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Active Space Debris Removal Imitation using Microsatellite Mock-ups on Air Bearing Test Bench "COSMOS"

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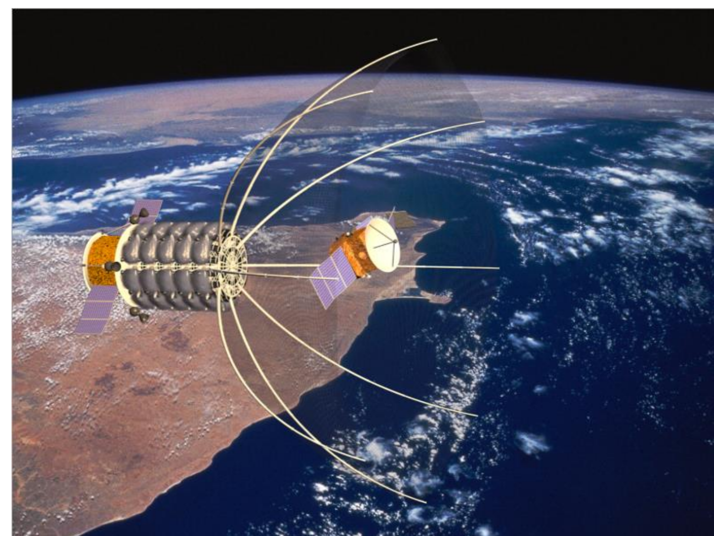
Content

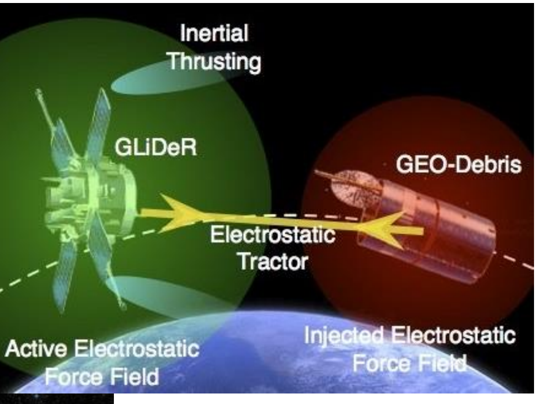
Active Space Debris Removal

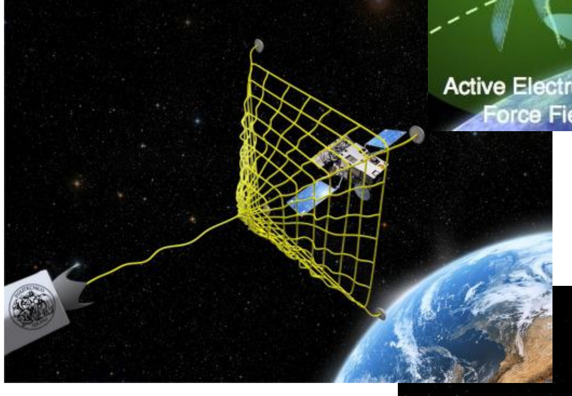
- Active spacecraft with capturing system
- Non-cooperative space debris
- The goal is to capture the debris and change its orbit

