Assessment of the Draft AIAA S-119 Flight Dynamic Model Exchange Standard

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An assessment of a draft AIAA standard for flight dynamics model exchange, ANSI/AIAA S-119-2011, was conducted on behalf of NASA by a team from the NASA Engineering and Safety Center. The assessment included adding the capability of importing standard models into real-time simulation facilities at several NASA Centers as well as into analysis simulation tools. All participants were successful at importing two example models into their respective simulation frameworks by using existing software libraries or by writing new import tools. Deficiencies in the libraries and format documentation were identified and fixed; suggestions for improvements to the standard were provided to the AIAA. An innovative tool to generate C code directly from such a model was developed. Performance of the software libraries compared favorably with compiled code. As a result of this assessment, several NASA Centers can now import standard models directly into their simulations. NASA is considering adopting the now-published S-119 standard as an internal recommended practice.

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I. Introduction

Very few standards exist in the flight modeling domain, aside from Greek symbols for various angles (and they are unique to Western aerodynamicists) and a limited set of axis systems.[1,2] As a symptom of this lack of standards, practitioners of simulation arts are aware that very few real-time (piloted) and/or batch (analysis) simulation frameworks are compatible with each other. When a simulation model is obtained from a 'foreign' simulation framework (e.g. another NASA Center or industry partner) considerable effort is sometimes required to re-format the data and equations to fit into the 'native' framework, and then to verify proper implementation, prior to use of the new model. At NASA Langley Research Center (LaRC), for example, this rehosting can take up to six months or longer. Suggestions of adopting a proprietary commercial product as a 'standard' may be misguided; these proprietary formats may be changed as often as desired by the vendor.

For nearly a decade, the AIAA Modeling and Simulation Technical Committee (MSTC) has been developing a standard format for encoding high-fidelity aerodynamic models of flight vehicles for exchange, training, and archival purposes.[3] This standard has been reported on numerous times to the AIAA Modeling and Simulation Technology community, including an earlier trial in which an aerodynamics model was exchanged between NASA and the U.S. Navy using a preliminary version of the standard.[4] During 2010, the NASA Engineering and Safety Center (NESC) sponsored an Agency-wide assessment of a draft version of the recently-published ANSI/AIAA S-119-2011 Flight Dynamics Model Exchange Standard.[5]

The NESC is charged with "promoting safety through engineering excellence."[*] This includes taking proactive steps to avoid future problems. Given simulation's increasing role in performing engineering evaluations and mishap investigations, the ability to easily move models between NASA Centers was judged worthy of investment, and an assessment of this proposed standard was undertaken.

The assessment was performed by members of the NESC's Flight Mechanics, Aerosciences, and the Guidance, Navigation and Control Technical Discipline Teams, including representatives from several NASA Centers: Ames Research Center (ARC), Dryden Flight Research Center (DFRC), Glenn Research Center (GRC), Johnson Space Center (JSC), LaRC, and Marshall Space Flight Center (MSFC). These representatives were familiar with simulation frameworks used at their respective Centers; for historical reasons, these frameworks were independently developed and somewhat incompatible.[6] Thus, a common means of exchange of flight dynamic models would be a benefit to this community.

The purpose of the assessment was to determine if adoption of the AIAA standard would be of benefit to NASA's flight mechanics, aerosciences, and guidance, navigation and control communities (which covers the research, development, design and analysis of aerospace vehicles and associated control laws).

As a result of several years of prior development by AIAA members, several tools were available to the assessment team. These included two separate Application Programming Interfaces (APIs) that provided C++ libraries that could load an S-119-compatible aerodynamics model at run-time. Most of the assessors chose to use one or more of these existing APIs; one participating Center (ARC) chose to update existing compile-time Perl scripts to convert from S-119 to the native Ames *SimLab* source code and function data table format.

The results of the assessment are the subject of this paper.

