MELISSA

MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

CREATING A CIRCULAR FUTURE

SPREADING AND SLIDING OF CONDENSED AIR HUMIDITY DROPLETS OVER METALLIC SUBSTRATES UNDER NON-ISOTHERMAL CONDITIONS

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AIR DEHUMIDIFICATION IN SPACECRAFT

IN COOPERATION WITH

European Space Agency

Breathing and metabolic moisture of spacecraft crew members

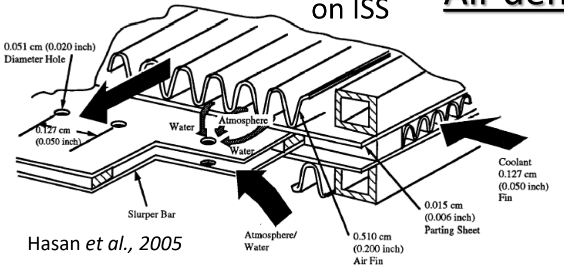
Air humidity accumulates in spacecraft

1) Thermal comfort is affected ➔ deteriorated health and human performance of the crew
2) Bacteria growth is triggered
3) On-board electronic devices can be damaged

Water resources for human consumption, cleaning and experimentation in long term space missions are limited

Water recycling is vital for the viability of a space mission

Condensing Heat Exchanger on ISS



Hasan *et al., 2005*

Air dehumidification due to condensation

Optimize wettability of condenser surface: COATINGS

- ➢ Favor adsorption/ absorption of moisture molecules
- ➢ Allow water condensate repellency and collection

EXISTING CONDENSATION COATINGS

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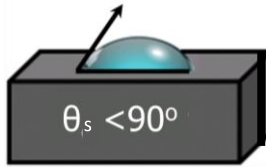
Coatings: 1) Change wettability of the condenser surface, 2) Do not affect thermal conductivity

Filmwise condensation on hydrophilic desiccant coatings



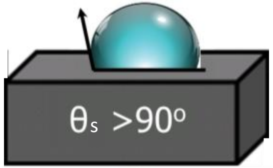
*θ_s: static contact angle

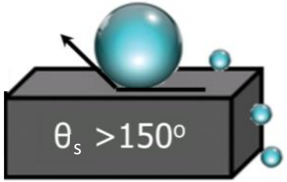
Miljkovic *et al., 2012*

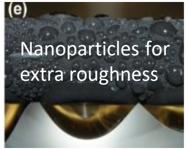
- ✓ Enhanced adsorption of liquid molecules/ High droplet nucleation rate

- X Condensation rate decrease during liquid film formation
- X Low durability

Dropwise condensation on (super)hydrophobic coatings







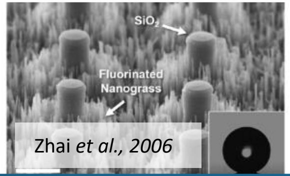
- ✓ Droplets roll on surface
- ✓ Condenser surface is free for heat transfer
- ✓ Higher durability

- X Higher droplet nucleation energy barrier
- X Vapor trapped between droplet and rough coating acts as heat insulation
- X Under high moisture supersaturation droplets collapse (Wenzel state) and form a film

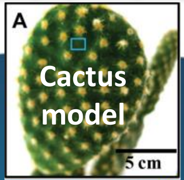
Hybrid hydrophilic- (super)hydrophobic coatings

Bumps attract water

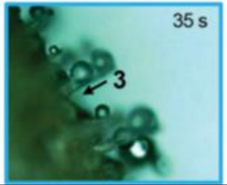
Flat areas repel water



Zhai *et al., 2006*

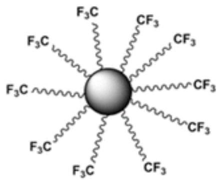


Mondal *et al., 2015*



Droplet nucleation on cactus needles

NEED FOR NOVEL CONDENSATION COATINGS

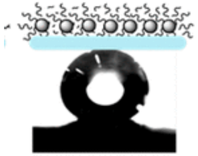


Drawbacks:

1) Superhydrophobic coatings often contain fluorinated compounds.

✓ Hexagonal closed alignment of -CF3 groups offer very low surface energy (<10 mJ/m^2).

X Perfluoroalkyl chemicals (PFAS) are persistent, bioaccumulative and toxic for environment and human body



Shirin et al., 2016

➢ Need to **synthesize fluorine free superhydrophobic condensation coatings**

Rius-Ayra et al., 2020: Coating aluminum plates with lauric acid and magnesium chloride

Kariper, 2021: Polypropylene fibers doped with fumed silica for fog harvesting

2) Durability of coatings is low and not extensively tested.

➢ Need to **test coatings durability** (i.e. with a tape peeling test) **upon accelerated ageing** via **thermal degradation, exposure in high humidity and radiation**, and/or contact with a corrosive liquid.

IN COOPERATION WITH

European Space Agency

'Dehumispace' RESEARCH PROJECT

'NOVEL APPROACH TO AIR DEHUMIDIFICATION PROCESSES FOR SPACE EXPLORATION'

Contract No: 4000136753/21/NL/GLC/my

Cofunded by: *European Space Agency & Aristotle University of Thessaloniki*

Duration: 02/2022 – 02/2024

Technical Officer: *Dr. Sebastien Vincent - Bonnieu*

Principal Investigator: *Prof. Thodoris Karapantsios*

Development of **novel, fluorine free, highly durable, superhydrophobic and water repellent coatings** that improve the dehumidification of air in spacecrafts.

Stage 1

Synthesis & Characterization of coatings

1) Select **fluorine free resins**
2) Prepare **resin dispersion**
3) **Spraying** on solid substrates
4) **Drying/ Curing**

Stage 2

Coatings treatment/ageing

- Thermal cycling (0-100°C)
- Humidity exposure (95%RH)
- UV/VUV exposure (5-10SC)

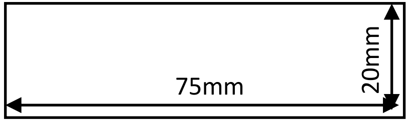
Stage 3

Characterization of treated coatings

- Surface morphology
- Thermal properties
- Wetting properties
- Durability

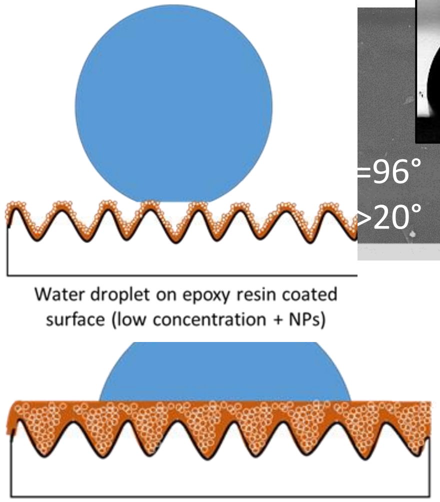
'Dehumispace' PRELIMINARY SYNTHESIS ATTEMPTS