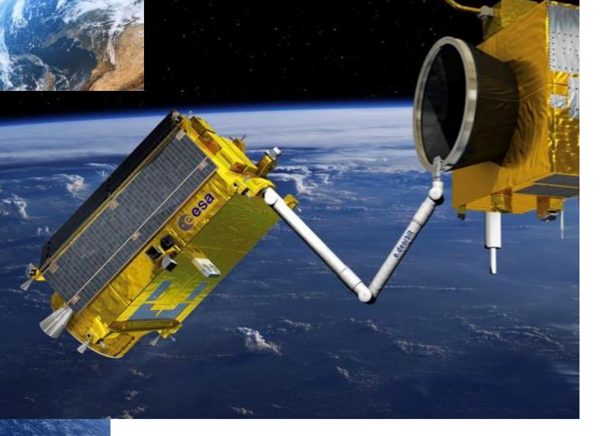


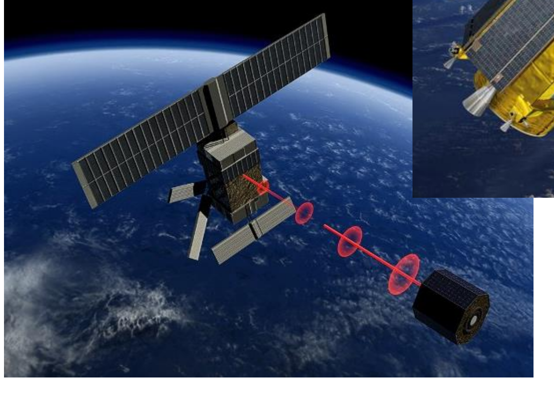
Capturing Systems

- Electrostatic tug
- Net on tether
- Harpoon on tether
- Space robotic manipulator
- Magnetic capture



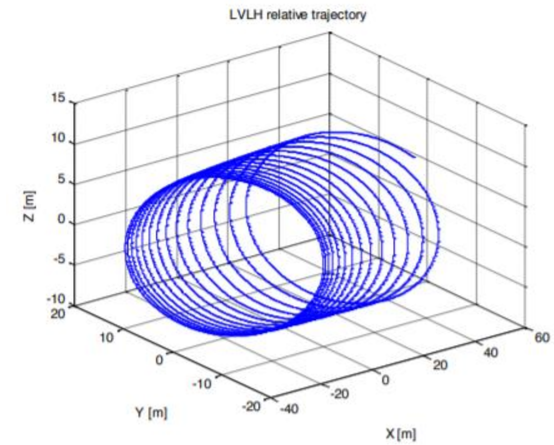




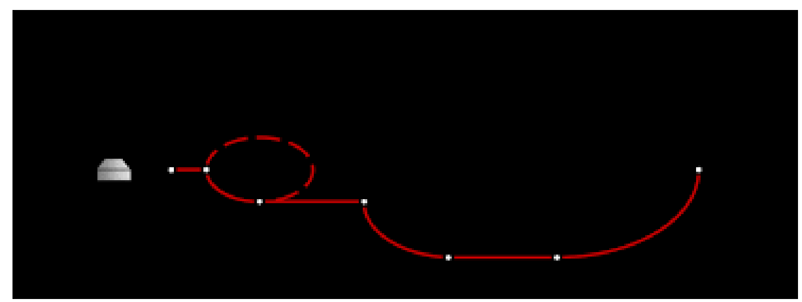


Main Stages of ASDR

- Rendezvous with debris
- Inspection debris motion for its parameters investigation
- Approaching for capturing
- Attitude stabilization after the capturing
- Changing the orbit of the spacecraft-debris system



