Russia
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Conditions for the emergence and growth of aeolian sand structures

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A chat line NP1.1

14-18 on Monday May 4

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Introduction

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Distance between particles
Surface roughness

2. Airflow near surface particles

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The influence of the air flow of a particle in a layer with a change in the distance

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Introduction

One of the important characteristics of the wind process of dust removal is a critical or threshold wind velocity [1]. Saltating flow grows with increasing of the effective roughness [2] that affecting shear stress and friction velocity [3]. The drag coefficient increases depending on the density of the coating by particles of the surface [4]. The location of particles in the aeolian structure, their size and relative position determine their resistance to wind. Aeolian structures change the structure of flows and the balance of mass transfer of particles deposited and rising from the surface [5]. The surface microstructures and ripples significantly affect of sand removal.

1 Shao Y. Physics and modeling of wind erosion. Springer.2008.p.452.
2 Martin R.L., Kok J.F. J.Geophys.Res.2018.**123**(7).1546-1565.
3 Turpin C et al. Earth Surf. Proc. and Land.2010.**35**(12). 1418-1429.
4 Yang X.I.A. et al. J. Fluid Mech.2019.**880**. 992-1019.
5 Luna M.C.M.M. et al. Geomorph.2011.**129(**3-4). 215-224.

1. Flow under surface particles

Scales, velocities

Particle size 2 · 10^{-4} m.

Aeolian structures:

micro-ripples mm-cm,

ripples from 3 cm,

dunes from 1 m.

Velocities according to experimental data [6]:

z, mm	Wind velocity over various elements of the shape of the aeolian ripples, m/s			
	over the slope	over the crest	behind the crest	at the bottom
0,5	2,8	2,8	1,2	2,1
1,5	3,1	3,1	2,1	2,3
z_0, см	0,002	0,002	0,01	0,01
u_*, м/с	0,24	0,25	0,32	0,31

[6] Semenov O.E. Introduction to experimental meteorology and climatology of the sand storms. Almaty. 2011. p.580 (in Russian).

Scales, velocities

Re~1-8

Vortices of 3-3000 mcm with a lifetime 0,64-0,86 c (sometimes up to 5,26 c)

1. Flow under surface particles

Distance between particles

Investigation of the influence of surface structure inhomogeneities (the presence of different distances between particles D_s)

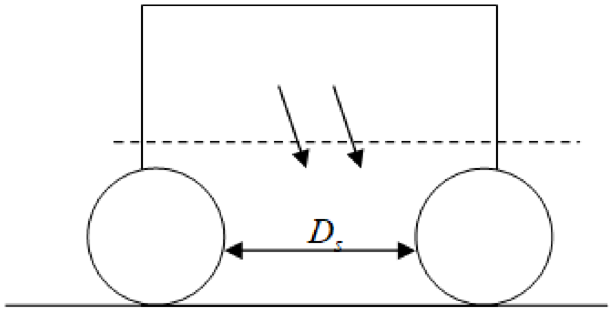
Volume fraction of voids in the layer

Sand porosity $\varepsilon_R = 0{,}33$:

$$\varepsilon = 1 - \tau = 1 - \frac{\rho_s}{\rho_p}$$

Particle spacing varies [7]

$$D_s \approx (0{,}07 - 0{,}11)d$$



[7] Malinovskaya E.A. Numerical simulation of surface flow. Trudy ISP RAN/Proc. ISP RAS, vol. 31, issue 6, 2019. pp. 225-236 (in Russian). DOI:10.15514/ISPRAS-2019-31(5)-15 https://elibrary.ru/item.asp?id=42386539

