Since July 2008, the Multidisciplinary Analysis & Optimization Working Group (MDAO WG) of the Systems Analysis Design & Optimization (SAD&O) discipline in the Fundamental Aeronautics Program’s Subsonic Fixed Wing (SFW) project completed one major milestone, “Define Architecture & Interfaces for Next Generation Open Source MDAO Framework” Milestone (9/30/08), and is completing the Generation 1 Framework validation milestone, which is due December 2008. Included in the presentation are: details of progress on developing the Open MDAO framework, modeling and testing the Generation 1 Framework, progress toward establishing partnerships with external parties, and discussion of additional potential collaborations.
Systems Analysis Design and Optimization (SAD&O) Technical Working Group (TWG) Meeting

Subsonic Fixed Wing Project
NASA Fundamental Aeronautics Program

Six Month Status Update:
Multi-Disciplinary Analysis & Optimization Frameworks

Cynthia Gutierrez Naiman

47th AIAA Aerospace Sciences Meeting
Orlando, FL

January 5, 2009
Topic Outline

- Brief Overview
- OpenMDAO Status
- Outreach
- Next Steps
- Conclusion
MDAO Task Goal & Objectives

• GOAL
  – Advance the state of the art of physics-based multidisciplinary analysis & optimization for both conventional & unconventional vehicles.

• OBJECTIVES
  – Focus on Subsonic Fixed Wing and Supersonics applications, but develop capabilities that can support all flight regimes.
  – Improve current MDAO tools and integration techniques.
  – Establish the groundwork and provide an open source next generation MDAO capability for far-term activities.
  – Collaborate with the MDAO community in industry, academia, and other government agencies throughout the development process to benefit all parties.
<table>
<thead>
<tr>
<th>Milestone</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
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- ☀: Completed Milestone
- ▲: Planned Milestone
- Timeline
# MDAO Milestone Roadmap

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<tr>
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- **Completed Milestone**
- **Planned Milestone**
- **Timeline**

![Completed Milestone](star)

![Planned Milestone](triangle)
# MDAO Milestone Roadmap

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</table>

- **Completed Milestone**: ⭐
- **Planned Milestone**: ⭐⭐
- **Timeline**: 🟢
OpenMDAO Status Highlights

- Completed initial “Next Generation Open Source MDAO Framework Architecture Document” (9/30/08 milestone)

- Implementing core OpenMDAO framework objects using python

- Held python training at LaRC and scheduled another session at GRC

- Evaluating variable fidelity objects from M4 Engineering SBIR

- Implementing “toy” distributed simulation to learn about python distributed objects
• Prepared to request **Requirements feedback**

• Revisiting MDAO Test Cases (interfaces and testing)

• Researching what’s needed to launch **OpenMDAO external website**

• Evaluating & setting up development tools (Bazaar, Trac) & **processes**
OpenMDAO Status Highlights (continued)

• Continuing to develop Problem Formulation Prototype using python

• Presented Papers at AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference in Victoria, CA:
  – “The Development of an Open-Source Framework for Multidisciplinary Analysis and Optimization” by Moore, Naylor, & Gray
  – “Reliability Based Design Optimization of a Composite Airframe Component” by Patnaik, Pai & Coroneos
Outreach: Collaboration

• Examples of parties who have indicated interest:
  – NASA (Constellation)
  – DoD
    • Computational Research & Engineering Acquisition Tools & Environments (CREATE) Program
    • AFRL: Air Vehicles & Propulsion Directorates
  – DoE
    • Sandia Labs: Design Analysis Kit for Optimization and Terascale Applications (DAKOTA)
  – Industry: Boeing, Lockheed, GE
  – Academia: Georgia Tech, Stanford, University of Toronto

• Example NRA & SBIR:
  – Subsonic Fixed Wing SBIR
    • Multidisciplinary Optimization Object Library (M4 Engineering)
  – Supersonics NRA
    • Control of Boundary Representation Topology in MDAO (MIT)
Outreach: Collaboration Ideas

• Requirements
  – Feedback on latest Requirements: suggest changes & additions
  – Propose additional Use Cases

• Testing
  – Test Cases
  – User feedback
  – Beta testers

• Identify areas of functionality to share & contribute
  – Geometry
  – Uncertainty Analysis
  – Optimization
  – Framework
  – Discipline codes
Outreach: Partnerships