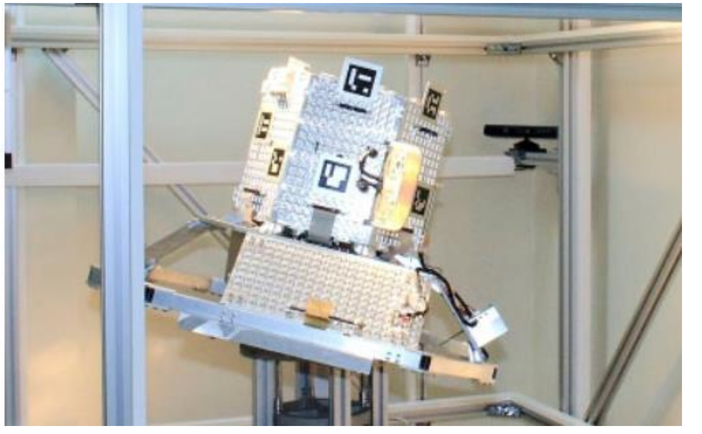
Relative trajectory for inspection



A sequence of relative trajectories during ASDR

Laboratory Testing of Satellite Motion Control Algorithms

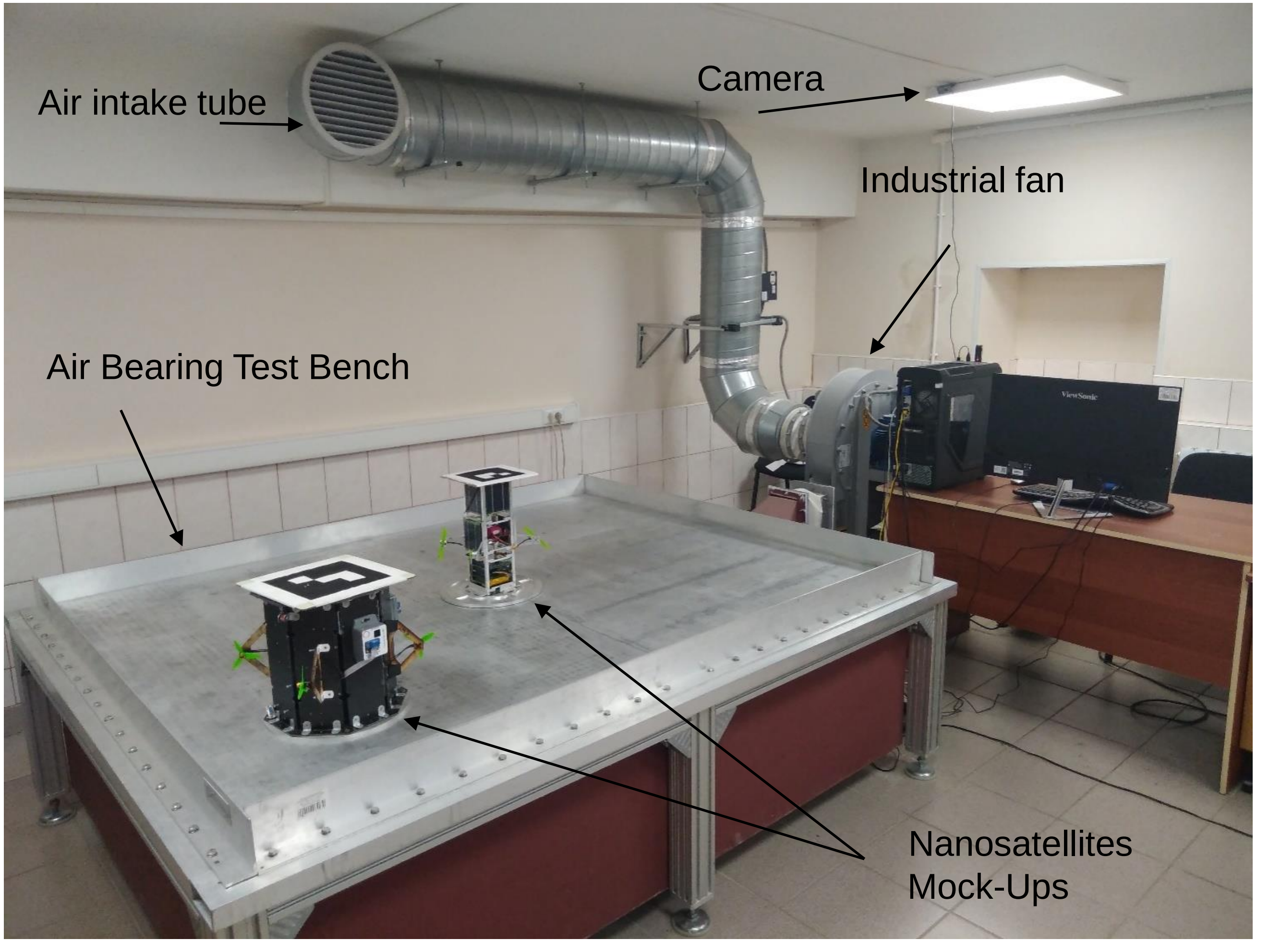
- Special laboratory facilities allows to test motion control algorithms
- There are two types of facilities for
  - Three-axis attitude control system
  - Planar formation motion control system
- In KIAM the planar air bearing laboratory facility is developed