Solid substrates: copper, aluminum, stainless steel



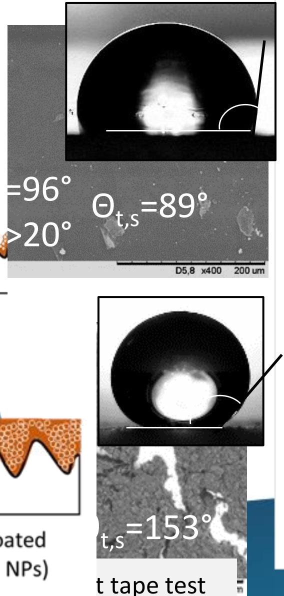
2mm width

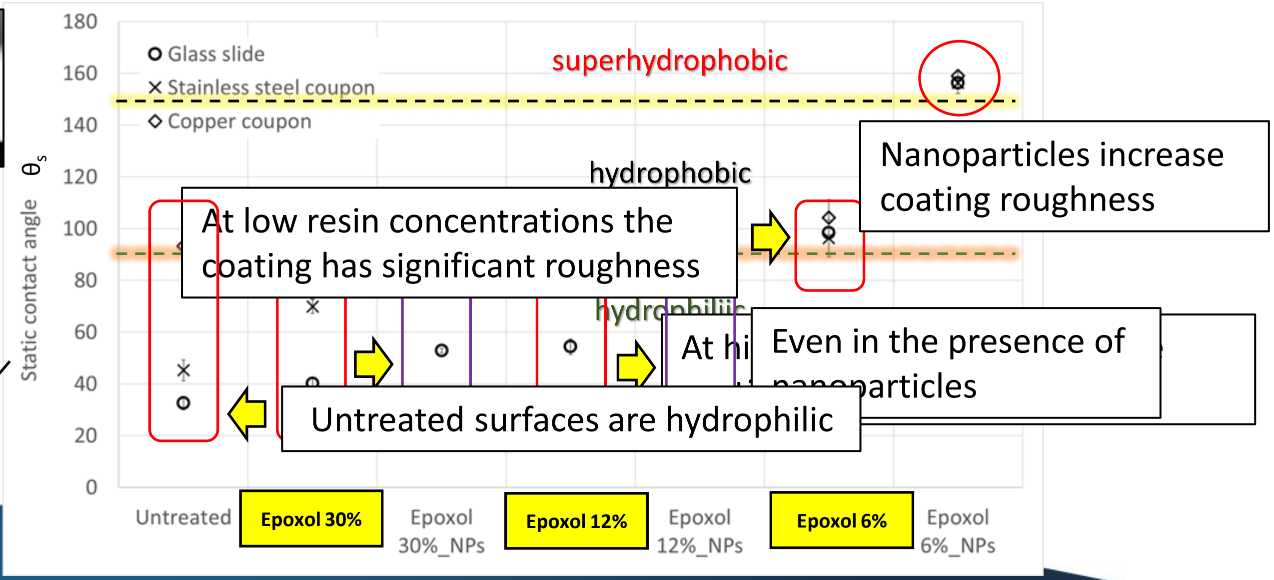
Synthesis	monomer/oligomers (5-30% w/w)	solvent (55-95% w/w)	nanoparticles (0-3% w/w)
	silanes/siloxanes, vinylicss, hyperbranched, dendrimeric and epoxy oligomers	ethanol, ethyl acetate	$Ca(OH)_2$, SiO_2



Water droplet on epoxy resin coated surface (low concentration + NPs)

Water droplet on epoxy resin coated surface (high concentration and NPs)





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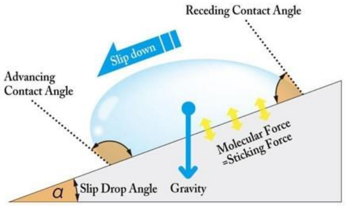
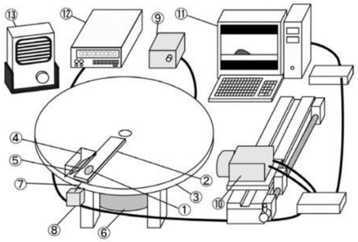
KERBEROS device concept

Tilted plate

Centrifugal setups





KERBEROS

To examine wetting/sliding behavior of droplets by combining **rotation** and **tilting** body forces for any droplet volume. Monitoring in **3 directions XYZ** and allowing 3D reconstruction of the droplet.

-Independent control of the normal and tangential forces

-Precise and complete monitoring of the phenomena

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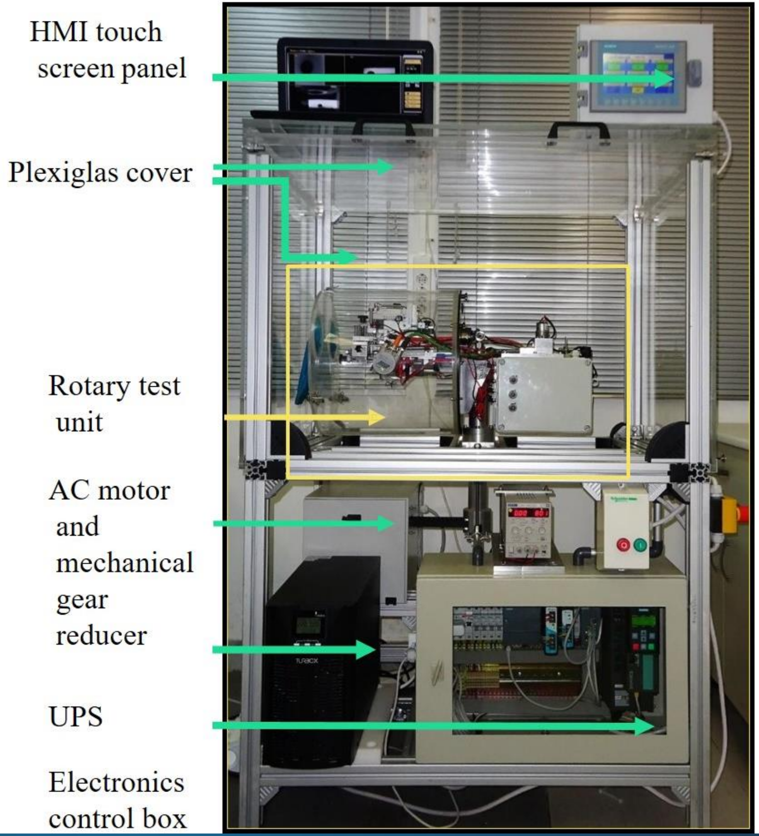
KERBEROS device overview



