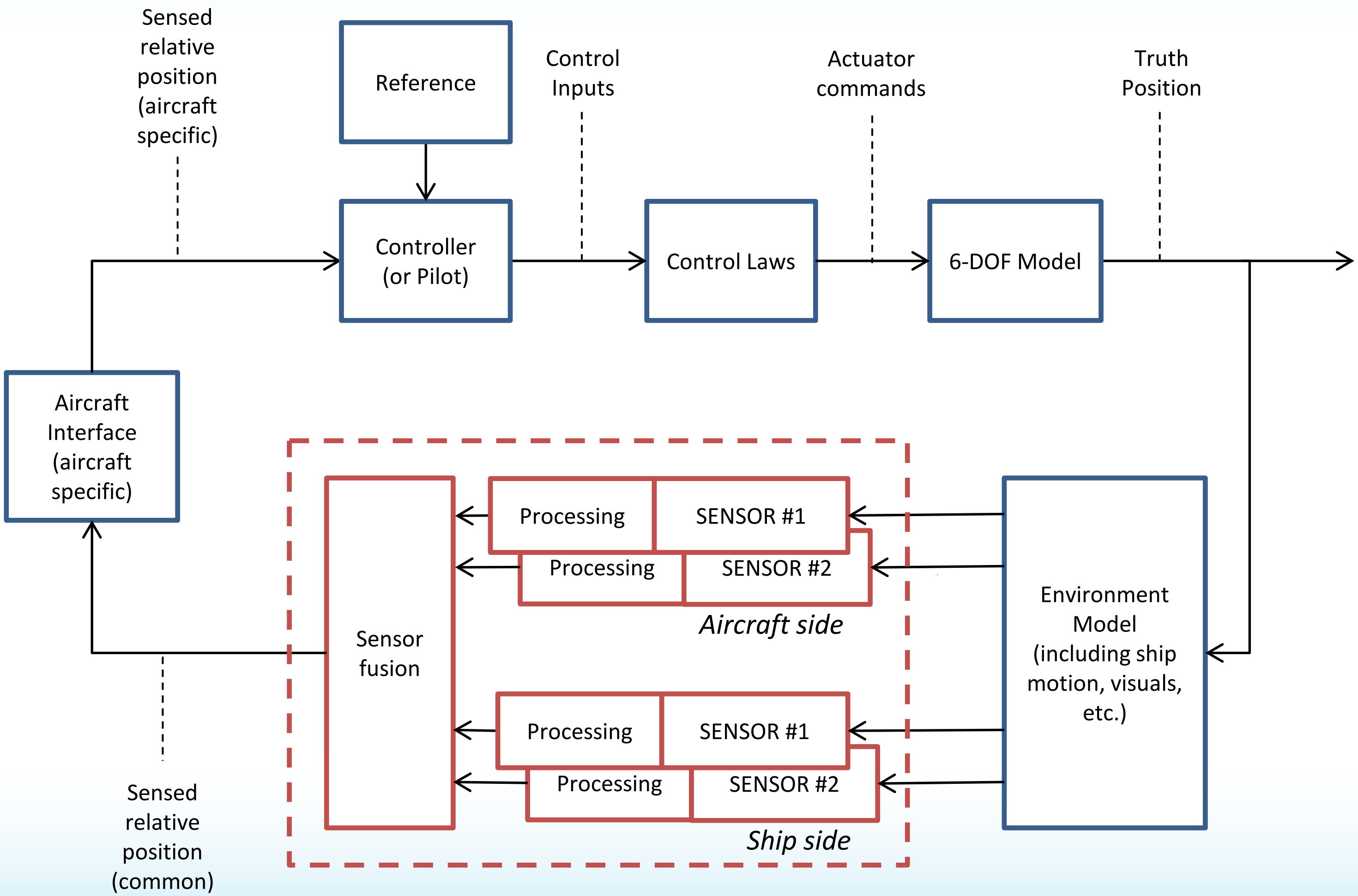
N. Holthaus

3/15/2013

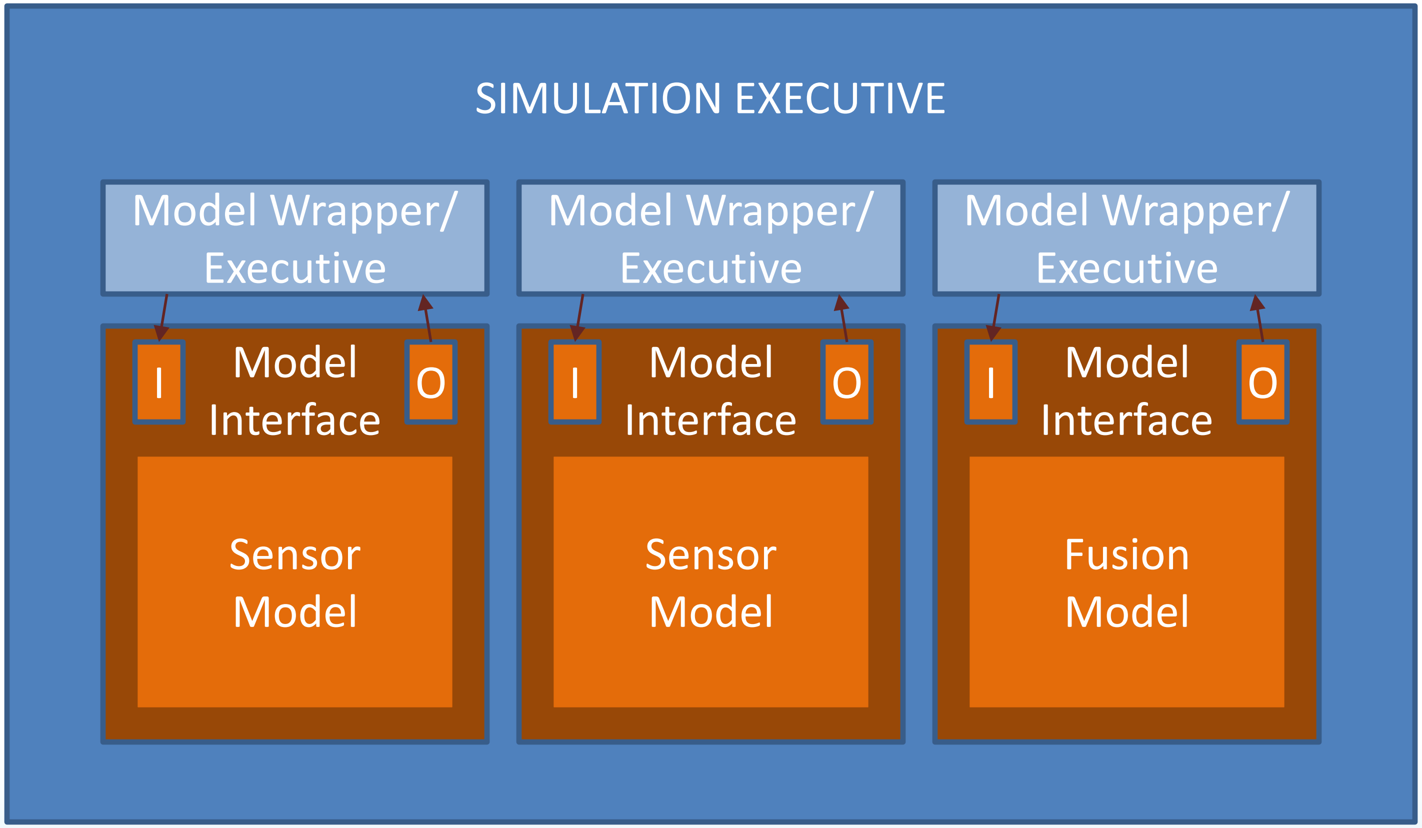
Sensor Model Requirements

- Delivered models shall conform to the government-provided c++ object interface
  - Only the interface is required to be c++
  - The internal model logic implementation is NOT specified (so long as all licenses/dependencies are included in any delivery)
- Delivered models shall not expand the public functional interface from that provided
- Delivered models may extend the data inputs/outputs of the model interface

Simulation Framework



Simulation Framework



Simulation Framework

- **Model** (industry provided)
  - May represent a sensor or fusion block
  - Contains all functional representation
- **Model Interface** (gov. provided/industry integrated)
  - Defines model I/O
  - Defines model functional interface
- **Model wrapper/executive** (gov. provided/ gov. integrated)
  - Connects I/O to simulation
  - Provides simple ‘glue logic’
- **Simulation Executive** (gov. provided/gov. integrated)
  - communicates with model wrappers to run overall simulation
  - E.g. CASTLE or equivalent

Model Interface - Data

- Data Interface
  - Inputs, Outputs, Set-up Parameters
  - May be expanded on a per-model basis
  - Models shall clearly document:
    - Required data
    - Which data is not used or not driven by the model
    - Units and allowable ranges of data (as appropriate)
- Inputs present in the sensor model interface are guaranteed to exist and be driven