• Identify partners interested in establishing Space Act Agreements or Interagency Agreements

• Follow-up with interested parties, establish agreements, and work as a group

• If your company/organization is interested in this MDAO activity, contact Cynthia Naiman
## Next Steps

<table>
<thead>
<tr>
<th>Sub Tasks</th>
<th>Activities</th>
<th>1Q FY09</th>
<th>2Q FY09</th>
<th>3Q FY09</th>
<th>4Q FY09</th>
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<tbody>
<tr>
<td>Requirements</td>
<td>• Document feedback on discipline requirements</td>
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<td></td>
<td>• Allocate groupings of requirements to be completed by 4QFY10</td>
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<td></td>
<td>• Identify, define, &amp; document test cases</td>
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<tr>
<td>GEN1 Validation</td>
<td>• Exercise GEN1 Capability for Commercial Transport</td>
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<tr>
<td></td>
<td>• Document validation results in GEN1 report</td>
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<tr>
<td>GEN2 HWB Toolset</td>
<td>• Identify HWB configuration to use for 3QFY10 milestone</td>
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<td></td>
<td>• Define GEN2 validation plan</td>
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<td></td>
<td>• Determine what discipline codes are needed</td>
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<td>• Identify which codes need to be integrated into ModelCenter</td>
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<td></td>
<td>• Identify needed code improvements and/or integration techniques</td>
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<td>• Implement code &amp; integration improvements</td>
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### Next Steps (continued)

<table>
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<tr>
<th>Sub Tasks</th>
<th>Activities</th>
<th>1Q FY09</th>
<th>2Q FY09</th>
<th>3Q FY09</th>
<th>4Q FY09</th>
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<tr>
<td><strong>Alpha OpenMDAO Framework</strong></td>
<td>• Continue prototyping using python</td>
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<td></td>
<td>• Offer python training</td>
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<td>✔️</td>
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<td></td>
<td>• Set up development environment</td>
<td>✔️</td>
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<td>• Research what is needed to setup an open source project</td>
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<td></td>
<td>• Setup technical infrastructure and communications mechanisms</td>
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<td></td>
<td>• Define processes for daily development &amp; release distribution</td>
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<td></td>
<td>• Prepare website and documentation for open source public release</td>
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<td>• Address export control &amp; legal issues</td>
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<td></td>
<td>• Implement core framework classes</td>
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<tr>
<td><strong>Outreach</strong></td>
<td>• Solicit feedback on requirements from potential external partners</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<td></td>
<td>• Host meetings with interested parties (industry, academia, gov)</td>
<td>✔️</td>
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<td></td>
<td>• Pursue potential collaboration in Open Source MDAO community</td>
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<td></td>
<td>• Leverage NRA &amp; SBIR MDAO efforts</td>
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<td>• Present status at SAD&amp;O Technical Working Group Meetings</td>
<td>✔️</td>
<td>✔️</td>
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**Timeline**
Conclusion

• Physics-based MDAO is a critical national need and is an extremely difficult challenge

• 2-Path approach benefits near- and long-term needs

• User involvement throughout the development life-cycle is critical

• Partnering with industry, academia, and other government agencies is essential to realize MDAO vision
• See SAD&O Website:
    • Userid “guest”
    • Password “sado”

• Contact Cynthia Naiman
  – Cynthia.G.Naiman@nasa.gov
  – 216-433-5238
“Toy” Simulation to Explore Distributed Object Communication