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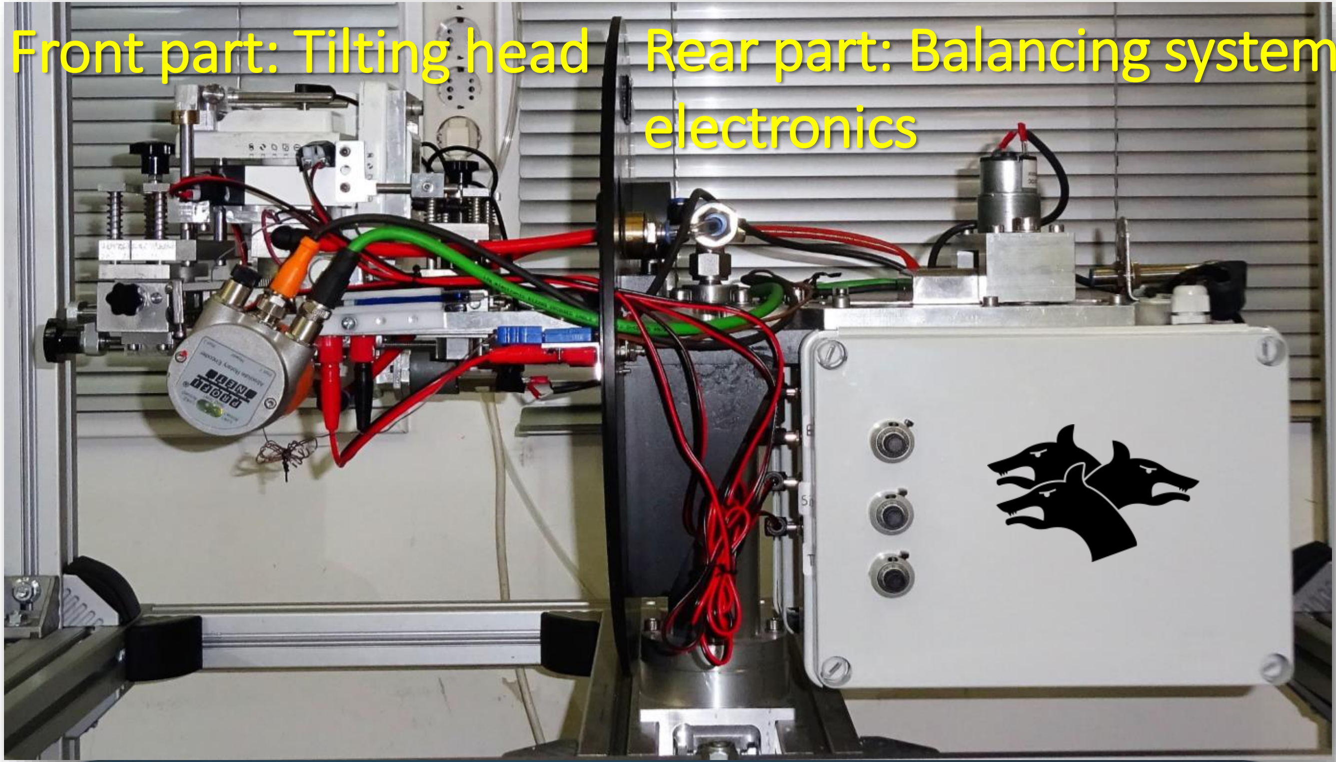
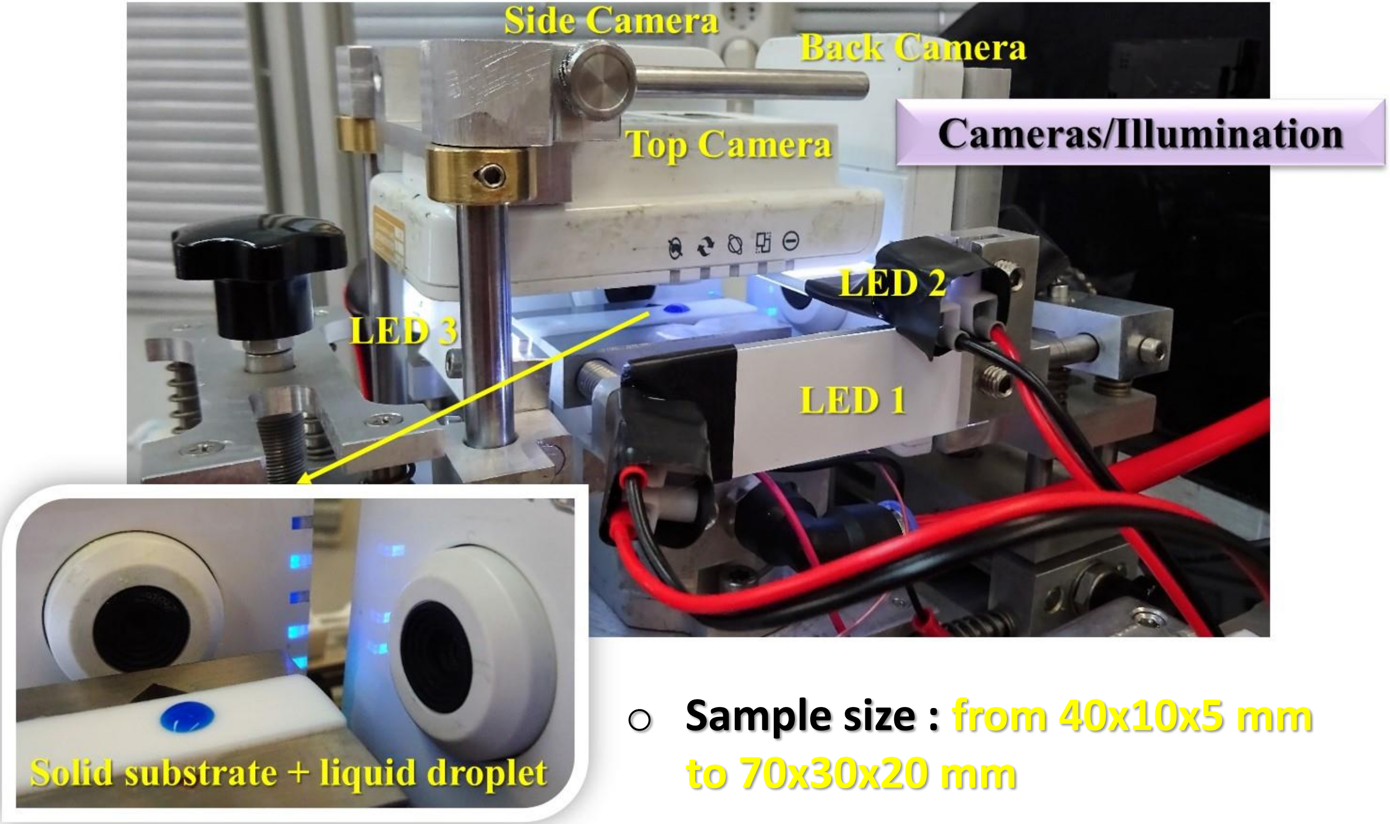
KERBEROS rotary test unit