II. The ANSI/AIAA S-119 Standard

The new standard, subsequently published in 2011, builds on existing ANSI and ISO standards as it spells out several conventions for axis systems, unambiguous variable names, abbreviations of units of measure and sign conventions for use in modeling flight dynamic vehicles. In addition, an Extensible Markup Language (XML) encoding grammar is included by reference: the Dynamic Aerospace Vehicle Exchange Markup Language (DAVE-ML).[†] DAVE-ML supports use of the Standard's axis systems, variable names, units and sign conventions while also providing features such as modification records, model provenance, hyperlinked references, linear function tables, arbitrary force and moment build-up equations, correlated uncertainty models, and verification data and tolerances. Mathematical relationships and dependencies of variables are specified using MathML 2 markup[‡] within DAVE-ML. Using DAVE-ML and the S-119 Standard conventions, it should be possible to automatically import most of a high-fidelity flight dynamics model, and to a lesser degree, make sharing of the model easier.

[*] see http://www.nasa.gov/offices/nesc/home/index.html
[†] see http://daveml.org
[‡] see http://www.w3.org/TR/MathML2/

The DAVE-ML grammar (version 2.0.1 as of this writing) is documented at the DAVE-ML website.* The ANSI/AIAA S-119-2011 standard is available from the AIAA, free for AIAA members and for a nominal charge for non-members.†

Prior to publication, the standard underwent two public comment periods; during the intervening months, the standard was amplified and improved for better mathematical rigor. The April 2010 draft version of S-119 was used in this assessment which included DAVE ML version 2, release candidate 3 (2RC3) for model encoding.

III. NESC Assessment

Representatives from five of the six participating Centers met in February 2010 at the National Institute of Aerospace in Hampton, Virginia for a one-day kickoff meeting. At that meeting, AIAA MSTC Standards subcommitee chair Bruce Hildreth briefed the team on the draft Standard. DAVE-ML lead designer Bruce Jackson went through the components of the XML markup that implemented the Standard. Finally, two representative aerodynamic models were provided (both of which are available from the daveml.org website): a simple but non-linear F-16 subsonic aerodynamics model, and a high-fidelity Mach 0.8 to 4.0 HL-20 lifting-body approach-and-landing aerodynamics model.

Copies of the existing S-119 software tools were provided, including the two run-time C++ API libraries (The Australian Defence Science and Technology Organisation (DSTO)'s *Janus* and LaRC's *DaveMLTranslator*).

Two goals were established as part of the assessment: to have each Center build the necessary tools to be able to import these aerodynamics models into their real-time and analytical simulation frameworks, and if resources allowed, build a complete lifting-body simulation for piloted assessment. The assessors agreed to a course of action that included regular telecons to report progress and to provide feedback to the AIAA, and set a goal of completing their assessment in November 2010, with a written report due to the NESC in early January 2011.

During the course of 2010, a monthly telecon was held that allowed participants to exchange experiences and questions about the standard. Several deficiencies were uncovered in the APIs that were subsequently fixed by the tool authors. Additional tools were developed, including an innovative C-code generator, and novel uses for the standard were explored.

Mid-way through the assessment, a sixth center (Glenn Research Center, GRC) joined the assessment; the maintainer of the Optimal Trajectory by Implicit Simulation, version 4 (*OTIS4*) analysis tool‡ agreed to join the effort and perform an assessment of the impact of applying the standard on OTIS models.

A final face-to-face meeting was held at JSC in October 2010. Each participating Center gave a brief presentation and provided a written summary of their experience. The team mutually agreed to recommend adoption of the standard, with changes, as a NASA recommended practice. A formal written report to the NESC was prepared and approved and is available from the NASA Technical Report Server.[7]

IV. Assessment Results

This assessment focused on the shared implementation of two existing aero-spacecraft models, specifically the F-16 subsonic aerodynamics and the HL-20 lifting body aerodynamics databases. With an accompanying fixed inertia model and Simulink®§ control law, an autolanding-capable, human-flyable HL-20 real-time simulation was realized within the duration of this assessment at three participating Centers.

Most of the effort by each participating center involved the development of import scripts or adapting existing API tools to allow their simulation framework to accept S-119 models. Some additional software development was necessary to implement the existing autocoded HL-20 control laws, landing gear and inertia models in the simulation, if a complete simulation was desired, as these elements were not available in S-119 format.