Laboratory facility for attitude motion control (developed by Sputnix Ltd)

Planar air bearing table (developed in University of Surrey)

KIAM Laboratory Facility for Formation Motion Simulation

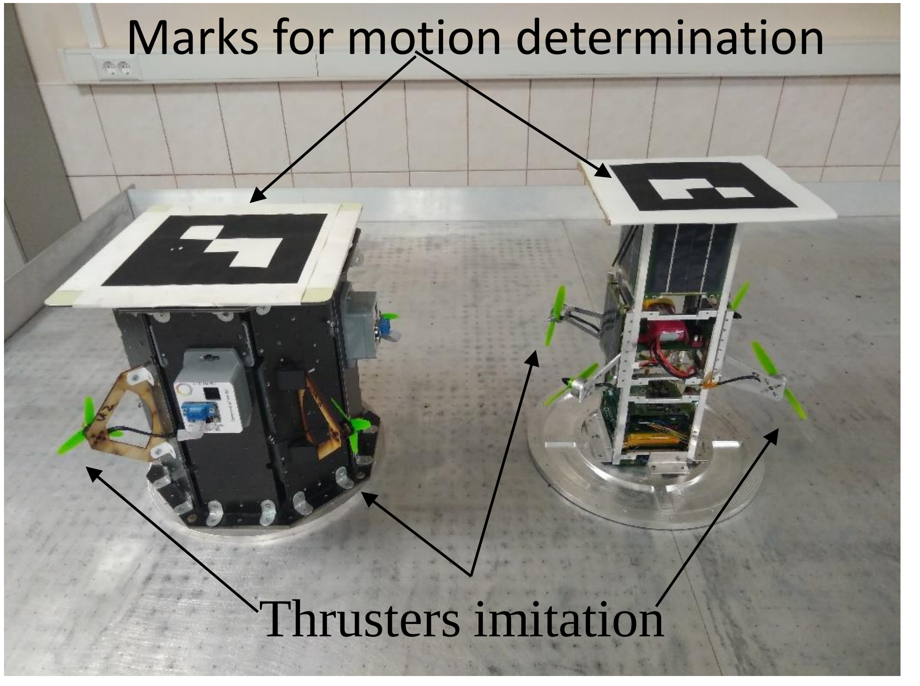


Laboratory Facility COSMOS
(Complex for Satellites MOtion Simulation)

Nanosatellites Mock-Ups

Mock-ups include:

- Onboard computer Raspberry PI
- Power supply system
- Communication system
- Sensors for motion determination
- Actuators:
  - one-axis reaction wheel
  - 4 ventilators imitating thrusters
- Wi-Fi channel



Mock-up based on TabletSat Constructor

Mock-up based on 3U CubeSat

Mock-ups motion model:

$$\ddot{\mathbf{q}} = \mathbf{u} + \mathbf{d},$$

$$\mathbf{q} = \begin{bmatrix} x \\ y \\ \varphi \end{bmatrix} \text{– phase vector, } \mathbf{u} = \begin{bmatrix} u_x \\ u_y \\ u_\varphi \end{bmatrix} \text{– control vector, } \mathbf{d} = \begin{bmatrix} d_x \\ d_y \\ d_\varphi \end{bmatrix} \text{– disturbances}$$

Software for Experiments

Module Sat

- Software for onboard computers
- Sensors measurements processing
- Mock-ups motion control
- Transmission data via Wi-Fi-channel