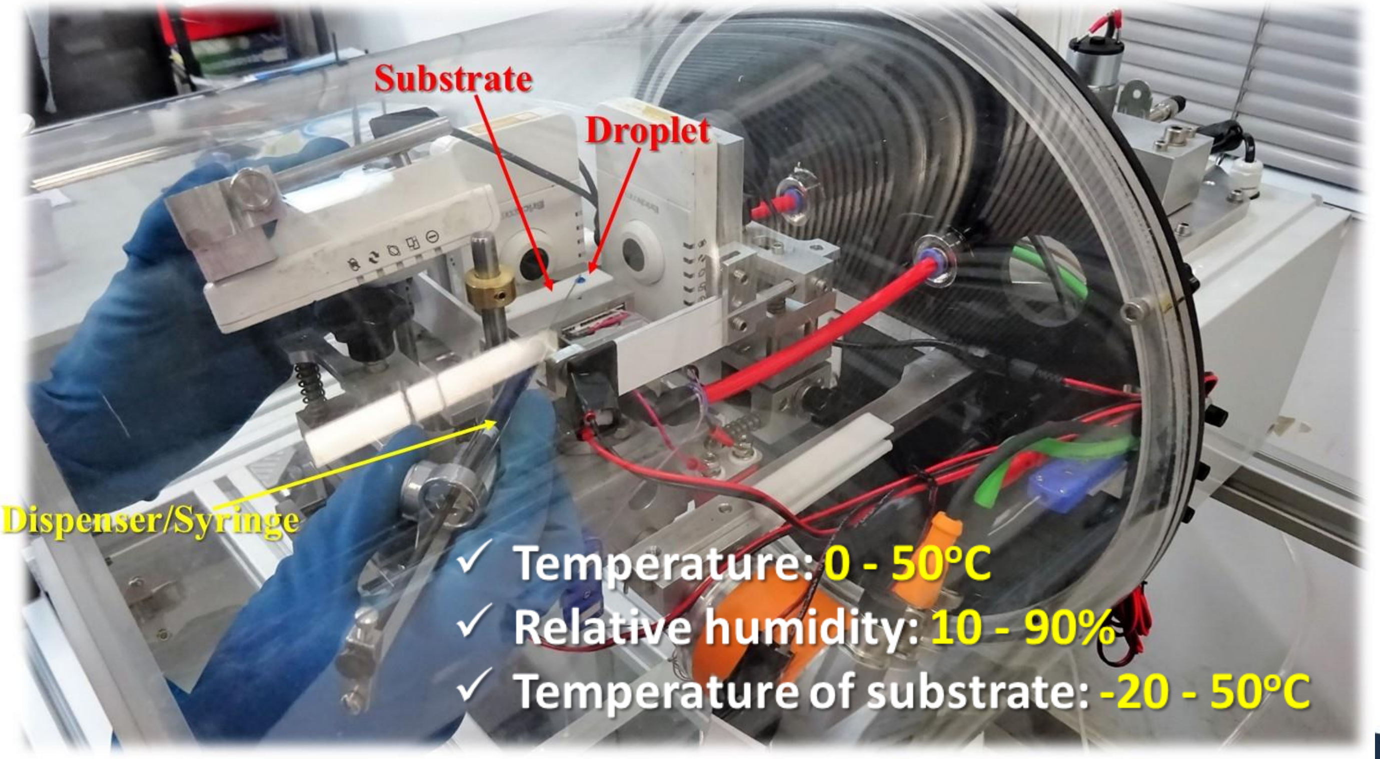
'Dehumispace' PRELIMINARY WETTING TESTS



- Sample size : from 40x10x5 mm to 70x30x20 mm

'Dehumispace' PRELIMINARY WETTING TESTS

Droplet deposition



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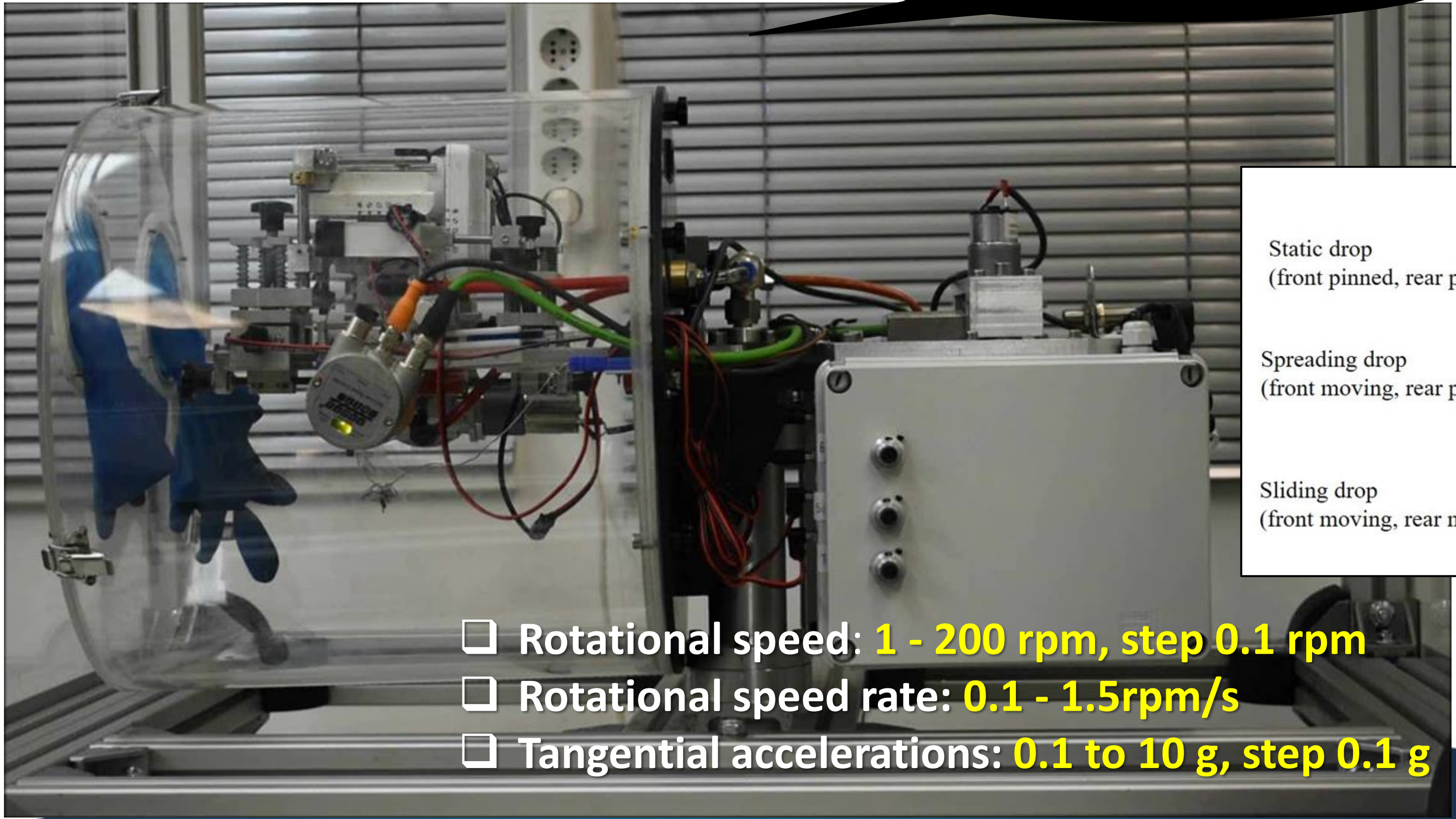
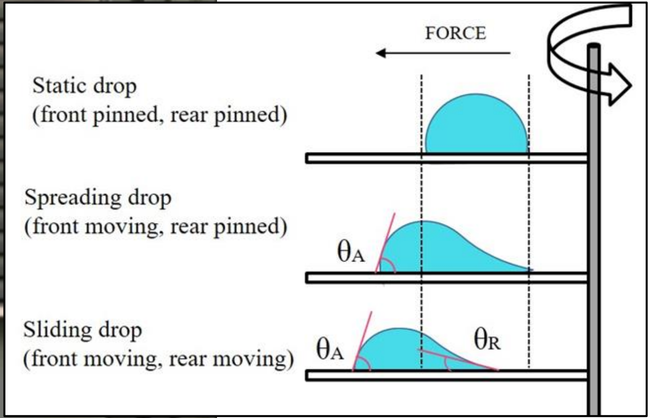
Rotation: 1-50 RPM





- ❑ Rotational speed: 1 - 200 rpm, step 0.1 rpm
- ❑ Rotational speed rate: 0.1 - 1.5rpm/s
- ❑ Tangential accelerations: 0.1 to 10 g, step 0.1 g

