



kdFlex

Flight Dynamics Simulator Demo

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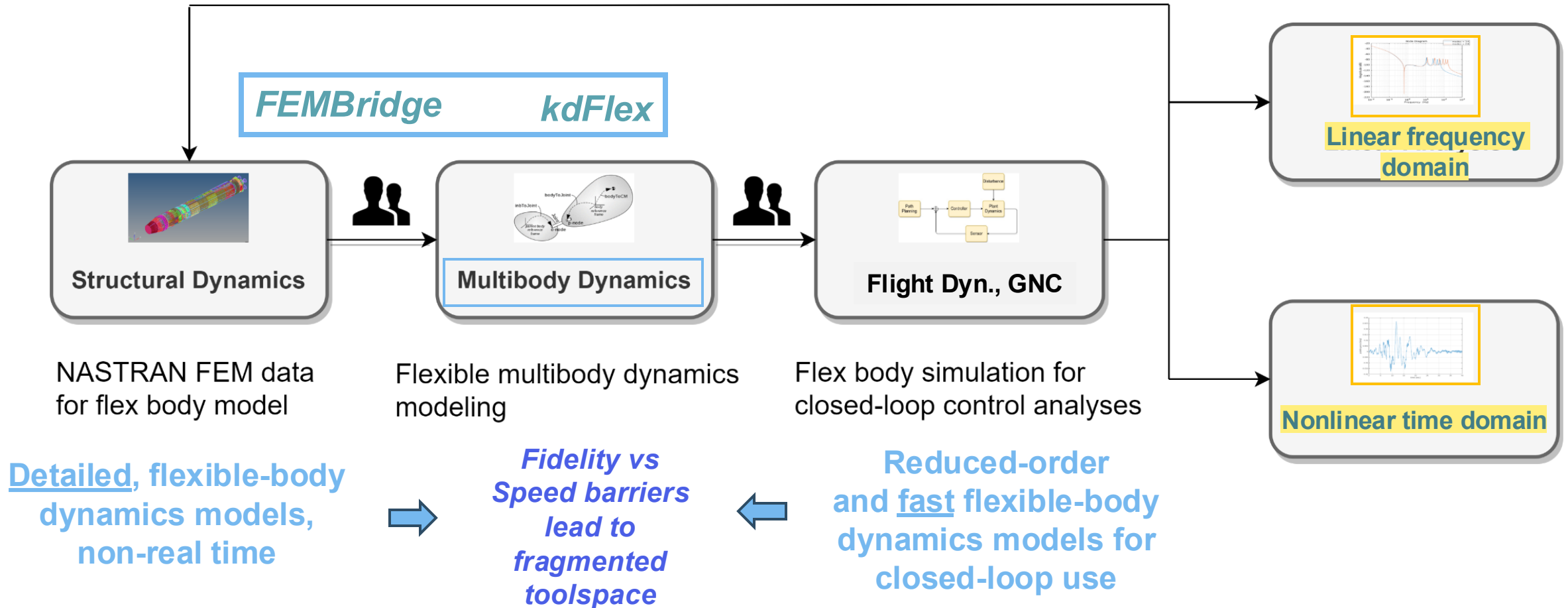
<https://karanadyn.com>

