1st Symposium on Space Educational Activities, December 9-12, 2015, Padova, Italy.

POLITECNICO
MILANO 1863

Robotic Refueling System for On-Orbit Servicing

L. Bucci, M. Brizioli, A. Bellanca, M. Lavagna

Politecnico di Milano, Department of Aerospace Science and Technology

Introduction

Feasibility study performed by 12 M.Sc. students at Politecnico di Milano.

Given high level requirements:

- Capability to refuel at least 3 GEO satellites
- Launch in the year 2020
- Use of European launchers preferred

A **robotic tug** was designed (Phase A), able to autonomously move in GEO, berth the clients and refuel them. Xenon is considered as fuel to be transferred, in line with near-future all-electric spacecraft trends.

Introduction

Why On-Orbit Refueling?

- Fuel depletion is one of the main constraints that limit spacecraft lifetime (up to 15 years), although payload and electronics could work for double the time.
- Space launch cost nowadays is still high (7-10 k$/kg LEO, 11-30 k$/kg GEO*)
- Refuelable systems would require lower fuel quantity, meaning smaller systems, lower weights and more payload.

*D. E. Koelle, R. Janovsky, Development and transportation costs for space launch systems, DGLR/CEAS European Air and Space Conference, 2007

Fuel transfer system: model

Requirements and **constraints**:

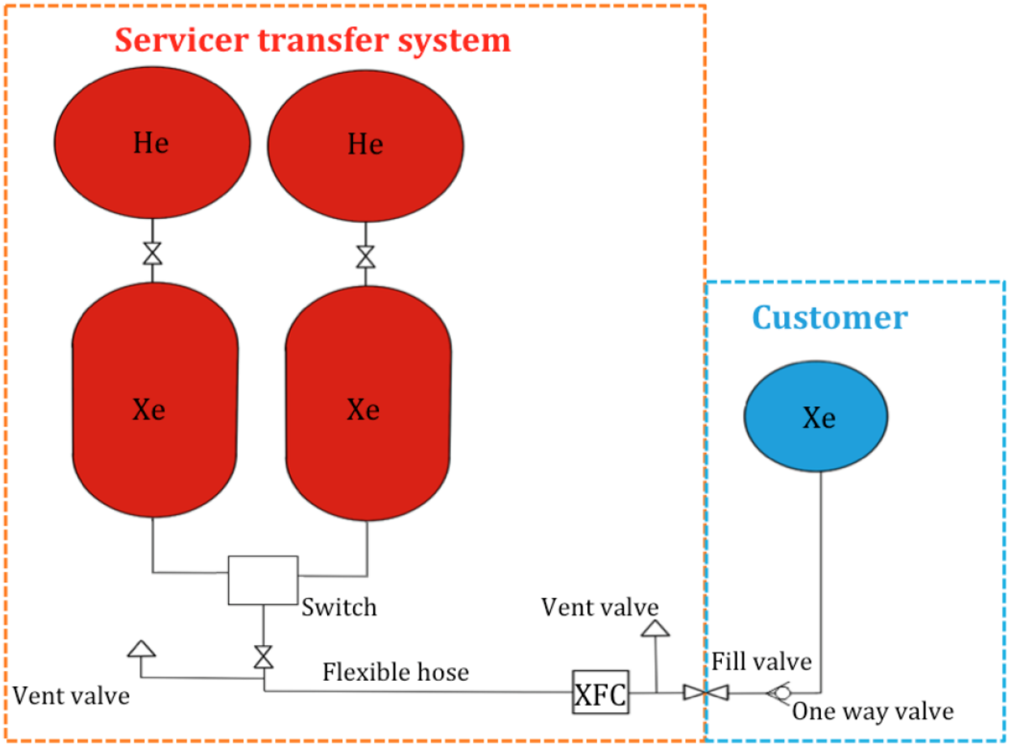
- Xenon kept slightly above critical conditions (289 K, 5.8 MPa)
- Limits on heat power provided by the client
- Minimize transfer time

Transfer strategy: constant **mass flow rate**, controlled by Xenon Flow Controller.