Module Station

- Software for stationary computer
- Terminal for control of the experiment
- Mock-ups motion determination
- Indications and saving of the experimental results

Mock-Ups Position Determination

From perspective geometry:

$$x = f\,\frac{X}{Z} \qquad y = f\,\frac{Y}{Z}$$

In the pixel reference frame:

$$x = f_x\,\frac{X}{Z} + c_x \qquad y = f_y\,\frac{Y}{Z} + c_y$$

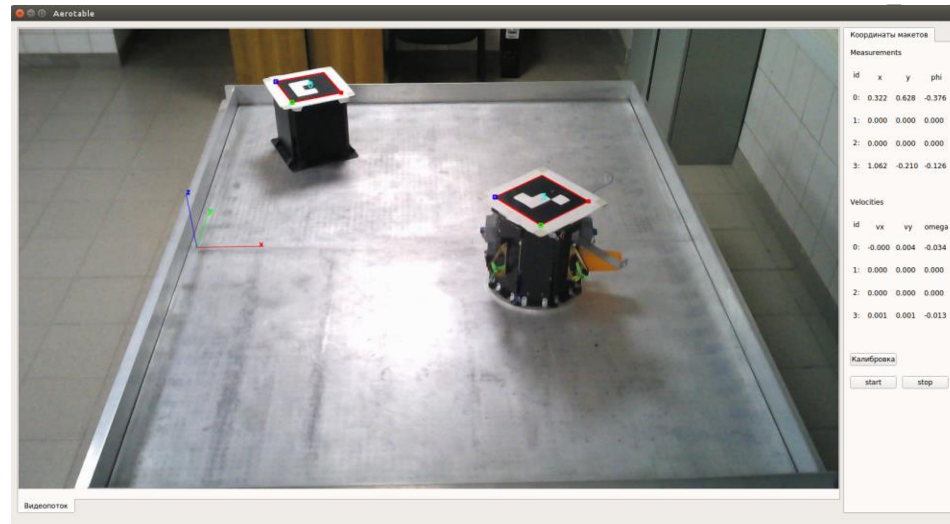
Correction for the pixel size:

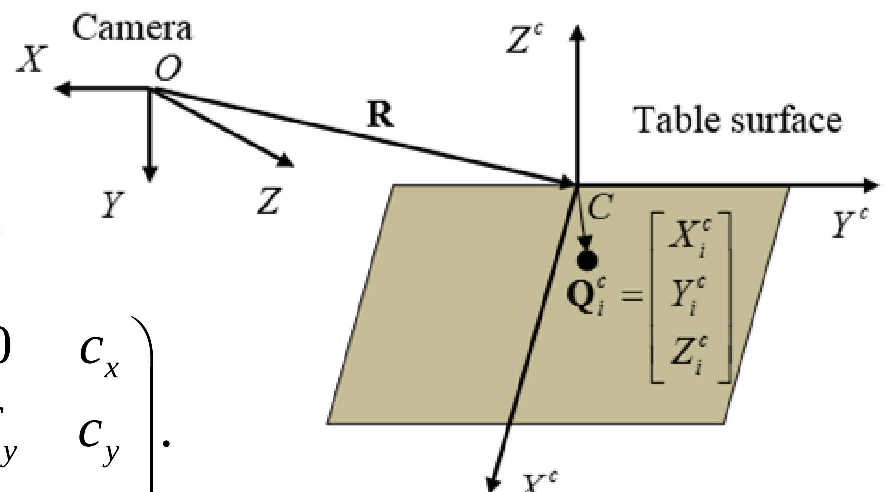
$$f_x = s_x f \qquad f_y = s_y f$$

Ref. point position in matrix form:

$$\mathbf{q}_{corr} = \frac{1}{Z} MA(\mathbf{Q}_{стол} + \mathbf{R}), \quad \text{where}$$

$$\mathbf{Q} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}, \qquad \mathbf{q} = \begin{pmatrix} x \\ y \\ 1 \end{pmatrix}, \qquad M = \begin{pmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{pmatrix}.$$