NESC Flight Mechanics TDT Briefing

kdFlex : Flexible Body Dynamics for Loads, Dynamics and Controls



Design Iteration



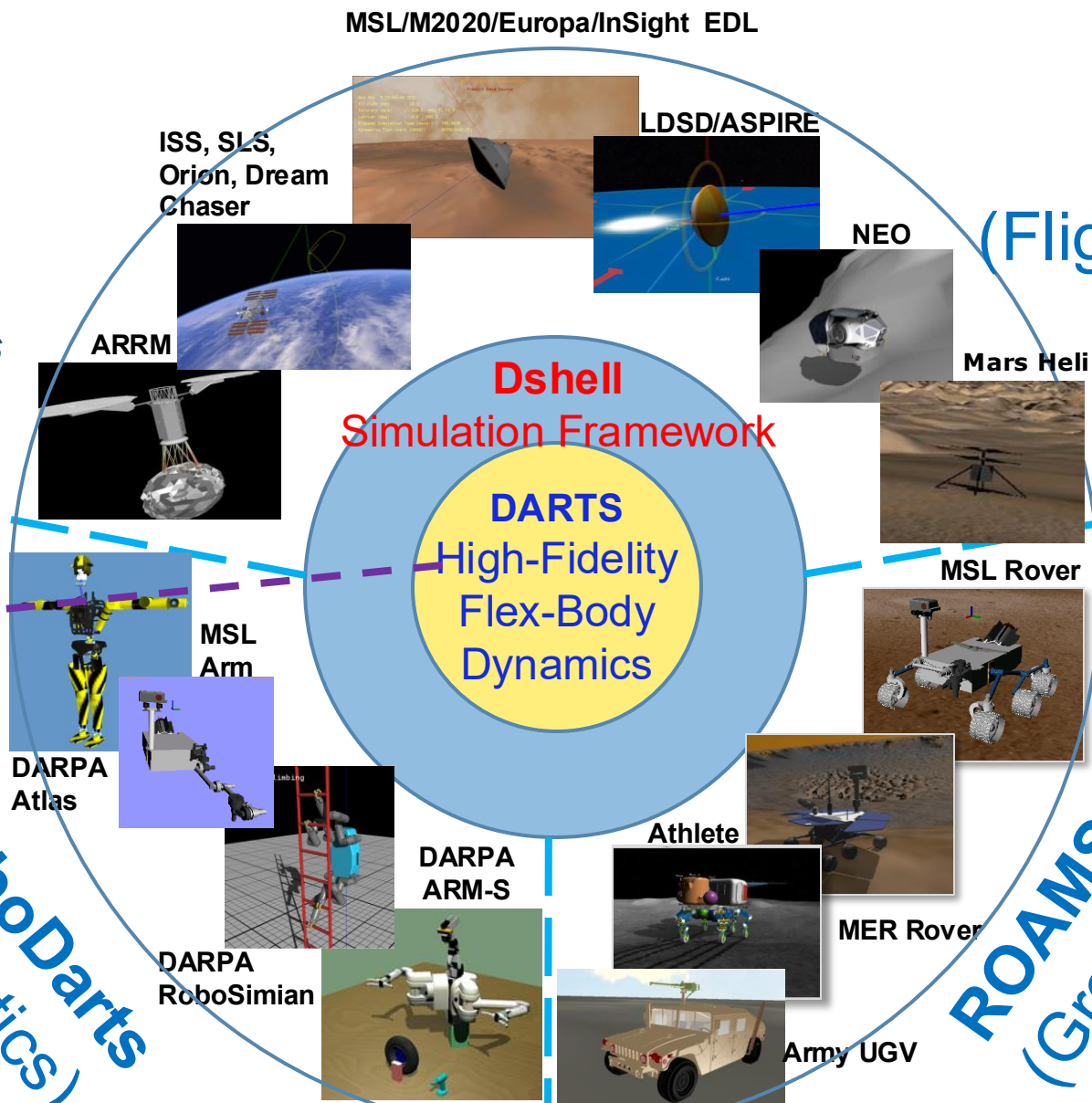
The team is ex-NASA/JPL – inventors & developers of the SOA dynamics methodology and the JPL DARTS simulator. kdFlex is a next-generation capability based on this rich experience heritage.

JPL DARTS (SOA-based) Simulator

Closed-loop dynamics
 Physics-based
 Engineering sims
 Advanced middleware
 Component based models
 Workflow for reuse

DSEENDS
HeliCAT
FLOATS
 (Flight Dynamics)

- MSR (SRL, NAV, SRH, EES)
- Lunar Terrain Vehicle
- Sierra Dream Chaser
- ARTEMIS I & II
- CADRE
- EELS
- Endurance
- Chopper
- M2020, Ingenuity
- ARRM, Europa Lander
- LDSD, ASPIRE
- MSL, InSight, Phoenix
- ...
- SIM
- SRTM
- Cassini



Based on
 'Spatial Operator
 Algebra (SOA)'
 methodology for
 multibody/robot
 dynamics



kdFlex

In the news ...



JSC FOD's **COMPASS** flight dynamics simulator is built on **DARTS**. Used for DOLILU on day of launch, and earth reentry flight dynamics simulations.