- Intended to provide semi-realistic environment for experimenting with different technologies.
- NOT intended as a prototype for the real framework, or something evolving into the real framework
- Supports typical data and process flows.
- Example problem is nested optimization of AXOD (AXial Off Design: a meanline axial turbine code that can generate off-design maps) input parameters to match a set of data.
- A genetic optimizer is used to set starting points for gradient optimizers distributed to nodes of local GX cluster.
- GX has 220 AMD Opteron (64-bit) processors connected via Infiniband running Debian Linux. It's local to GRC.
- Has experimental support for driving wxPython and web GUIs from the same GUI code.
- Matplotlib does the plotting.
- Distributed objects
  - Need support for distributing sub-models (for optimization, etc) as well as remote objects within a single model.
  - 'Twisted' package provides basic networking support for multiple protocols. Twisted is a stable, widely used package. Twisted depends on various sub-packages like zope.interface, Crypto, OpenSSL. Twisted is used for HTTP, OpenSSL for HTTPS and RPyCS.
  - 'RPyC' package provides transparent support for distributed objects. Not an exact fit for our requirements. RPyC is a new, evolving project. A modified RPyC does the distributed object communication.
- Beginning to explore how M4 work can be incorporated into a framework similar to that defined in the architecture document.
  - Numeric, numarray, numpy, scipy get pulled-in for M4 objects as well as matplotlib.
### DesignAssistant Simulation Manager

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<tr>
<th>Name</th>
<th>Host</th>
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<th>HTTP</th>
<th>HTTPS</th>
<th>RPyc</th>
<th>RPys</th>
<th>Manhole</th>
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<td>46365</td>
<td>37259</td>
<td>57539</td>
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</tbody>
</table>

**Simulation Manager**

The SimulationManager acts as a portal, allowing you to connect to existing simulations, launch new simulations, and terminate simulations. This manager is running on the remote host gxterm3, which is a front-end to the GX cluster.
OpenMDAO Website Concept

Scenario 1:
The typical NASA open source website.

Scenario 2:
(Desired)
Full open source community.

INSIDE NASA

OUTSIDE NASA

openmdao.grc.nasa.gov
*short description
*download link

directly linked

directly redirected

DOMIAN NAMES
openmdao.org
openmdao.com
openmdao.net

www.openmdao.org
full open-source software site available to all, hosted outside NASA
*news
*forums
*source code
*documentation

Other domain names:
openmdao.com
openmdao.net
openmdao.info
OpenMDAO Life Cycle Process

A registration process must be completed prior to submitting a Change Request (CR).

Minimum CR submission Criteria for the OpenMDAO Framework project:

REQ Criteria:
- Get full framework requirement description from the latest Software Requirements Specification (SRS).

RFE Criteria:
- Provide the following information:
  - A detailed description of the RFE
  - The release version in which you are working
  - A brief rationale as to why this RFE is needed

DEF Criteria:
- Find and document the defect with the following minimum submission requirements:
  - An input file that reproduces the problem
  - A corresponding output file which notes the results
  - Suggested documentation updates
  - The release version in which the problem was found
  - User's environment when problem was found

Submitter enters CR into a configuration controlled tracking system.

SUBMITTED - Email sent to SCM & Submitter

REQ CR Submission:
- Development Team evaluates REQ CRs
  - CR Not Accepted
    - NOT_ACCEPTED
      - Already_Submitted
      - Email sent to SCM & Submitter
  - Passes development evaluation?
    - Yes
    - CR Accepted
      - ACCEPTED - Email sent to Dev Lead, SCM & Submitter
    - No
    - CR Not Accepted
      - NOT_ACCEPTED
      - Already_Submitted
      - Not_Framework_CR
      - Rejected
      - Email sent to SCM & Submitter

RFE CR Submission:
- Development Team evaluates RFE CRs (via forum)
  - CR Not Accepted
    - NOT_ACCEPTED
      - Not_Framework_CR
      - Rejected
      - Email sent to SCM & Submitter
  - Passes development evaluation?
    - Yes
    - CR Accepted
      - ACCEPTED - Email sent to Dev Lead, SCM & Submitter
    - No
    - CR Not Accepted
      - NOT_ACCEPTED
      - Already_Submitted
      - Not_Reproducible
      - Rejected
      - Not_Framework_CR
      - Email sent to SCM & Submitter

DEF CR Submission:
- V&V Team evaluates Defect CRs
  - CR Not Accepted
    - NOT_ACCEPTED
      - Already_Submitted
      - Not_Reproducible
      - Rejected
      - Not_Framework_CR
      - Email sent to SCM & Submitter
  - Passes V&V evaluation?
    - Yes
    - CR Accepted
      - ACCEPTED - Email sent to Dev Lead, SCM & Submitter
    - No
    - CR Not Accepted
      - NOT_ACCEPTED
      - Already_Submitted
      - Not_Reproducible
      - Rejected
      - Not_Framework_CR
      - Email sent to SCM & Submitter
OpenMDAO Life Cycle Process (cont’d)
Problem Formulation Tool Prototype
Backup Charts
Role of OpenMDAO.org Website