'Dehumispace' PRELIMINARY WETTING TESTS

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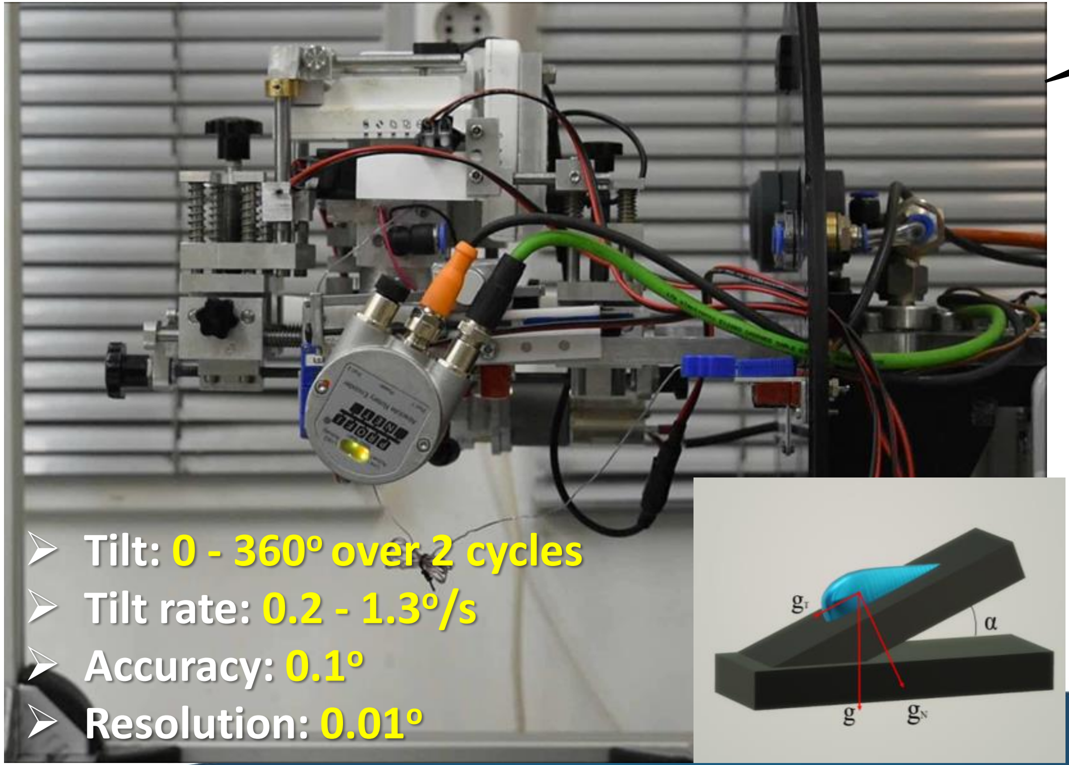
Front part: Tilting

Tilting: 1-260º



- Tilt: 0 - 360º over 2 cycles
- Tilt rate: 0.2 - 1.3º/s
- Accuracy: 0.1º
- Resolution: 0.01º

Rear part: Balancing system movement

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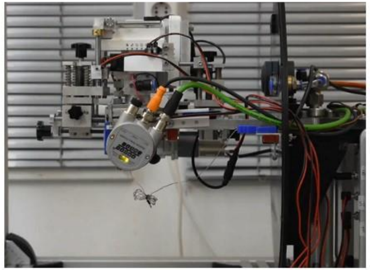
‘Dehumispace’ PRELIMINARY WETTING TESTS