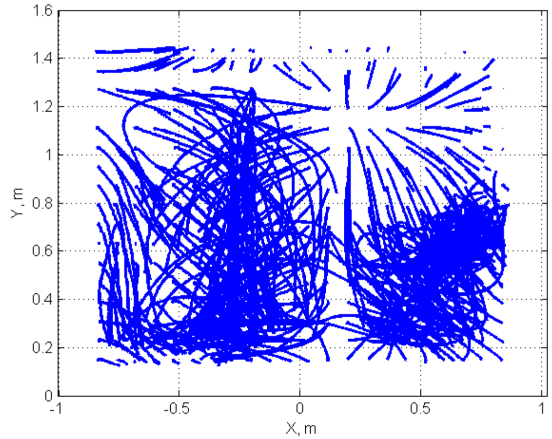
Disturbances on the Table

Sources of the disturbances on the table surface:

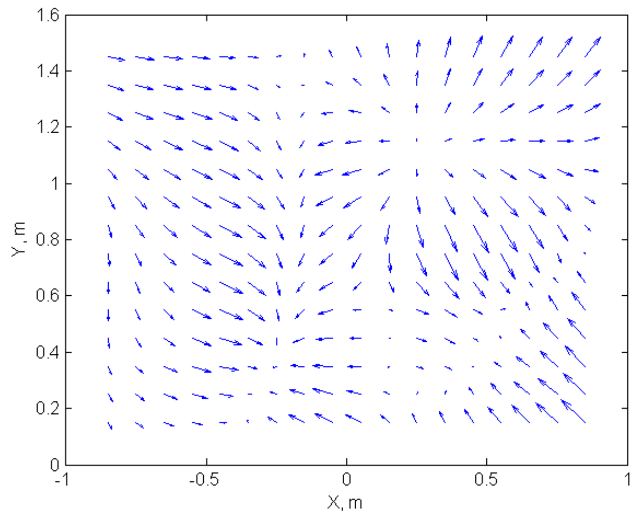
- Gravitational
  - Surface roughness
- Aerodynamic
  - The airflow is not uniform along the surface
  - The air cushion depends on mock-up mass and position of the center of mass

It is possible to estimate disturbances experimentally and take it into account in control calculation

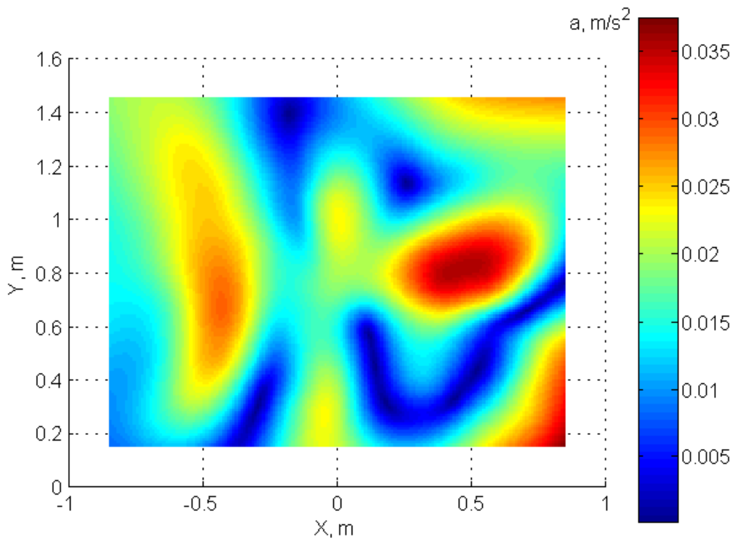
Free motion trajectories of the mock-up on the table surface