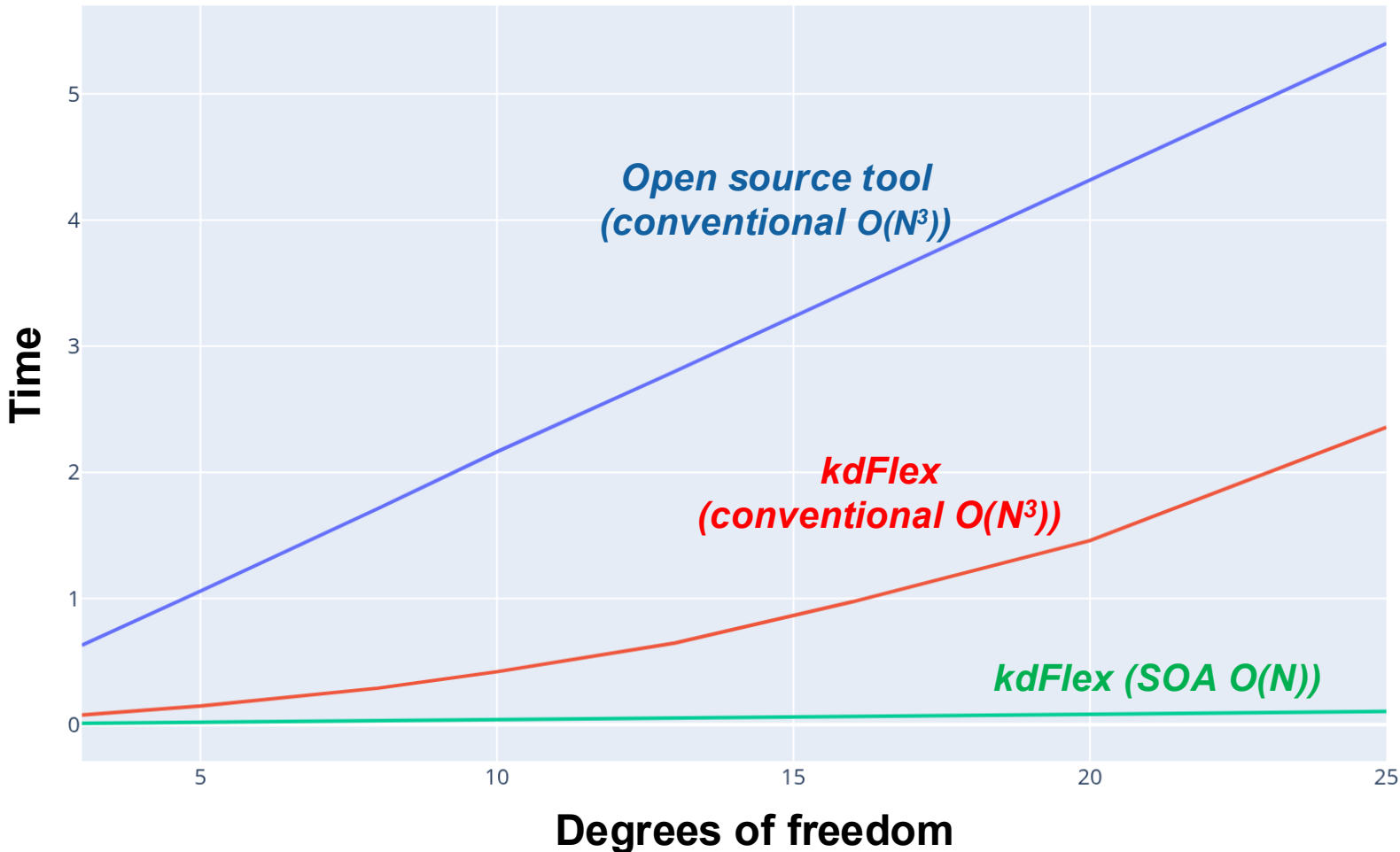


The new **Mars Skyfall** project is building on **Ingenuity** Mars Helicopter legacy. **Ingenuity** used **DARTS** based **HeliCAT** simulator for full life-cycle – concept, to GNC closed-loop software development, to mission operations – simulations.

Unique kdFlex SOA based Fast Dynamics



Benchmark problem: Solve dynamics equations of motion for an n -Link rigid-body pendulum dynamics with revolute joints with n varying from 3 to 25

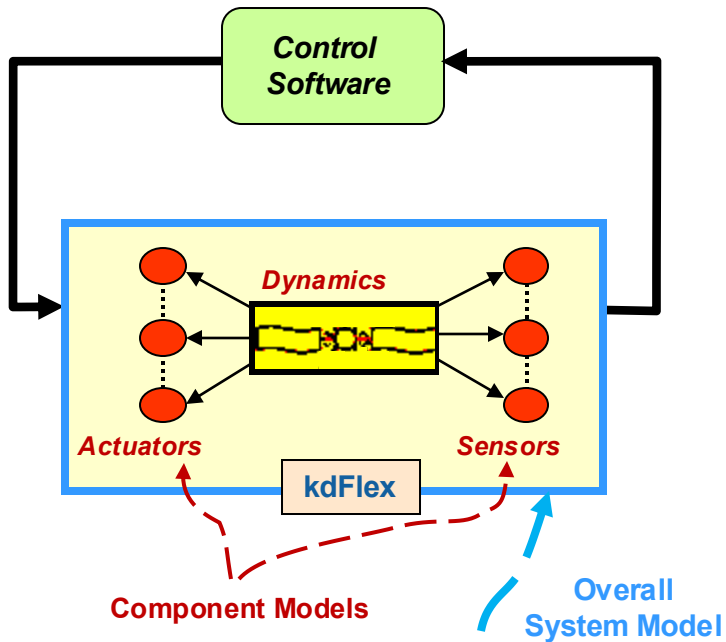


SOA Recursive Dynamics

- General, rigorous rigid+flex
- Exact dynamics, no approximations
- No constraint error drift
- Simpler ODE solvers
- Larger time steps

Do not need to know SOA to use kdFlex!

kdFlex Overview



Closed-loop, G&C in the loop flexible body spacecraft simulation

- Extensive API
- C++, Python
- Linux, MacOS, Windows
- Chatbot, documentation, tutorials