Fuel transfer system: hardware

Fuel transfer is assumed to be **isobaric** and **isothermal**, ensuring a smooth process and preventing phase changes.

- Use of a pressure-regulated system (10 MPa) with helium as pressurant
- Use of active thermal control to keep temperature steady (300 K)

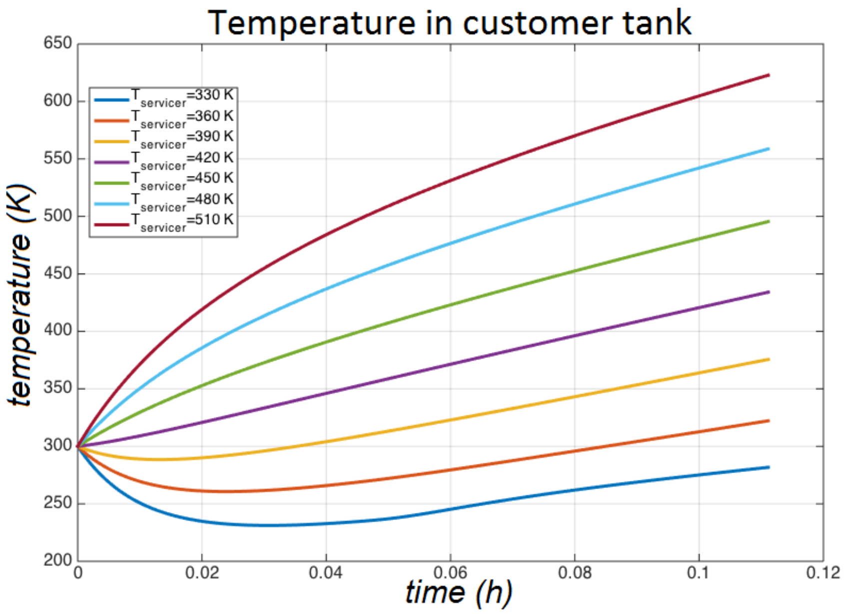


Fuel transfer system: results

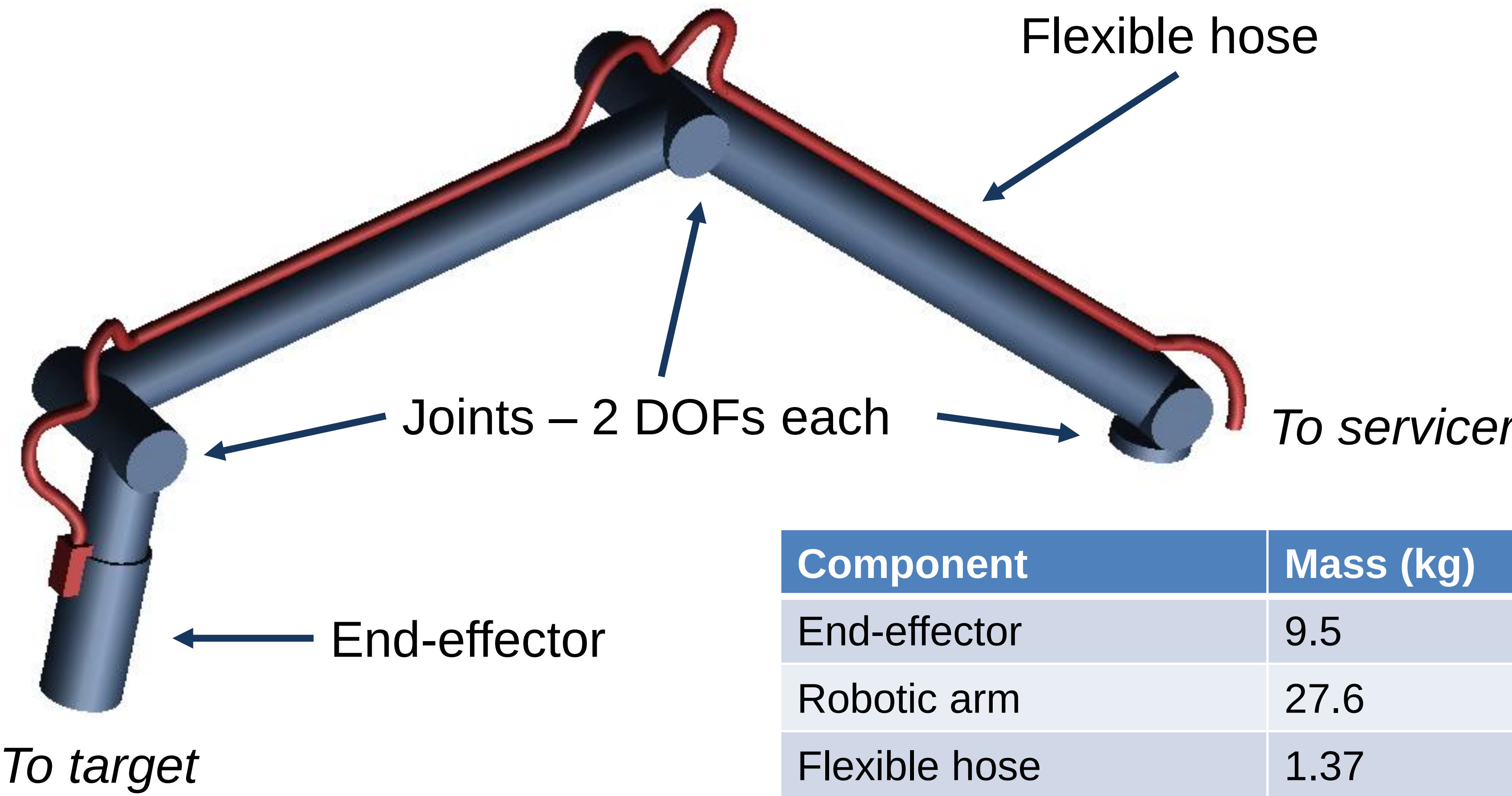
Initial Xenon condition highly affect the transfer, due to its non-linear behavior.