Experimental Protocol

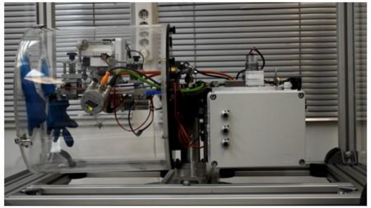
INPUT

HMI interface

Tilting



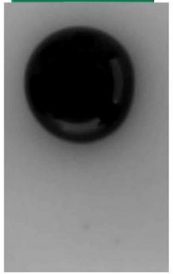
Rotation



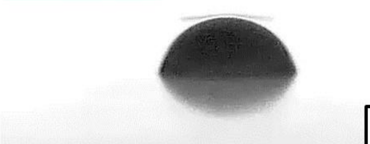
OUTPUT

Side view

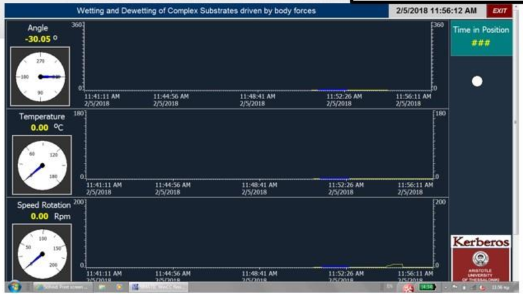
Top view



Back view



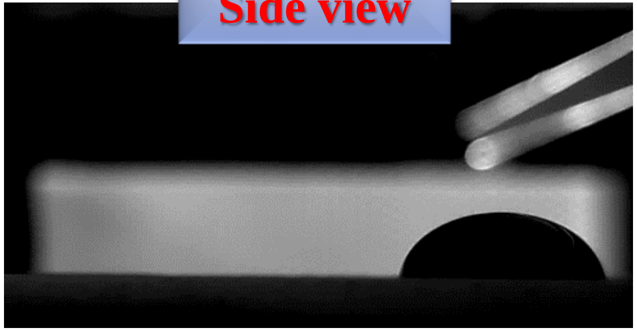
Scada recording



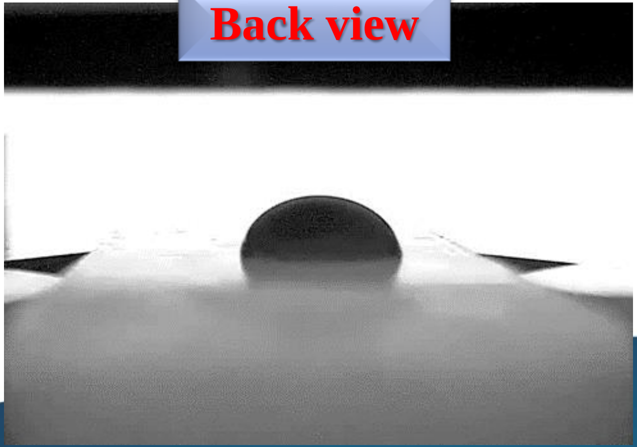
'Dehumispace' PRELIMINARY WETTING TESTS

Raw data

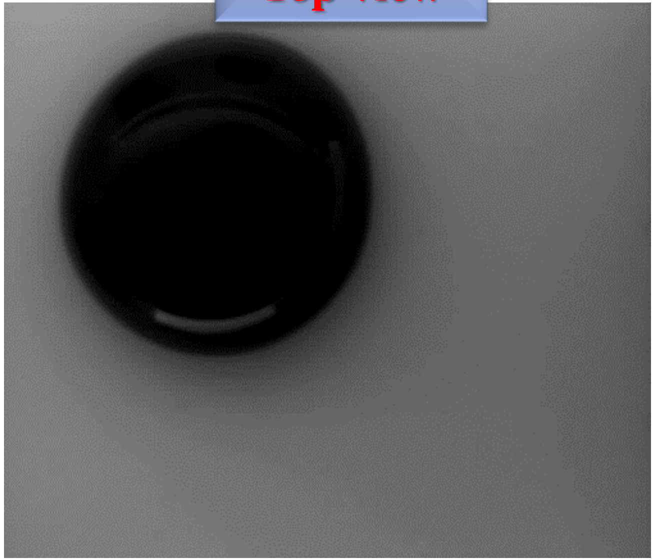
Side view



Back view

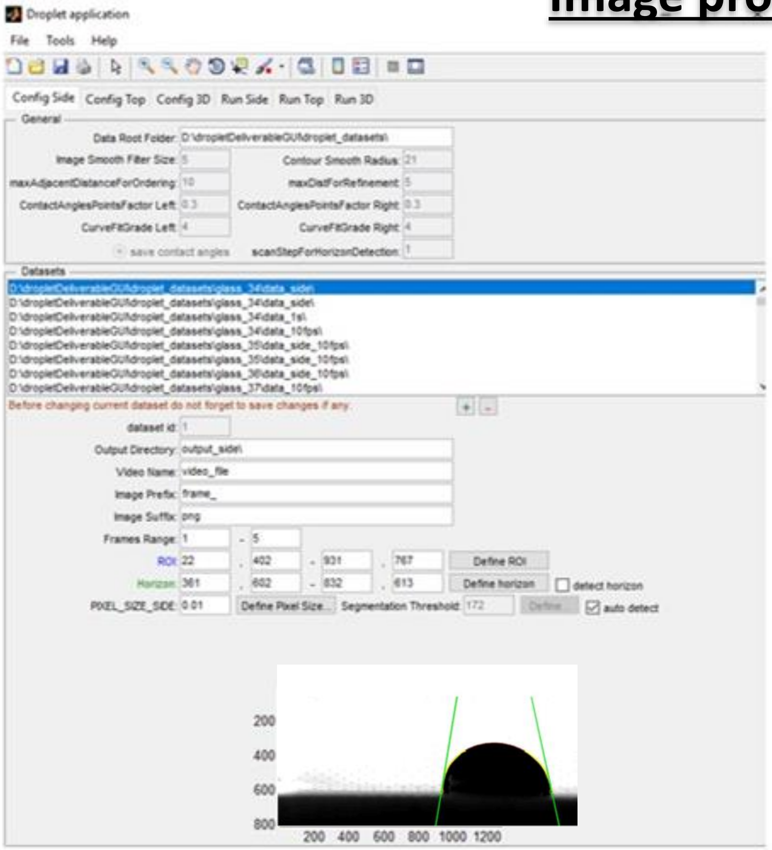


Top view

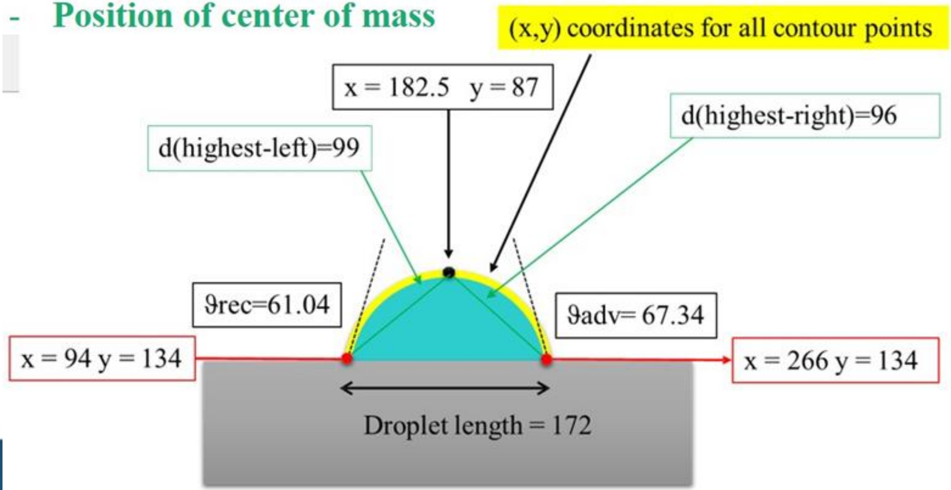


'Dehumispace' PRELIMINARY WETTING TESTS

Image processing software



- Contact angles
- Length
- Edges position
- Height
- Highest point
- Coordinates for all points
- Position of centroid
- Position of center of mass



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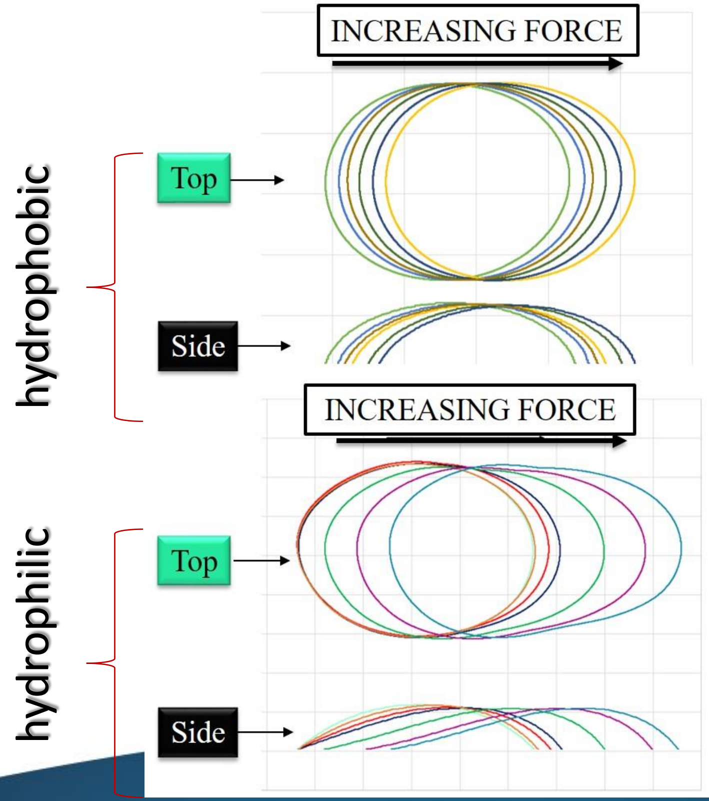
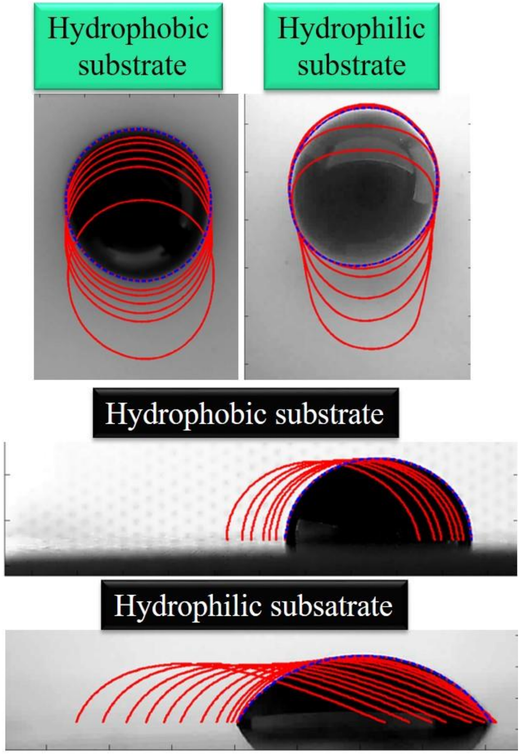
European Space Agency

Analysis of droplet contour





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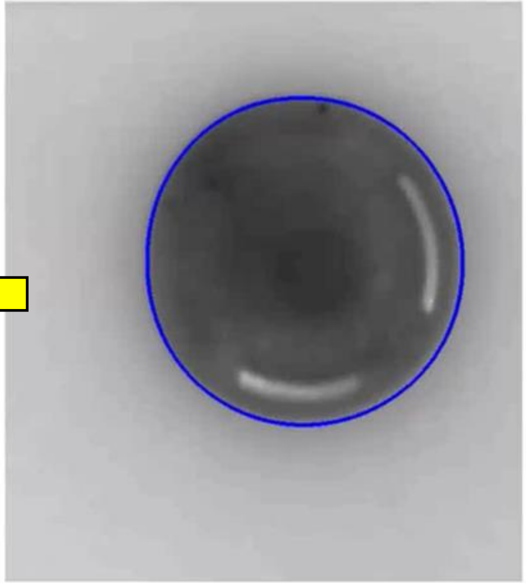
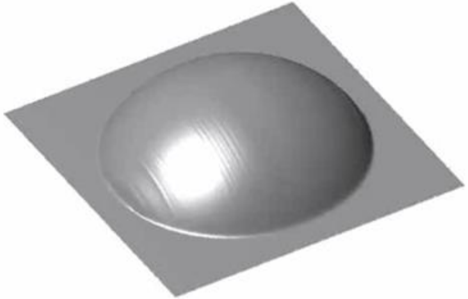
Droplet 3D reconstruction

Top view



Side view

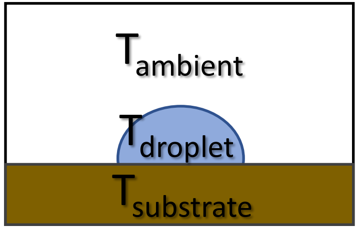
3D view



'Dehumispace' PRELIMINARY WETTING TESTS

IN COOPERATION WITH esa European Space Agency

Is wetting affected by temperature of the three phases?