- Outputs present in the fusion model interface are required

Model Interface - Functional

- Notional Functional Interface
  - Initialize
    - One-time model setup
    - Happens prior to run
  - Run
    - Implementation of a single time-step of the model
    - The time step is determined by the simulation executive
  - Freeze/Restart
  - Reset
  - Functional interface implementation is required, and may not be expanded

Model Interface

```
class cAbstractSensor
{
public:
    class cParameters;
    class cInputs
    {
        // some guaranteed inputs here
    };
    class cOutputs;
public:
    virtual void init(cParameters &parameters) = 0;
    virtual void run(double dt_ms) = 0;
}
```

Model Interface

```
class cAbstractFusion
{
public:
    class cParameters;
    class cInputs;
    class cOutputs
    {
        // some required outputs here
    };
public:
    virtual void init(cParameters &parameters) = 0;
    virtual void run(double dt_ms) = 0;
}
```

Summary

- SALRS Virtual Testbed exists and is being further developed to provide the high fidelity closed-loop simulation capability and framework to evaluate PS-RN technologies emerging from SALRS BAAs
- Existing research team and body of knowledge with center of gravity at Patuxent River Center of Excellence for Naval Aviation
- Variety of models available for use by SALRS Team Members
  - Multiple ships and aircraft models (visual and dynamic)
  - Environment models (ship motion, airwake)