Results are selected to **minimize active thermal control** on servicer's tanks, satisfying the client's tanks thermal requirements.

- Design mass flow rate: 2 g/s
- Heat power request: 5.6 W (per g/s of mass flow rate)
- Critical conditions guaranteed at the end of the transfer



Robotic system: overview



Component	Mass (kg)
End-effector	9.5
Robotic arm	27.6
Flexible hose	1.37

Robotic arm

Tasks:

- Connection between target and servicer
- Fluidic link support

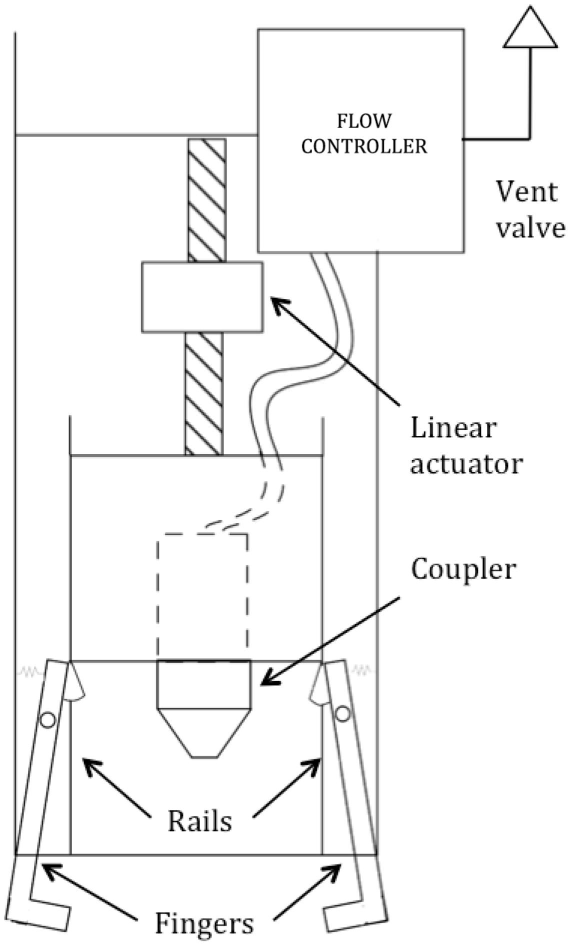
Sizing:

- Good dexterity
- Trade-off between structural and kinematic tasks
- Displacement at tip <0.1 mm
- Strength check at root

End-effector

It **grabs** the interface and provides the **force** to ensure engagement (350 N).

Task	Device
Ensure and maintain valve engagement	Mechanical fingers
Return to initial position in case of malfunctioning	Spring back safety mechanism
Avoid fuel droplets permanence	Vent valve



Validation tests: fuel transfer

Test **assumptions**:

- Mass flow rate actively regulated
- Adiabatic hose

The test shall validate the **numerical simulations**, performing a fuel transfer between two tanks on ground.

Use of **vacuum** chamber is suggested; it is possible to avoid vacuum environment if convective heat exchange is negligible (i.e. the system is insulated).

Validation tests: robotic system

Manipulator:

- Stiffening effect due to fuel passage in the **hose** shall be assessed
- **Dexterity** and capability to reach correct valve position must be tested for various configurations
- Preset paths and autonomous **path planning** have to be validated, seeking accordance to numerical simulations

End-effector:

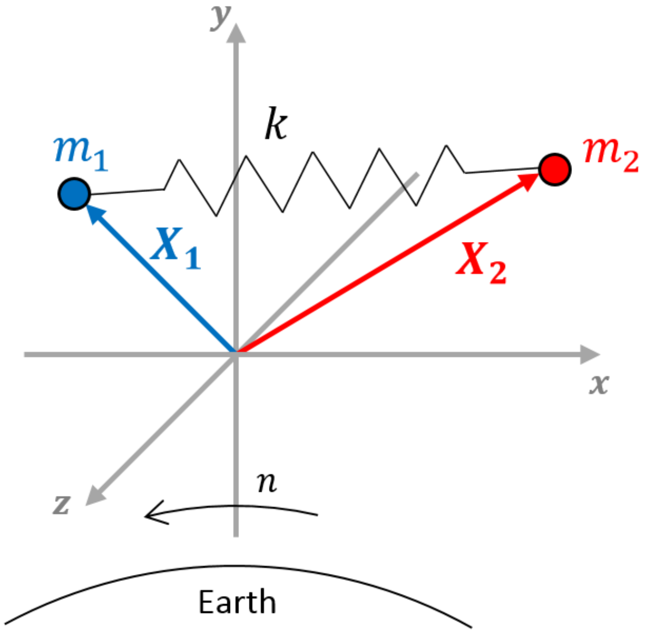
- **Fingers** closure and opening tests shall validate correct and safe operations
- The **force** provided by the actuator must not be transmitted to the arm

In-Orbit Demonstration

The whole system should be tested in-orbit.

Coupled chaser-target dynamics, with flexible interface, shall be validated.

- **Scaling** on LEO microsatellites allows cost reduction
- Off-the-shelf components can be considered
- Effect of small **structural vibrations** shall be compared to linear analysis model



Conclusions

- Feasibility study of an OOR system (Phase A)
- Driving design parameter: **mass flow rate**
- **Criticalities**: autonomous operations, high cost of ground tests, challenges in thermodynamical simulations

Future works

- Consider carbon dioxide for ground tests
- Refinement of pressure and temperature control system
- Evaluate mockup complexity for testing environment

Thank you for your attention!