Device, environment interaction models

Parameterized models; dynamics aware
Scratch, state variable structs; **pre-fabs**
Multi-rate execution; time delays
Run-time enable/disable
Time stamped outputs

State Propagator

Integrators – fixed & **variable step**
Multi-rate scheduler, state propagation
Step rollback; **zero-crossing** detection
Kinematics and dynamics simulation
Timed events; Hard and soft resets

Model Manager

Multibody and component models
Callback registries for methods
Integrated state management
System **equilibration, linearization**
Multiple solver modes

Multibody dynamics

O(N) SOA fast recursive dynamics
Tree & **graph, rigid/flex** bodies; subgraphs
Collision & contact dynamics
Variable topology & constraints, loads
FEM pipeline; constraint embedding

Simulation services

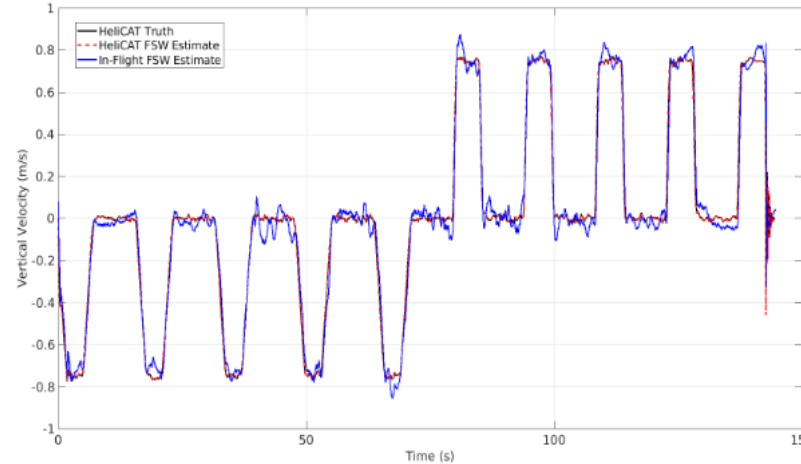
Frames layer, **ephemerides**
Data logging, message verbosity control
Web based 3D graphics, stripcharts, gui
Data import/export - YAML, JSON, HDF5
Units/quantities support, Monte Carlo

kdFlex Validation

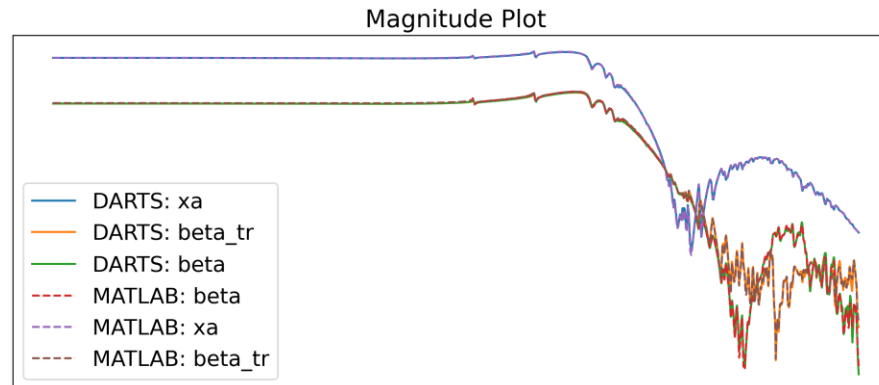


Cross-Validation

- NESC check cases
- DARTS comparisons
- MSFC cross-validation
- Ingenuity flight data
- JSC COMPASS validation
- Sierra Space validation
- Mars missions validation
- Long history with missions
- Apparent mass checkouts for DrgonFly
- ADAMS comparisons
- ...



Ingenuity flight data vs HeliCAT/DARTS simulation data comparisons (Flight 59)



Cross validation of MSFC MASV simulation model of SLS flex dynamics model (1299 modes) against DARTS.

Core/Unit testing

- Description
 - SOA book on algorithms
 - Papers
 - Online lectures
- Compare multiple soln paths (eg. different fwd dynamics)
- Round trips (eg. Inverse and forward dynamics)
- Fuzz testing (randomized systems, large, varied, automated)
- Flex – NASTRAN comparisons
- Conservation properties
- ...

Why flex multibody dynamics?

Multibody dynamics

- Launch vehicle (tail wags dog, TVC etc)
- Articulation (solar panels, platforms)
- Separation events (heat shields, SRBs)
- Parachutes, apparent mass
- Landers, EDL
- Rendezvous and docking, prox-ops
- Rotorcraft
- Fuel slosh
- Aerobots
- Aeroflight (Dream Chaser)
- Deployments
- In space assembly
- ...