- News/Information
- Source Code & Distributions
  - Read-only access to framework and open-source plug-ins to the general public
    - Changes to the framework come through NASA gatekeeper
    - Closed-source plug-ins (e.g. NPSS) have restricted access
  - Anyone can write a custom plug-in, and since it does not impact the framework source, it needn’t go through a gatekeeper
    - Custom components and variable types that are written can be kept to oneself or shared with the community
    - Custom components that are shared could be rated by the community
    - Highly-rated custom components could be added to OpenMDAO standard lib
- Documentation
  - OpenMDAO User Guide
  - OpenMDAO Developer Guide
  - Use Case ”How To” Guide
- Discussion Forums
- Submission of Defects
- Proposals for Enhancement
- Adding New Developers
Outreach: NRA and SBIR Activities

- **Subsonic Fixed Wing NRAs**
  - Develop parametric blade geometry modeler (AVETeC/University of Cincinnati)
  - “System Analysis & Design Approach to the Hybrid Wing/Body Aircraft” (AVID LLC)
  - Improve structural modeling, meshing and rapid grid morphing capabilities within Vehicle Sketch Pad (Cal Poly/Phoenix Integration/J R Gouldemans)
  - “Enhanced Modeling & Analysis for Emission Prediction” (Georgia Tech/ASDL)
  - “Adv Multidisciplinary Optimization Techniques for Efficient Subsonic Aircraft Design” (MIT/Stanford/Purdue/Boeing)

- **Supersonics NRAs**
  - “High Fidelity MDO: Software Infrastructure & Application to Supersonic Aircraft” (M4 Engineering/Phoenix Integration)
  - “Control of Boundary Representation Topology in MDAO” (MIT)
  - “Multifidelity Analysis and Design Methods for Supersonic Aircraft” (Stanford/MIT)

- **Subsonic Fixed Wing SBIRs**
  - Cumulative Metamodelingw/Uncertainty Estimation (Nielsen Engineering)
  - Advanced Modeling Concepts for Conceptual Design (NextGenAeronautics)
  - Multidisciplinary Optimization Object Library (M4 Engineering)
  - Multi-Disciplinary, Multi-Fidelity Design Environment (Phoenix Integration)

Details on any NRA & SBIR efforts are available.
Example: Optimization Using a Cluster

1. User requests simulation to run.
Example: Optimization Using a Cluster

1. User requests simulation to run.
2. Genetic optimizer replicates sub-model.
Example: Optimization Using a Cluster

1. User requests simulation to run.
2. Genetic optimizer replicates sub-model.
3. Genetic optimizer allocates resources.
1. User requests simulation to run.
2. Genetic optimizer replicates sub-model.
3. Genetic optimizer allocates resources.
4. Genetic optimizer loads copies of sub-model.
1. User requests simulation to run.
2. Genetic optimizer replicates sub-model.
3. Genetic optimizer allocates resources.
4. Genetic optimizer loads copies of sub-model.
5. Genetic optimizer starts gradient optimizers.
1. User requests simulation to run.
2. Genetic optimizer replicates sub-model.
3. Genetic optimizer allocates resources.
4. Genetic optimizer loads copies of sub-model.
5. Genetic optimizer starts gradient optimizers.
6. Gradient optimizers perform AXOD runs.
Incremental Software Development

Requirements: Define/Update/Prioritize UseCases

Submit Change Requests: Requirement, Enhancement, Defect

Stakeholder Input

Customer Feedback

Validate & Use Release:
- NASA
- Other Government Agencies
- Industry Partners
- Academia

All phases are iterated as needed.

Developers & Leads

Analyze → Design → Implement Change → Run Unit & Regression Tests

Code Inspections & Peer Reviews

Verification & Validation: Run Regression Tests

Software Configuration: Merge, Test, Generate Release

Daily Builds
- Increments
- Full Versions

Project Management

Evolutionary Delivery Schedule

Top 10 Risks

Metrics Collection & Analysis

Lessons Learned

Improve Processes

Customer/User involvement in all phases of development is critical.