Direction of the translational disturbances



Value of the translational disturbances, m/s^2



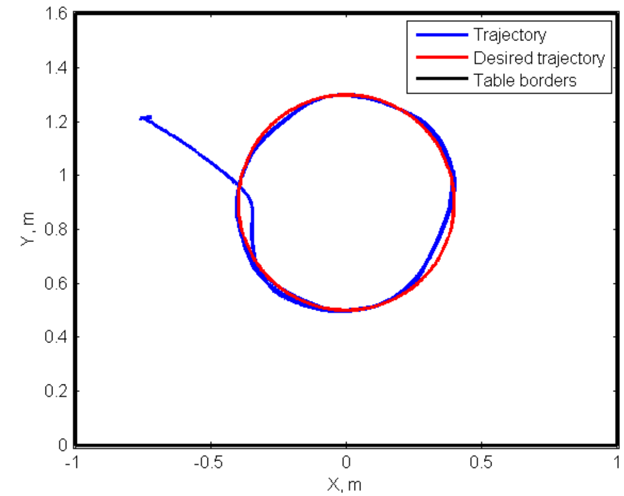
Mock-Ups Control Algorithms

- Mock-Ups tracks the 6 DoF reference trajectories
- Lyapunov-based control is implemented
  - Lyapunov function

$$V = \frac{1}{2}\left(\mathbf{e}_r^T K_1 \mathbf{e}_r + \mathbf{e}_v^T \mathbf{e}_v\right),$$

where $\mathbf{e}_r = \mathbf{q} - \mathbf{q}_d$, $\mathbf{q} = [x, y, \varphi]^T$

  - Control algorithm



Example of tracking circular reference trajectory

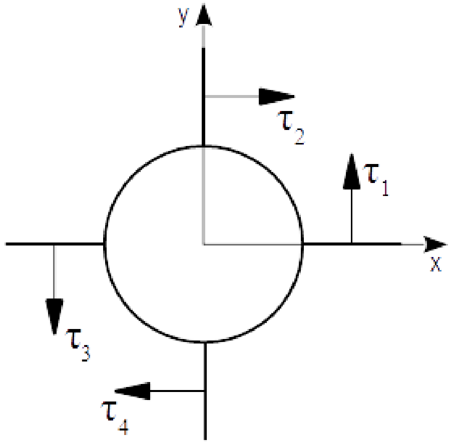
- Control implementation by 4 ventilators

$$\mathbf{u} = -K_1 \mathbf{e}_r - K_2 \mathbf{e}_v + \ddot{\mathbf{q}}_d$$

$$\tau_1 = 0.25\left(T_s / l + 2F_y\right) + \Delta,\ \tau_2 = -0.25\left(T_s / l - 2F_x\right) + \Delta,$$

$$\tau_3 = 0.25\left(T_s / l - 2F_y\right) + \Delta, \tau_4 = -0.25\left(T_s / l + F_x\right) + \Delta,$$

$$\Delta = \left|\min\left(\tau_1 \quad \tau_2 \quad \tau_3 \quad \tau_4\right)\right|$$



Scheme of ventilators placement and control forces

Features of the ASDR Imitation on the Laboratory Facility

Inspection

- Satellite moves along the circular relative trajectory
- Its camera directed to the debris for debris observing

Phasing

- Satellite achieving required position on circular trajectory for docking
- Its attitude track the attitude of the debris