Flexible body dynamics

- Control Structure Interaction (CSI)
- Servoelastic analysis
- Aeroelastic analysis
- Landing loads
- Rotorcraft dynamics
- GNC design & analysis
- Solar panels
- Precision pointing
- TVC for launch vehicles
- Loads and stress analysis
- Deployables
- Robotic arms – SSRMS, servicing
- Starshields, solar sails
- ...

kdFlex provides rigorous, validated (and fast) rigid/flex dynamics out of the box for simple to complex flight dynamics needs

Rendezvous Scenario

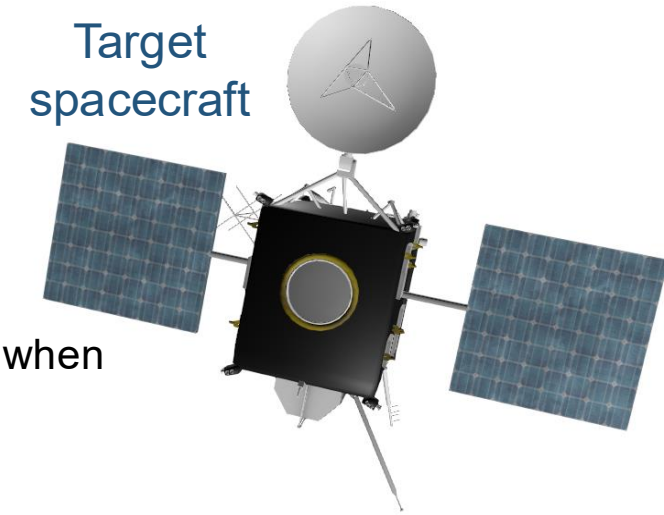


Phases

- Orbit insertion
- Approach
- Sync velocities
- Dock
- Combined maneuver
- Separation

Simulation modeling needs:

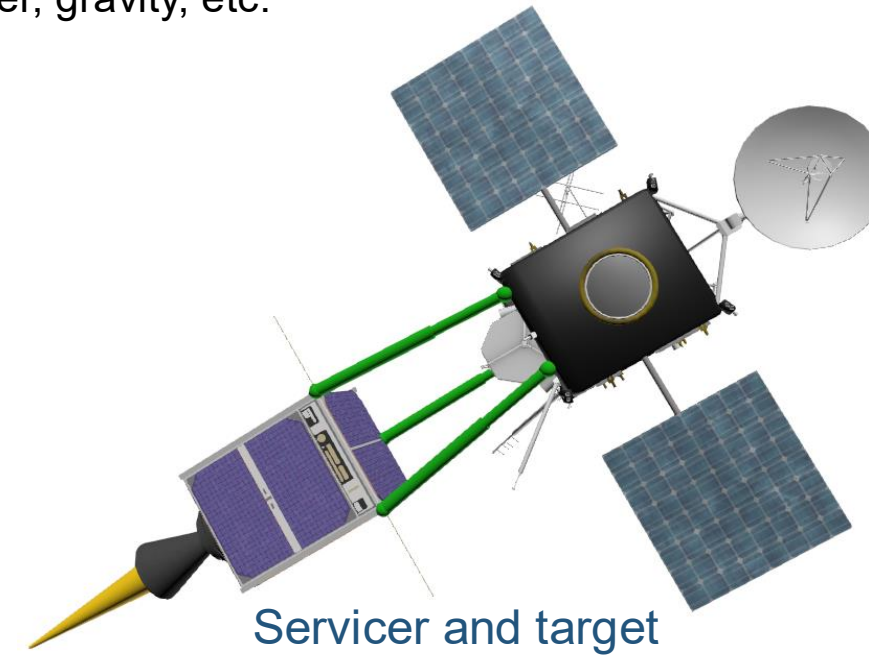
- Multibody
- Flexible body modeling
- Structural changes to the multibody (adding constraints when the two spacecraft connect)
- Collision and contact modeling
- Vision sensors
- Incorporate external models for flight controller, gravity, etc.
- Measure loads/stresses in the bodies
- Inject failures