In isothermal conditions:

$T_{ambient} = T_{droplet} = T_{substrate}$

During CONDENSATION (in non-isothermal conditions):

$T_{ambient} = T_{droplet} > T_{substrate}$

Test rotation speed: 30-70 rpm

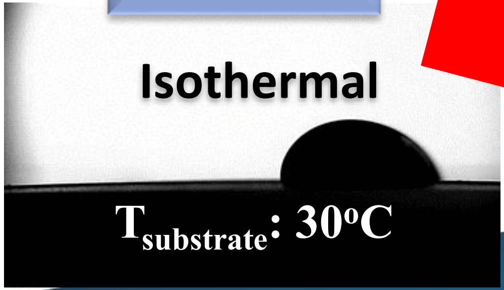
Rotation speed increase: 1rpm/s

$T_{ambient}$: 30°C

$T_{droplet}$: 30°C

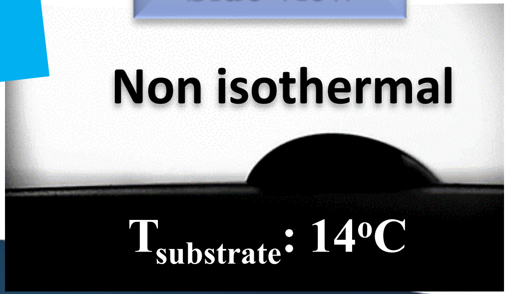
Top view

Side view



Substrate: Uncoated Copper

Side view



Top view

‘Dehumispace’ PRELIMINARY WETTING TESTS

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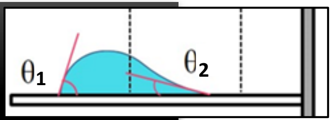
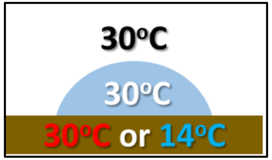
Wetting under rotation

Comparison of isothermal & non-isothermal conditions

- θ_1: front contact angle
- θ_2: rear contact angle
- Rotation speed increase: 1rpm/s

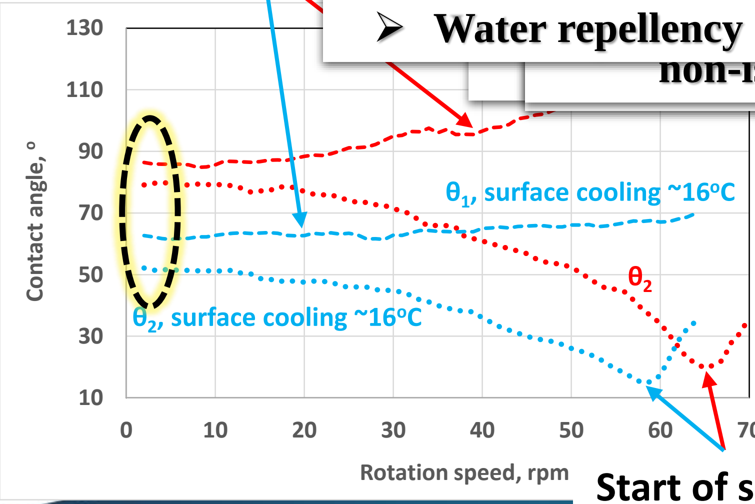




➢ Water repellency is favored during condensation

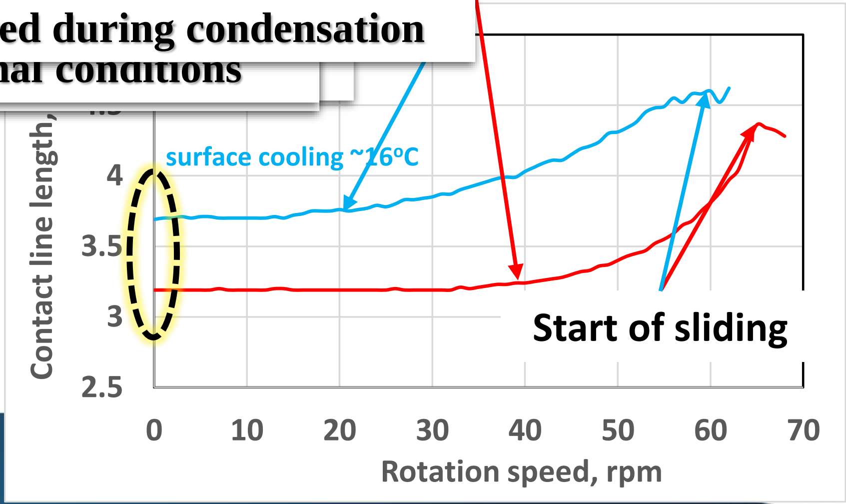
non-isothermal conditions

Start of spreading



Start of sliding

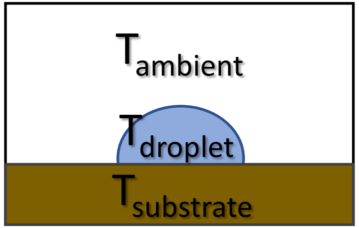
Start of spreading



Start of sliding

'Dehumispace' PRELIMINARY WETTING TESTS

Is wetting affected by temperature of the three phases?



In isothermal conditions:

$T_{ambient} = T_{droplet} = T_{substrate}$

During CONDENSATION (in non-isothermal conditions):

$T_{ambient} = T_{droplet} > T_{substrate}$

Test tilting angle: 30-90º

Tilting increase: 1º/s

$T_{ambient}$: 30ºC

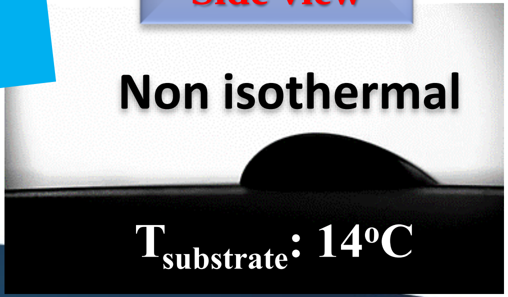
$T_{droplet}$: 30ºC

Top view

Side view

Substrate: Uncoated Copper

Side view

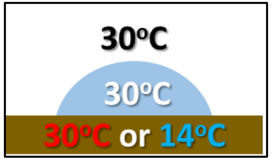


Top view

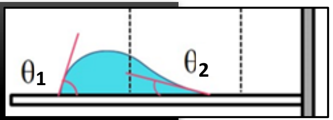
'Dehumispace' PRELIMINARY WETTING TESTS

Wetting under tilting

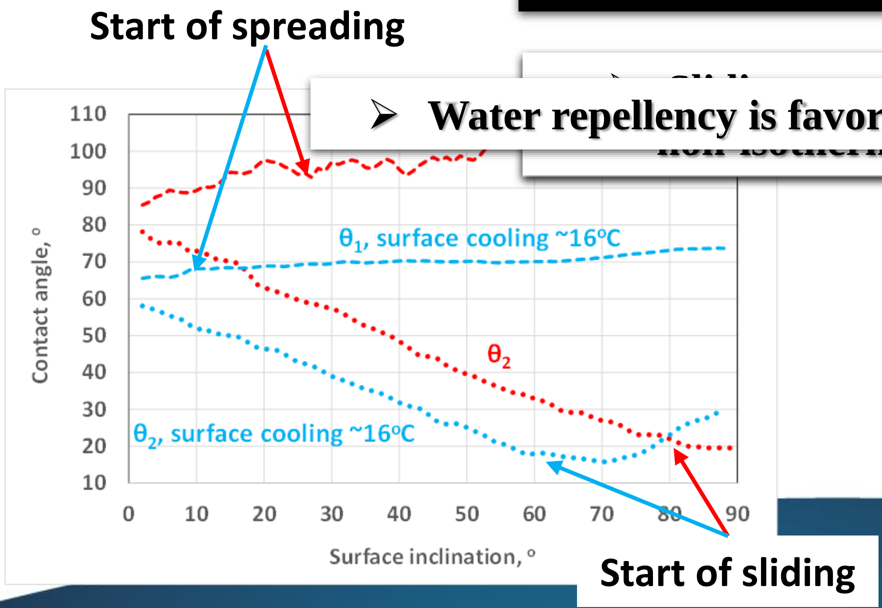
Comparison of isothermal & non-isothermal conditions