Approaching

- Radial relative trajectory is decreasing until the magnetic catching

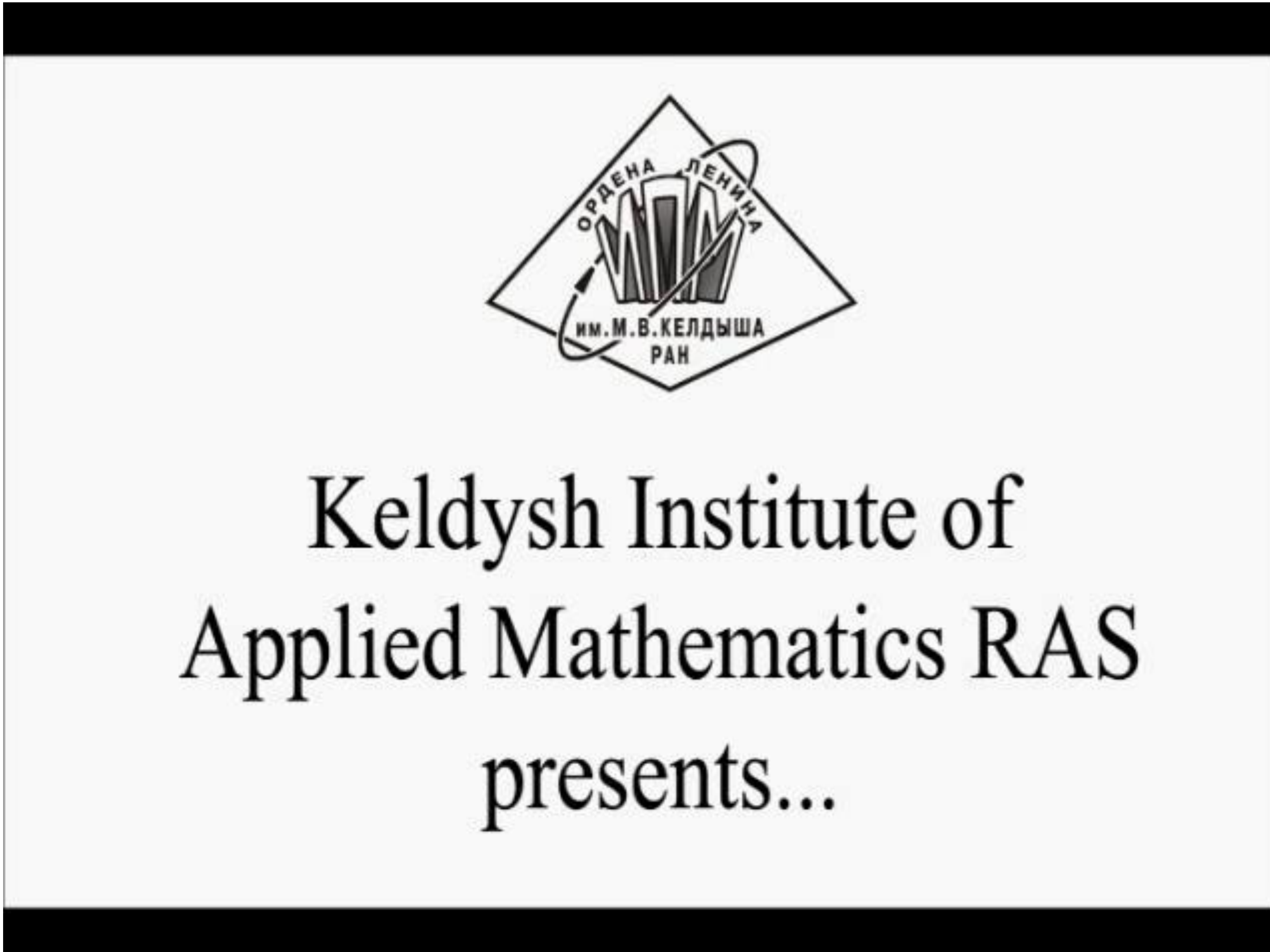
Stabilization

- Angular velocity damping and stabilization after the debris catching

Deorbiting

- Changing the debris position on the table surface

ASDR Imitation Experiment



Conclusion

- Active space debris removal imitation on planar air bearing table requires taking into account laboratory facilities features
- The laboratory experiments helps for deep understanding the ASDR most critical factors for each control stage

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Thank you for attention!