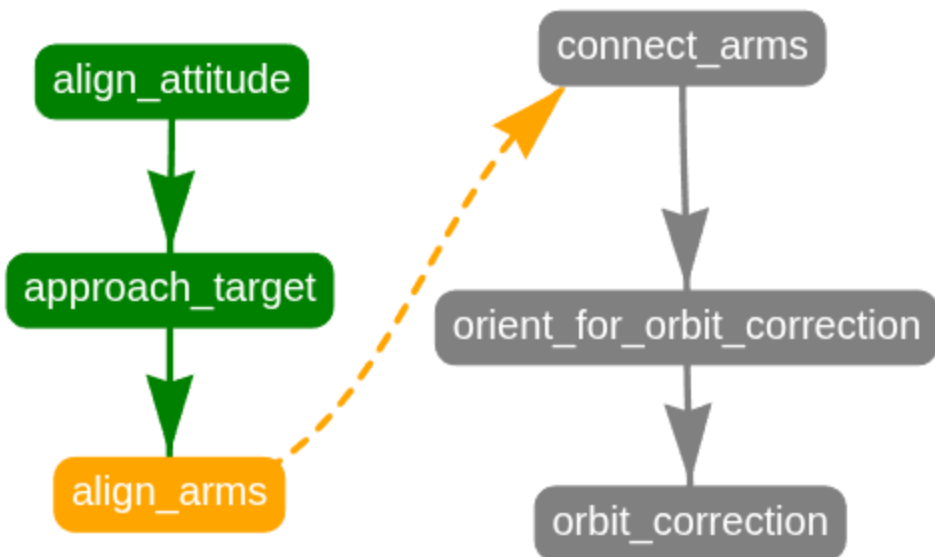
Target spacecraft



Servicer spacecraft

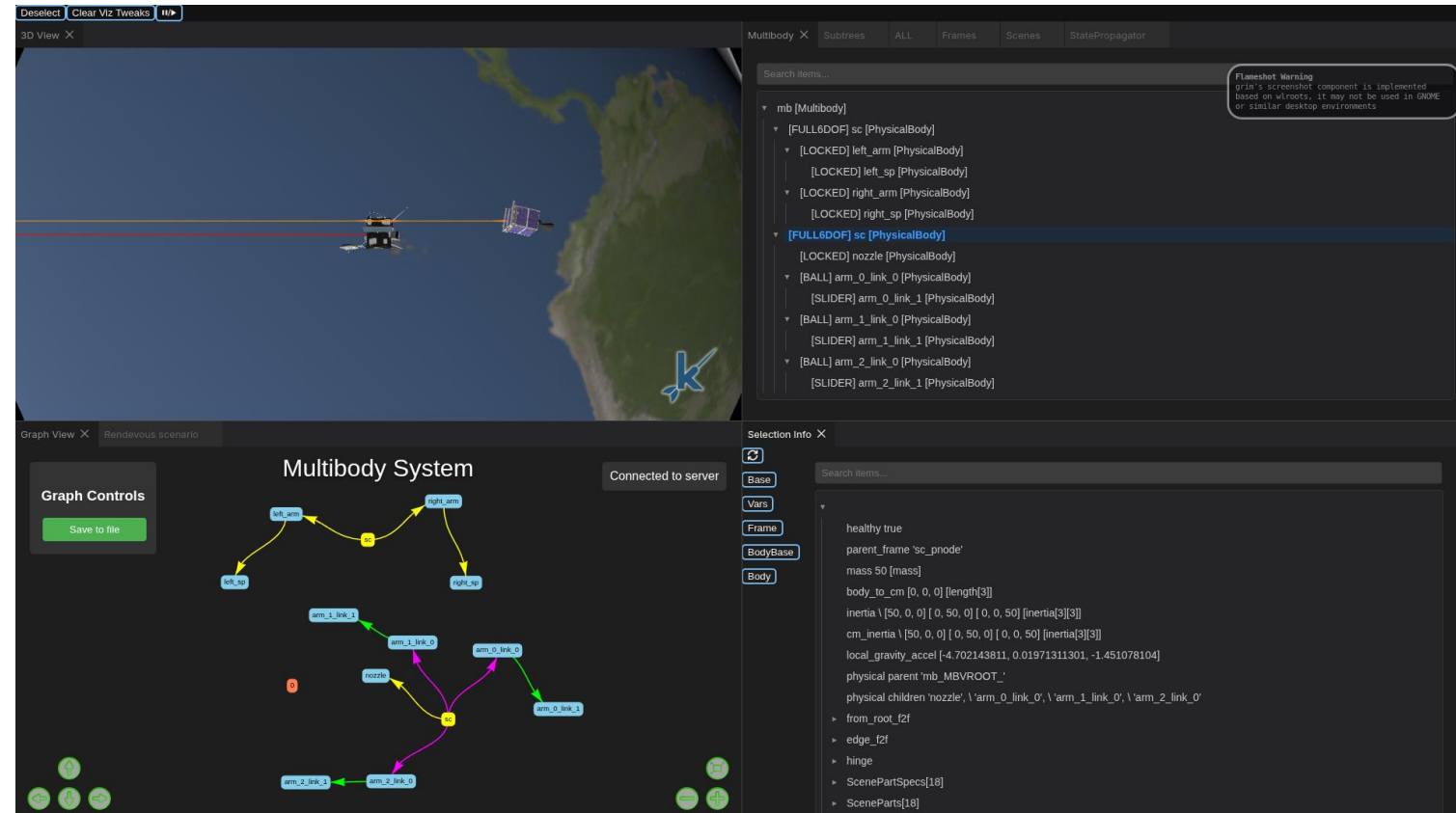


Servicer and target during orbit boost

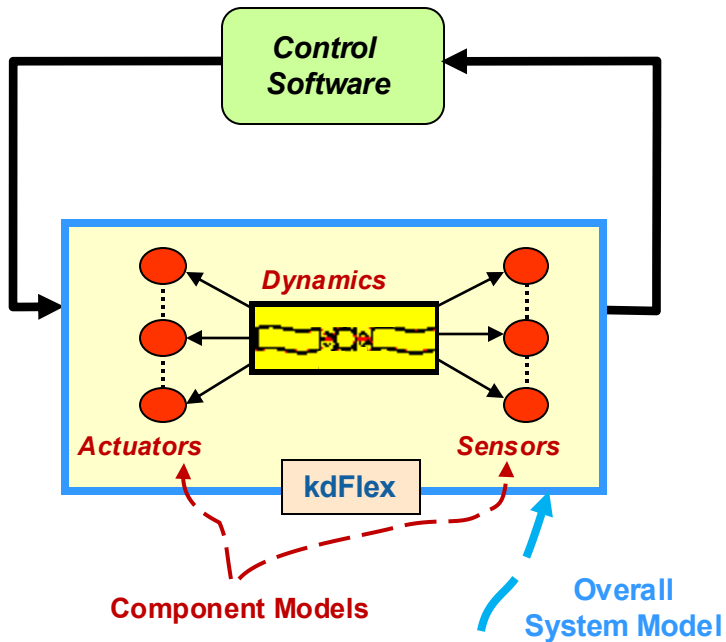


Rendezvous Demo Scenario

- Servicer spacecraft with 3 arms (2 dof) connects to target spacecraft and performs an orbit boost.
- The target spacecraft has two solar panels connected to its bus with one arm each.
- Simulation content:
 - Rigid Multibody
