

# Stow-and-Go for Space Travel

Caltech researchers use Abaqus FEA to design self-deploying composite booms for satellites



Figure 1. MARSIS satellite nearing Mars, showing one composite antenna boom already deployed and a second boom in the process of unfolding. Image courtesy of European Space Agency.

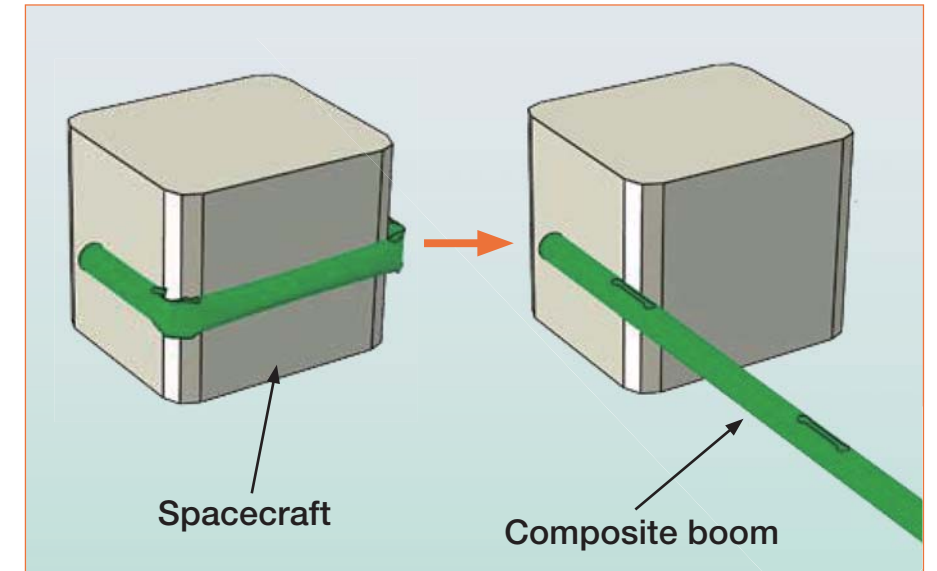
earlier boom components were usually refined through repeated, costly physical experiments (including ones conducted during the 22 seconds of weightlessness generated in a plunging test aircraft).

“But now we can accurately portray these features using realistic simulation,” says Chinthaka Mallikarachchi, a postdoctoral scholar working with Professor Sergio Pellegrino at the Space Structures Laboratory of the California Institute of Technology. “We can optimize the structural design of self-deployable booms through finite element simulations and conduct physical tests only on our final designs. Since ground testing on Earth of structures that are going to be deployed in the zero-gravity vacuum of space is either difficult or very expensive, such virtual testing is the answer to a lot of the challenges we face.”

Mallikarachchi’s work over the past several years—on the simulation of a carbon-fiber-reinforced boom that can be folded around a spacecraft—was carried out almost exclusively using Abaqus Unified Finite Element Analysis (FEA). “3DS SIMULIA’s academic package has been quite helpful to us in conducting this kind of research,” he says. “We used the meshing and visualization features in Abaqus/CAE a lot. The Abaqus/Explicit solver is the most important feature for us since it accurately captures all the complexities of our boom designs. And the general contact, shell general section, equation constraint and restart features were very user-friendly, as were the availability of Python scripting and keywords for input files.”

The modeled boom was a one-meter long, thin-walled (0.22 mm) tube (38 mm diameter) made of two plies of plain-weave carbon fiber in an epoxy matrix. Certain regions of the tube were weakened by cutting away some of the composite material to form tape-spring hinges so the tube could be folded around the satellite (“spacecraft” in Figure 2) without causing any damage. Three possible hinge designs, with different slot parameters, were considered. The FE mesh was made finer over the hinge regions to capture the details of the complex deformation occurring in these regions.

Figure 2. The boom design challenge: fold it around a satellite, then release it and have it fully extend.



## Abaqus supports years of research challenges

Early research used micromechanical modeling to capture the behavior of the boom’s thin laminate material through homogenization of a periodic unit cell (with Abaqus/Standard). From this, the material stiffness was computed in the form of a matrix and used to define the shell elements in the Abaqus/Explicit simulations of the quasi-static folding and dynamic deployment. The numerical simulations were then integrated with a material failure criterion. The combination of these tools allowed an analysis of the detailed effects of hinge design changes on three different boom models. This led to identifying the design that could be most safely folded and deployed.

Modeling the boom deployment involved first pinching the hinges to fold the boom around the spacecraft, then releasing all constraints so the boom dynamically deployed and self latched. “This behavior needed to be fully understood and optimized since overshooting at the end of deployment could damage the boom, the spacecraft or other equipment attached to it,” says Mallikarachchi. “Alternatively, a too-slow, highly damped deployment might never achieve the fully expanded configuration that’s needed.”

## Project test launch: simulation versus reality

During the FEA simulations, the first boom design overshot the fully deployed configuration and was rejected. When the failure analysis and hinge angle were optimized against the time response (full deployment occurred in about 0.3 seconds), Design III performed better than Design II. With their simulation data in hand, Mallikarachchi’s team then built and tested a boom according to Design III specs, filming the results from two different camera angles. Side-by-side motion comparisons of Abaqus FEA and boom deployment confirmed that the real boom also deployed in 0.3 seconds, became fully latched, then oscillated around the deployed configuration in excellent agreement with the simulation.

“Our studies showed that the most critical points are the fully folded configuration and

during deployment, the point at which the second hinge latches, affecting the load on the root hinge,” says Mallikarachchi. “The hinge transition region between the straight and curved part of the slot experiences the most stress/strain, so special care should be given to this area during fabrication of this kind of boom.”

The Caltech team’s validation of their boom design paves the way for further exploration of satellite hardware deployment. “Our simulation techniques can be used to design deployable booms with multiple hinges and optimized boom geometry to meet specific mission requirements,” says Mallikarachchi. “Future work could consider alternate laminates and thermal and viscoelastic effects in different materials.”

## About Chinthaka Mallikarachchi

Chinthaka Mallikarachchi has a Ph.D. from the University of Cambridge, U.K., and a B.Sc. in civil engineering from the University of Moratuwa, Sri Lanka. Now a postdoctoral scholar at the Space Structures Laboratory of the California Institute of Technology (Caltech), he has been interested in space structures since childhood and was inspired by the deployable structures work of his thesis advisor, Professor Sergio Pellegrino. The son of an electrical engineer, Chinthaka has brothers studying mortar mechanics and computer science. He plays cricket and badminton and is interested in photography.

## For More Information

<http://pellegrino.caltech.edu>  
[www.3ds.com/SCN-Feb2012](http://www.3ds.com/SCN-Feb2012)

