Abstract for 40th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit on Numerical Propulsion System Simulation (NPSS)

The Numerical Propulsion System Simulation (NPSS) is a framework for performing analysis of complex systems. Because the NPSS was developed using the object-oriented paradigm, the resulting architecture is an extensible and flexible framework that is currently being used by a diverse set of participants in government, academia, and the aerospace industry. NPSS is being used by over 15 different institutions to support rockets, hypersonics, power and propulsion, fuel cells, ground based power, and aerospace. Full system-level simulations as well as subsystems may be modeled using NPSS. The NPSS architecture enables the coupling of analyses at various levels of detail, which is called numerical zooming. The middleware used to enable zooming and distributed simulations is the Common Object Request Broker Architecture (CORBA). The NPSS Developer’s Kit offers tools for the developer to generate CORBA-based components and wrap codes. The Developer’s Kit enables distributed multi-fidelity and multi-discipline simulations, preserves proprietary and legacy codes, and facilitates addition of customized codes. The platforms supported are PC, Linux, HP, Sun, and SGI.
**Numerical Propulsion System Simulation (NPSS)**

**Architecture**

**AIAA/ASME/SAE/ASEE 40**\(^{th}\) **Joint Propulsion Conference**

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**Background**

**Development History**

1987 - 1995
- Conceptual, Prototypes

1996
- NDA, NICE-1, Formal Requirements Definition

June 1997
- Space Act Agreement 3-83

July 1997
- NCP Beta Release

March 2000
- NPSS Version 1 - Full 0-D Functionality

March 2002
- NPSS Version 1.5 - Initial Zooming, Code Coupling, Visual Based Syntax (VBS, the GUI), Space Components

August 1998
- Initial NPSS Release (NCP Version 1)

March 2002
- NPSS Version 1.5 - Initial Zooming, Code Coupling, Visual Based Syntax (VBS, the GUI), Space Components

July 2003
- NCP Beta Release

September 2003
- NPSS Version 1.6 - Enhanced Functionality (based on user feedback)

- VBS 1.6 - Enhanced Capabilities (based on user feedback)

- CCJK Version 1.0 - CORBA Component Developer’s Kit (Multi-Fidelity, Multi-Structural Distributed Objects)

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**Technical Overview**

**What is NPSS V1.X?**

- NPSS V1.X is a framework for performing analysis of complex systems.
- First major propulsion thermal/fluid design and analysis system developed using a programming paradigm designed for simulating complex engineering systems (i.e. object-oriented programming).
- Extensible Framework:
  - Expand models easily
  - Build new models on-line, interactively
  - Build larger models, including more subsystems, in less time
  - Flexibility to model wide variety of complex systems
  - Add individual customized or proprietary components, component libraries, and legacy codes
  - Four different mechanisms to add new components
    - Interpreted components
    - Internal components
    - External components
    - Dynamically Loadable Module (DLM) components
- Deploy locally/distributed/parallel using high-end computing and communications as required
- Uses Common Object Request Broker Architecture (CORBA)
  - Middleware communication
    - Permits mixture of codes such as C, FORTRAN, and C++ to be collected within any simulation

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**Technology Transfer**

- **NPSS V1.X** utilisé pour la simulation de systèmes aérospatiaux
- **NPSS V1.X** is nationally recognized and impacting the US aviation industry
- **NPSS V1.X** has been developed and used for various applications, including:
  - **Engine Design** (e.g., GE90 for the Airbus A380)
  - **Vehicle Design** (e.g., Joint Strike Fighter Program)
  - **System Verification** (e.g., DARPA/ONR HyFly Program)

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**Architecture**

- **PDM Compliant**
- **CAD**
- **Compilers**
- **Visualization tools**
- **CORBA**
- **Fast Parallel High-Performance Computing**
- **Massively Parallel Supercomputing Clusters**
- **Network piping**

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**Vision & Objective**

- **Vision**: Create a “Numerical Test Cell” enabling complete aerospace propulsion simulations overnight on cost-effective platforms.
- **Product Objective**: Provide a common tool and extensible framework to enable rapid, high-confidence, cost-efficient design of aerospace systems.

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**Partnerships**

- Established Space Act Agreement (SAA 3-83) and NASA Industry Cooperative Effort (NICE) Agreement
- Established a SAA for Commercialization of NPSS V1.X
- Currently working with partners to establish new SAA with same partners as SAA 3-83, plus Lockheed, Amjet, and Rockwell

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**Object-Oriented Architecture Chosen**

- **Formal Development Process Mandated**
Technical Overview (continued)

Building An Object-Oriented Model

- NPSS is an object-oriented framework for executing systems of components.
  - No matter what the user needs to simulate, the steps are the same.
  - Divide system into discrete components (i.e., elements)
    - The user’s conceptual view of the physical components can be mapped directly onto the object class hierarchy.
    - An object may be one component or an assembly of components.
- Link components
- Setup solver and execution sequence

This same basic recipe is followed to build any NPSS model.

Technical Overview (continued)

Building Blocks of A Model

- Elements
  - Primary building blocks connected together via Ports
  - Perform high level calculations
- Subelements
  - Interchangeable secondary building blocks that plug into Elements or other Subelements
  - Perform detailed calculations
- Flow Stations
  - Responsible for thermodynamic and continuity calculations
  - Access the thermodynamic packages (Janaf, GasTbl, CEA, H2, O2, Combusted H2O2, Tabular Data)
- Ports
  - Used to connect Elements together
    - Five types (Mechanical, Fluid, Fuel, Thermal, Data)
    - Directional in nature (i.e., outputs connect to inputs)
- Tables
  - Organized set of numbers that relate n-dimensional inputs to one or more outputs
  - Support linear and second or third order LaGrange interpolation
  - Support fixed value end-points or extrapolation (linear/2nd/3rd order LaGrange)
  - May be used at any location a function is called and vice-versa

All simulations are created from a collection of 5 basic types (classes) of building blocks, which represent engine components, and describe how components are linked together.

Technical Overview (continued)

Running A Model

- Batch
- Interactive
- Graphical

Technical Overview (continued)

Zooming

- NPSS Zooming is the coupling of analyses at various levels of detail.
- Run one or more components at a specified fidelity while the rest of the system-level simulation runs at another fidelity.

Zooming

1-D
3-D
Component Library

3-D Unsteady

NPSS System Model

0-D

NPSS V1 (2nd Q FY 00)– Baseline 0-D Model

Technical Overview (continued)

Summary

- NPSS object-oriented architecture has been proven on a wide variety of applications
- Involving partners throughout the development process has been invaluable and the main reason for success
- Flexible architecture supporting multi-fidelity, multi-discipline components using high-end computing and communications provides excellent candidate to support broader market
- Focus on Technology Transfer will continue
Backup Slides

Incremental Release Process

Original Requirements Specification
Initial Requirements Analysis
Define & Implement Architecture (BETA)

Requirements Definition for Version 1

Plan and Develop Version 1 per Incremental Releases

Assess & Incorporate Customer Feedback

Incorporation & Acceptance Testing

Incorporate & Acceptance Testing

Develop Subset of Version N Requirements

Requirements Definition for Version 1

Customer Feedback

Audit of Full Version N

Incremental Release

NPSS V1.X Package Descriptions

NPSS Release Package

NPSS V1.6

Visual Based Syntax
Components
Therm
Documentation
Customer Desk DevKit
DLLDevKit
Mico tar

Add-On Packages

CCDKBase
CCDKHiFi
CCDKRocketsITAR
Wrapper Tools

DevKit – developer’s kit
DLL – dynamically loadable library

CSDK – CORBA Component developer’s kit
HiFi – high fidelity