 - ACS in closed loop
 - Flexible body modeling
 - Structural changes to the multibody (adding constraints when the two spacecraft connect)
 - Included models for gravity, etc.
 - Measure loads/stresses in the bodies
 - Inject failures



Rendezvous demo kdFlex features recap



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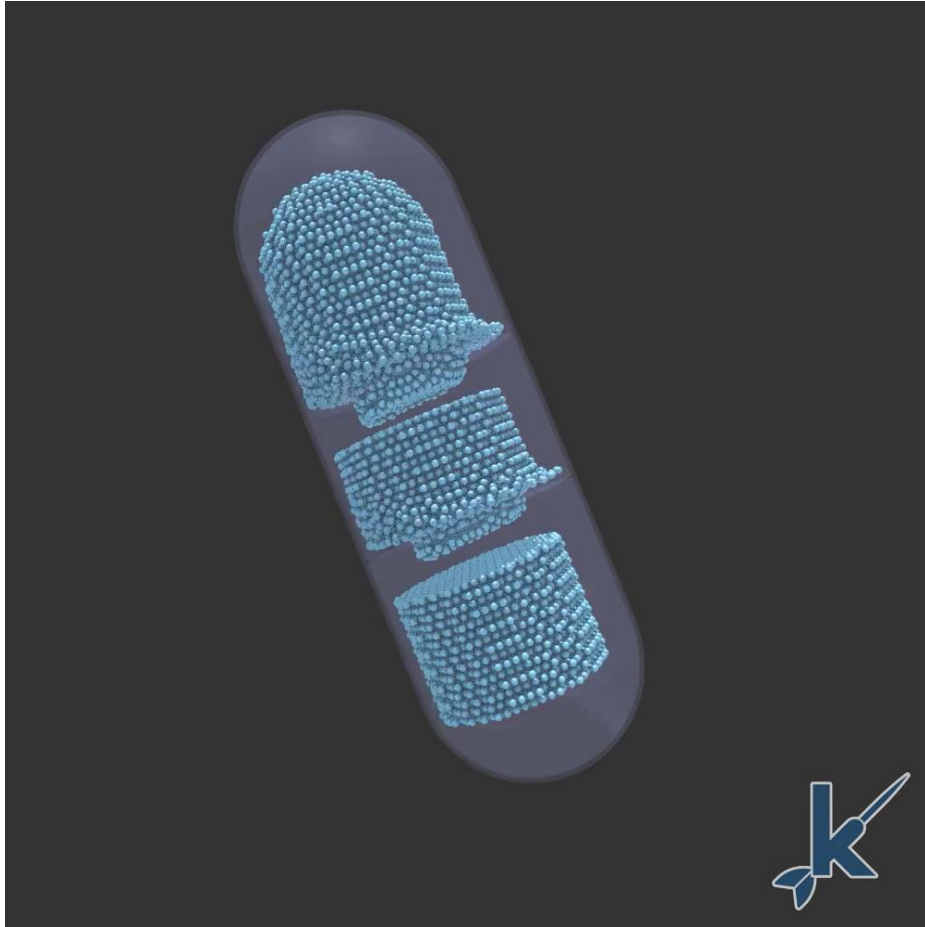
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Other Advanced Capability Examples