A. Implementation Experiences

One center (ARC) had participated in a previous exploration of the DAVE-ML grammar; as a result, their efforts concentrated on updating the Perl scripts that had been used to convert DAVE-ML models into FORTRAN equations and Function Table Processor input decks (a compile-time approach). This was successfully accomplished but somewhat time-consuming; a full simulation was not completed.

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*see http://daveml.org

†see http://www.aiaa.org/content.cfm?pageid=363&id=1896

‡see http://otis.grc.nasa.gov/

§Simulink® is a registered trademark of The Mathworks, Inc.

Another center (MSFC) chose to install the LaRC-developed API, *DaveMLTranslator*, in their simulation framework (*MAVERIC*). The *DaveMLTranslator* library provides the capability at simulation run-time of loading, verifying and interrogating DAVE-ML models. The experience at MSFC in particular was of interest: the API was linked into Marshall's *MAVERIC* simulation framework and had successfully loaded and verified both the F-16 and HL-20 aerodynamics database in one work day of effort.

In addition, the MSFC representative converted an existing launch vehicle model from native *MAVERIC* into DAVE-ML and found the simulation results were identical to the original model.

A third center (DFRC) used the other C++ API, *Janus*, developed by the DSTO of Australia's Ministry of Defence. (*Janus* is available via open-source license on request to DSTO.)* Difficulties were initially encountered in some incompatibility of the Dryden host computer's Unix-based operating system and another open-source component of Janus that required some discussions with DSTO to resolve; in addition, a syntax error was discovered in the HL-20 simulation's DAVE-ML file that had not previously been found and was subsequently corrected. Another shortcoming in the DAVE-ML 2RC3 grammar was identified; it was corrected in the final release of DAVE-ML 2.0. Ultimately the HL-20 simulation was successfully built and flown with separately-provided GNC, landing gear, and inertia models at DFRC.

JSC chose to evaluate both APIs in a head-to-head comparison and was ultimately successful with linking either API into their simulation framework, Trick.[8]

Finally, the OTIS4 maintainer at Glenn was successful in developing scripts to import the majority of the DAVE-ML model into OTIS input deck format, despite a late start in the assessment.

B. New tool developed

The JSC team developed a useful capability of directly generating C-code from an S-119 model using a custom XML Stylesheet Language Translation (XSLT) script.† This capability had not existed previously without having to move the model first into a third-party simulation modeling tool and then autocoding the resulting block diagram. This 480-line XSLT script is being prepared for open-source distribution from the Tools page of the daveml.org website.

C. Performance comparison

The JSC team undertook an in-depth investigation into several aspects of the S-119 standard. One of these was a comparison of the performance of the two run-time APIs against both hand-written equivalent C-code and the C-code created by the XSLT translator script developed at JSC. Figure 1 shows the amount of CPU time required to calculate the full HL-20 aerodynamics model during an autolanding from Mach 4. The range of values is on the order of one order of magnitude, reflecting the difference between compile-time implementations (legacy and XSLT) vs. run-time APIs (*DaveMLTranslator* and *Janus*). However, the run-time APIs are still quite fast at performing a high-fidelity model that includes 168 non-linear function tables with 6,240 points in under 100 microseconds.

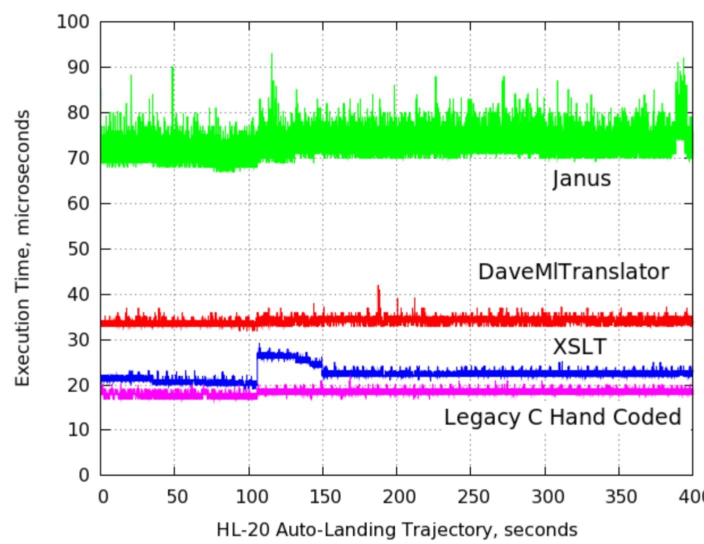

Figure 1. System time per call for the HL-20 aerodynamics model, microseconds

D. Uncovered API and Markup Language Deficiencies

A relatively small number of problems were discovered in the course of the assessment, in either the APIs or the S-119 format itself:

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*see http://www.dsto.defence.gov.au/research/4675/

†see http://www.w3.org/TR/xslt

- A bug in the *DaveMLTranslator* that made the variable definitions order-dependent (they are not supposed to be) was found and fixed.
- The S-119 format did not allow specification of a minimum or maximum value for input variables; specifically, a divide-by-zero could result in the aerodynamics models if velocity was allowed to be zero. A revision to the DAVE-ML grammar has been made (in the released 2.0 version) address this issue.
- The Janus code base made available to the team was not compatible with a later version of one of its dependent sublibraries, *qhull*. A new version of *Janus* (1.10) was made available to the team that corrected the incompatibility.
- Two separate problems in the interpretation of the MathML `<piecewise>` nonlinear construct were discovered (and fixed) in Janus and a separate utility, LaRC's *DAVEtools*.
- An errant static variable declaration in *DaveMLTranslator* was found and fixed.

E. Unanticipated Applications

Two novel and unanticipated applications of the draft S-119 model format were demonstrated by the JSC assessors. One was to demonstrate adding dynamics (state variables) to a reaction control system algorithm expressed in DAVE-ML; this required no additional grammar to the DAVE-ML file itself but the calling program had to be modified to handle state propagation external to the model. The second was in using either XSLT or a high-level scripting language (Ruby) to expand macro definitions in a preliminary DAVE-ML model; these expansions generated fully-compliant S-119 model, saving considerable model editing time.

Information about these demonstrated capabilities is in the NASA NESC assessment report.[7]

F. Identified opportunities for improvements

Several improvements were suggested to the S-119 developers by the assessment team:

- Support for check data of models with no inputs (constant blocks). The draft DAVE-ML grammar required at least one input for a checkcase, even if the model itself had no inputs; this has been corrected in the released version 2.0 grammar of DAVE-ML.
- Identifier for each table even if not reused. In the draft DAVE-ML grammar, a function table that was defined and used within one specific function definition block did not have to include a table identifier (gtID or utID); this made development of the XSLT conversion script much more difficult as a unique pseudo name had to be generated. The released version 2.0 of DAVE-ML now requires table identifiers for all tables.
- Consider using UnitsML* for units-of-measure markup. The units-of-measure defined in S-119 are unique to that standard. The AIAA authors considered adopting UnitsML as part of the standard, but decided this was much too "heavyweight," the implementation details outweighed the advantages of adoption.
- Several improvements in the description and intended-use discussion in the DAVE-ML reference manual of the `<uncertainty>` element. Several of these suggestions were incorporated into the released version 2.0 DAVE-ML reference manual.†
- Add support for vectors and matrices (presently, DAVE-ML models are all scalar). This topic is addressed in another paper being presented at the 2011 AIAA Modeling and Simulation Technologies conference and should be available in the conference proceedings.[9]

V. Conclusion

As a result of this assessment:

- Major real-time and analysis simulation facilities at six NASA Centers can now more easily import aerodynamics models in a common format,
- The proposed AIAA flight dynamic model exchange standard was improved and field-tested,
- At least one new tool that increases the utility of the standard was developed,
- Some deficiencies in existing S-119 tools were identified and corrected,
- Several desirable improvements in S-119 were suggested, and

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*see http://unitsml.nist.gov/

†see http://daveml.org/DTDs/2p0p1/Ref/DAVE-ML_ref.html

- NASA is considering adoption of AIAA S-119 as an internal recommended practice for development and exchange of flight simulation databases.

The S-119 standard, published this past spring, was updated and improved using results from this internal NASA assessment. Having the draft standard and format assessed by several other simulation experts across NASA has given the AIAA MSTC S-119 authors positive feedback about the standard and its benefits.

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