

Updates and Modernization of NASA's Chemical Equilibrium with Applications (CEA) Code

NASA's Chemical Equilibrium with Applications (CEA) code is a foundational tool for propulsion system analysis. It provides equilibrium chemistry, rocket performance, shock, and detonation calculations used across NASA and the broader aerospace community. NASA Engineering and Safety Center (NESC) Activity TI-22-01730 modernized the legacy CEA2 Fortran code into CEA v3, a Fortran 2008, object-oriented software package with expanded interface support, updated thermochemical data, improved maintainability, and substantially improved workflow integration. The modernized code preserves backward compatibility with legacy CEA input workflows while enabling direct use from modern analysis environments, including Python, C, MATLAB, and automated design studies.

Background

CEA2 was released in 2002 and has remained widely used for propulsion and thermochemistry analysis. However, the original procedural Fortran implementation became increasingly difficult to maintain, extend, and integrate into modern engineering workflows due to the lack of a subroutine interface. Current propulsion analysis increasingly requires automated parametric sweeps, integration with other modeling tools and engineering workflows, and support for emerging propellants and fuels, including green propellants and sustainable aviation fuels. These needs motivated a comprehensive modernization effort to preserve CEA's validated technical basis while improving its maintainability, usability, and integration with modern engineering software.

Technical Improvements

Modern Software Architecture

CEA v3 is implemented in Fortran 2008 using object-oriented data structures, stricter typing, and a thread-safe equilibrium solver architecture. The software supports Fortran, C, Python, MATLAB, and Excel interfaces. These interfaces allow CEA to be used directly in automated analysis pipelines, multidisciplinary design frameworks, and high-volume design-of-experiments studies. Backward compatibility is supported through a legacy command-line interface, allowing existing CEA input files and workflows to be carried forward with minimal disruption.

Expanded Species and Thermodynamic Data

The thermodynamic database has been expanded to support additional propellants and fuels relevant to current NASA applications, including green propellant constituents such as ADN, HAN, and LMP-103S, and sustainable aviation fuel candidates such as n-Butanol. This expanded species coverage improves the applicability of CEA for next-generation propulsion, green propellant, and sustainable aviation fuel studies.

New Modeling Capabilities

CEA v3 adds or improves support for several modeling capabilities, including:

- Subroutine interface enabling direct integration and high-volume calculations
- Negative reactant amounts
- Inert hydrocarbon fuel representations, including RP-1, Jet-A, and JP-series fuels
- Analytic total derivatives for coupling with optimization and sensitivity-analysis workflows

Performance Improvements

For standalone use, individual equilibrium calculations in CEA v3 are moderately slower than comparable CEA2 calculations because the modernized architecture and added robustness introduce additional computational overhead. In representative testing, a single calculation was approximately 40 percent slower, but the absolute difference was only about 0.004 seconds per case. However, the modernized architecture provides substantial performance advantages for multi-case workflows,

which are common in design-of-experiments studies, parametric sweeps, optimization, and uncertainty analyses. In one benchmark, a sweep of 108,500 cases completed in approximately 1.11 seconds with CEA v3, compared with approximately 15 minutes using CEA2. This corresponds to an approximately 800-times reduction in runtime for that workflow. These improvements make large-scale propulsion trade studies and automated design-space exploration significantly more practical.

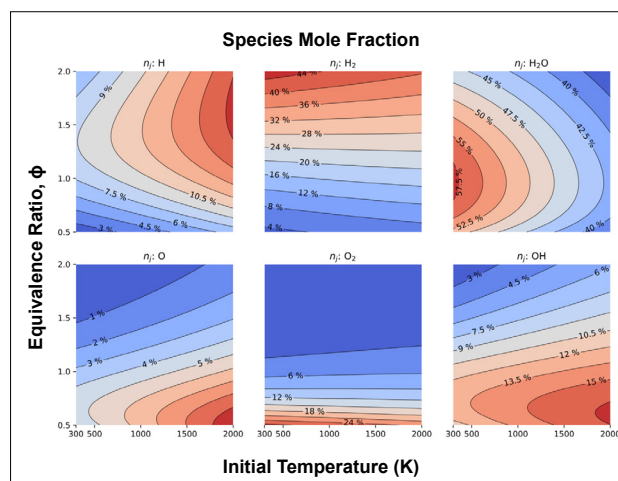
Guidance for Engineering Use

NASA engineering users should consider the following guidance:

- Use CEA v3 for new propulsion and thermochemistry analyses when possible to take advantage of the modernized interfaces, expanded database, and improved workflow integration.
- Use the Python, MATLAB, or C interfaces for automated workflows, including parametric sweeps, optimization studies, and iterative design analyses.
- Use the updated species database for green propellant and sustainable aviation fuel studies when the relevant species are included and validated for the intended application.
- Use the classic command-line interface when continuity with legacy CEA workflows or input files is required.
- Retain appropriate engineering review and validation when transitioning established CEA2 workflows to CEA v3, particularly for mission-critical analyses or cases that depend on legacy assumptions.

References

1. NASA/TM-20260007987
2. CEA documentation: <https://nasa.github.io/cea>
3. CEA repository: <https://github.com/nasa/cea>



Mole fractions resulting from a sweep of equilibrium analyses varying reaction temperature and equivalence ratio.



NESC tech bulletin