Fuel slosh dynamics
in tank with baffles
using SPH

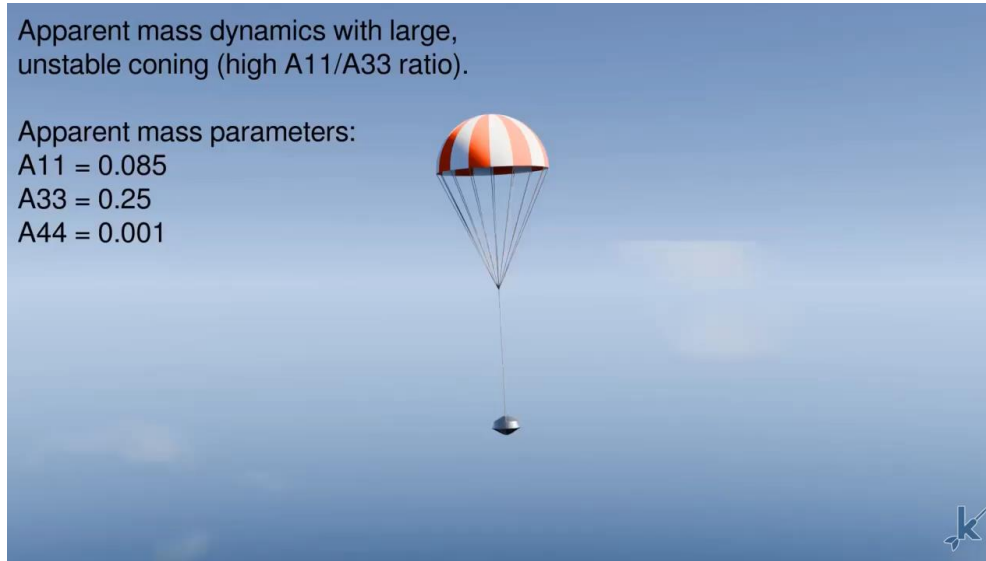
Apparent mass dynamics with large,
unstable coning (high A_{11}/A_{33} ratio).

Apparent mass parameters:

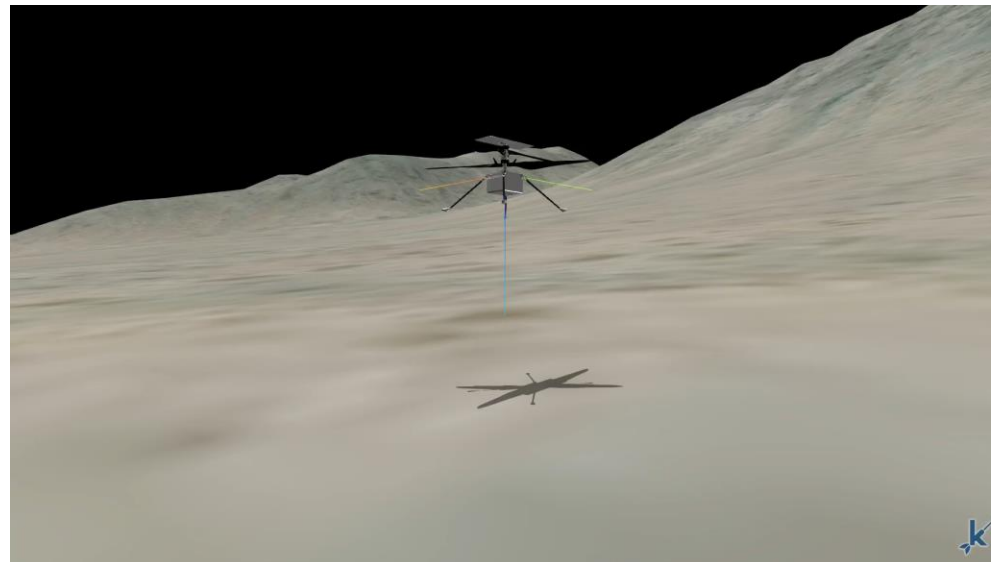
$A_{11} = 0.085$

$A_{33} = 0.25$

$A_{44} = 0.001$



Explicit
formulation
apparent mass
for parachute
dynamics for
DragonFly
(NESC)



Landing on
geotiff terrain
with collision
and terrain
interaction
dynamics

In conclusion ...

- **kdFlex** is a unique and comprehensive **cutting-edge** rigid/flexible dynamics modeling capabilities.
- The **speed, fidelity, and rigor** combination is unparalleled.
- Can avoid **toolset fragmentation** across programs, orgs, and life-cycles, which improves workflows.
- Rich and **mature heritage** from NASA missions use.

- **kdFlex** is available for **evaluation** at <http://karanadyn.com>
 - Free, no commitment or obligations
- **Resources:** Online documentation, chatbot, several examples and tutorials.
- **Collaborations welcome:** from near-term pilot studies to long-term partnering.

Thank you!

Questions?