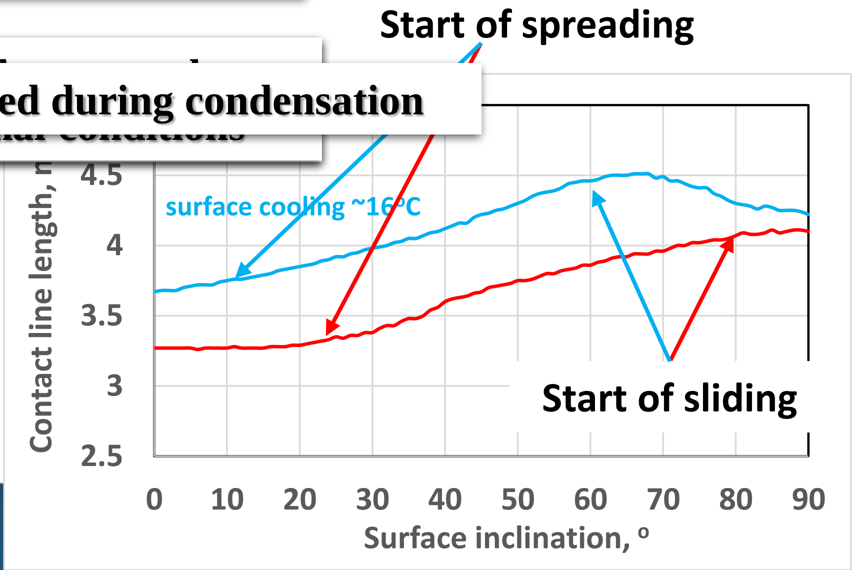


- θ_1: front contact angle
- θ_2: rear contact angle
- Tilting increase: 1°/s



- ➢ **Water repellency is favored during condensation**



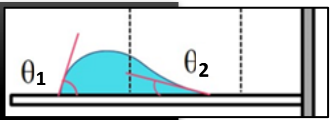


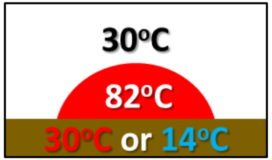
'Dehumispace' PRELIMINARY WETTING TESTS

Wetting under tilting

Non-isothermal conditions, low and high ΔT

- θ_1: front contact angle
- θ_2: rear contact angle
- Tilting increase: 1º/s

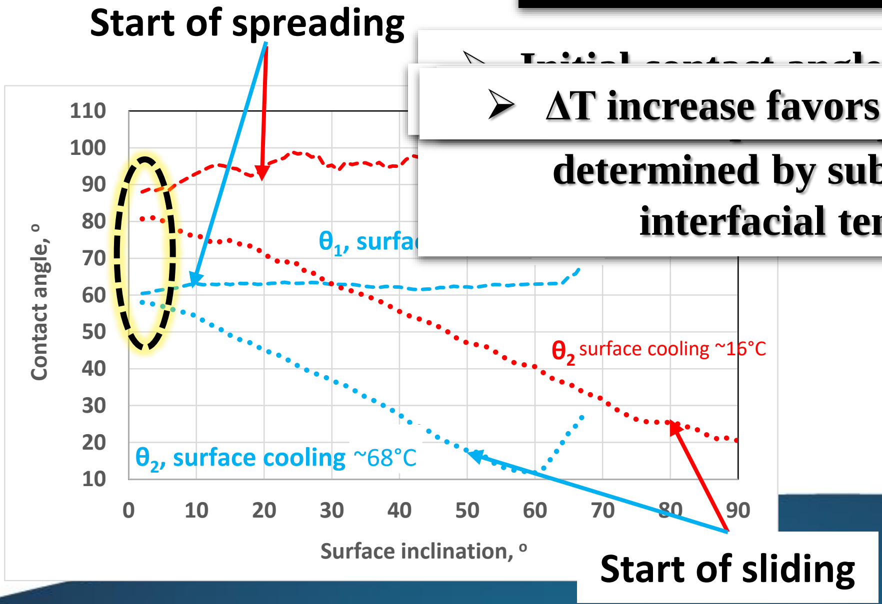


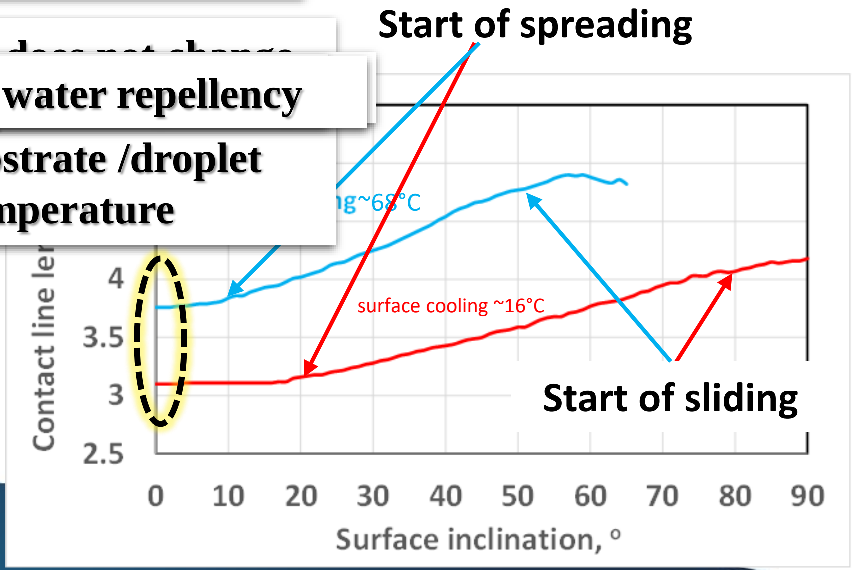


➢ Initial contact angle does not change

➢ ΔT increase favors water repellency

determined by substrate /droplet interfacial temperature





CONCLUSIONS

- Primary synthesis attempts for novel, fluorine free, highly durable, superhydrophobic & water repellent coatings as condenser surfaces for air dehumidification in spacecraft.
- The addition of nanoparticles promote surface roughness and superhydrophobicity at low monomer concentrations.
- Preliminary surface wettability tests using Kerveros tilting & centrifugal device . Dynamic contact angle measurements under external normal & tangential body forces, to simulate condensation conditions.
- Temperature at the liquid/solid interface affects surface static contact angle, spreading and sliding behavior.
- Droplet spreads more on a cold substrate. Liquid film formation hinders heat transfer & condensation.
- During condensation, cold substrate accelerates droplet spreading and sliding, thus favors water repellency.

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