“MULTI-DISCIPLINARY ANALYSIS & OPTIMIZATION FRAMEWORKS”

presented at the
Systems Analysis Design & Optimization (SAD&O) Technical Working Group
Meeting, Orlando, FL, January 2009

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
• 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.
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<th>Milestone</th>
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- **Starred** marker: Completed Milestone
- **Triangle** marker: Planned Milestone
- **Timeline** marker: Timeline
# MDAO Milestone Roadmap

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- **Completed Milestone**: Starred milestones have been completed.
- **Timeline**: Light blue line indicates planned milestones.
- **Planned Milestone**: Yellow triangle indicates milestones planned for future years.
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- **Completed Milestone**: Star symbol
- **Timeline**: Blue line
- **Planned Milestone**: Yellow triangle
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
• 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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<tr>
<td>Requirements</td>
<td>• Document feedback on discipline requirements</td>
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<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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<td>GEN1 Validation</td>
<td>• Exercise GEN1 Capability for Commercial Transport</td>
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<td>• Document validation results in GEN1 report</td>
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<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>• 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>• Identify needed code improvements and/or integration techniques</td>
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<td>• Implement code &amp; integration improvements</td>
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![Planned Milestone](triangle)

![Timeline](timeline)
### Next Steps (continued)

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<td><strong>Alpha OpenMDAO Framework</strong></td>
<td>• Continue prototyping using python</td>
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<td>• Offer python training</td>
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<td>• Set up development environment</td>
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<td>• Research what is needed to setup an open source project</td>
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<td>• Setup technical infrastructure and communications mechanisms</td>
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<td>• Define processes for daily development &amp; release distribution</td>
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<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>• Implement core framework classes</td>
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<td><strong>Outreach</strong></td>
<td>• Solicit feedback on requirements from potential external partners</td>
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<td>• Host meetings with interested parties (industry, academia, gov)</td>
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<td>• Pursue potential collaboration in Open Source MDAO community</td>
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<td>• Leverage NRA &amp; SBIR MDAO efforts</td>
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<td>• Present status at SAD&amp;O Technical Working Group Meetings</td>
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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
Additional Information Available

• 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.
“Toy” Simulation
Scenario 1:
The typical NASA open source website.

Scenario 2:
(Desired)
Full open source community.
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
- Already Submitted
- Email sent to SCM & Submitter

Passes development evaluation?

Yes
CR Accepted
Email sent to SCM & Submitter

No

NOT_ACCEPTED

RFE CR Submission:
Development Team evaluates RFE CRs (via forum)

CR Not Accepted
- Not Framework_CR
- Rejected
- Email sent to SCM & Submitter

Passes development evaluation?

Yes

CR Accepted
Email sent to SCM & Submitter

No

NOT_ACCEPTED

DEF CR Submission:
V&V Team evaluates Defect CRs

CR Not Accepted
- Already_Submitted
- Not_Reproducible
- Already_Incorporated
- Rejected
- Not_Framework_CR
- Email sent to SCM & Submitter

Passes V&V evaluation?

Yes

ACCEPTED - Email sent to Dev Lead, SCM & Submitter

No

NOT_ACCEPTED
OpenMDAO Life Cycle Process (cont’d)

Assign CR to team member

ASSIGNED - Email sent to assigned team member

Assignee opens branch

WORKING - Email sent to SCM & Submitter

Assignee works CR

Assignee submits changes for review

REVIEWING - Code changes for review

Conduct review

Revisions required?

Yes

REWORKING - Code changes to Assigned

No

DOC_UPDATE

Assignee sends associated document changes to Tech Writer

Tech Writer works documentation

Reviewer submits CR for merge

READY_MERGE - Email sent to SCM, V&W & Assignee

SCM merges CR

TESTING - Email sent to V&W & Assignee

V&W does testing

Pass all V&W testing?

Yes

READY_FOR_RELEASE - Email sent to SCM

RELEASED

Email sent to Submitter & Team

No

REWORKING - Test Failure

Email sent to Assignee

Major Changes Required
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.
Example: Optimization Using a Cluster

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.
Example: Optimization Using a Cluster

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

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

Customer Feedback

Submit Change Requests:
Requirement, Enhancement, Defect

Developers & Leads

Analyse
Design
Implement Change
Run Unit & Regression Tests

Code Inspections & Peer Reviews

All phases are iterated as needed.

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.

Software Configuration: Merge, Test, Generate Release

Verification & Validation: Run Regression Tests

Daily Builds
Increments
Full Versions

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