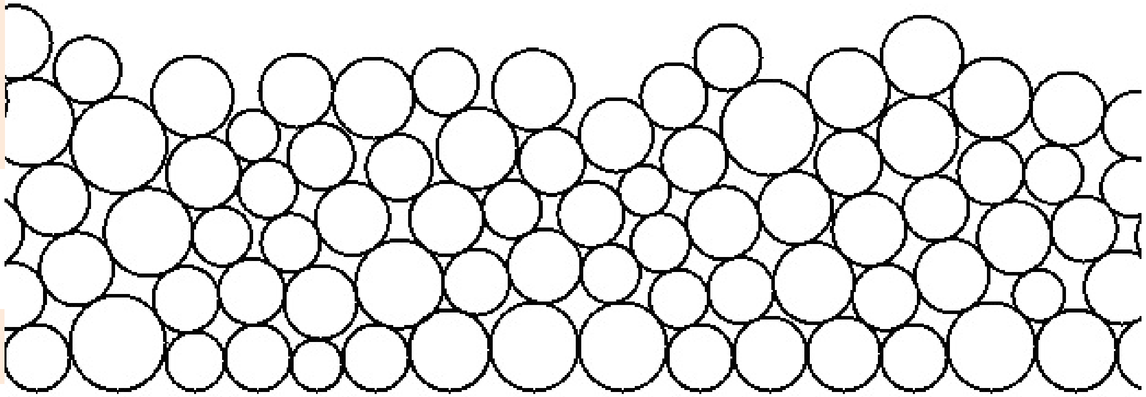


Fig. 1. The result of numerical generation of randomly located particles whose sizes correspond to the normal distribution.

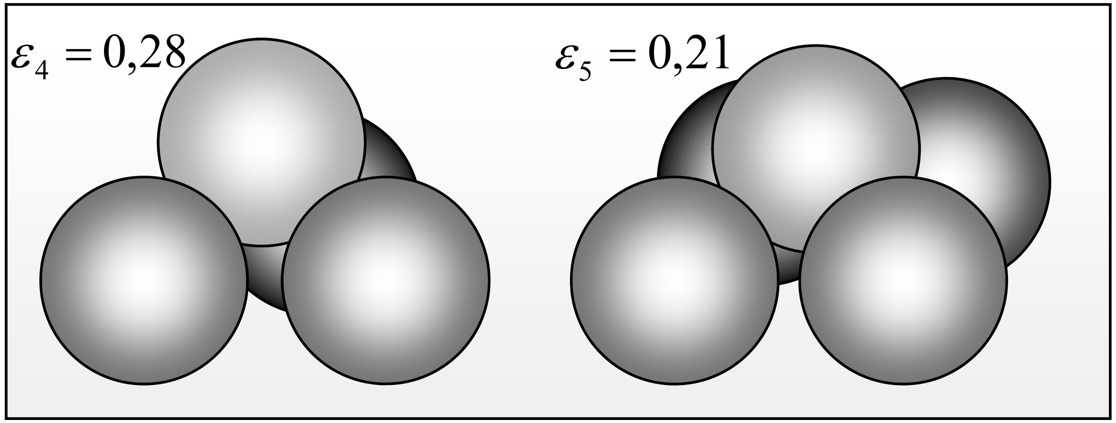


Fig. 2. Surface structure model

1. Flow under surface particles

Surface roughness

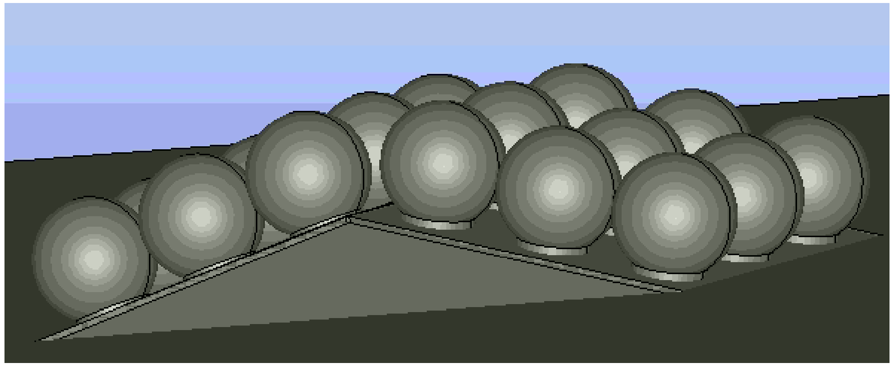


Fig. 3. Changing the orientation of surfaces

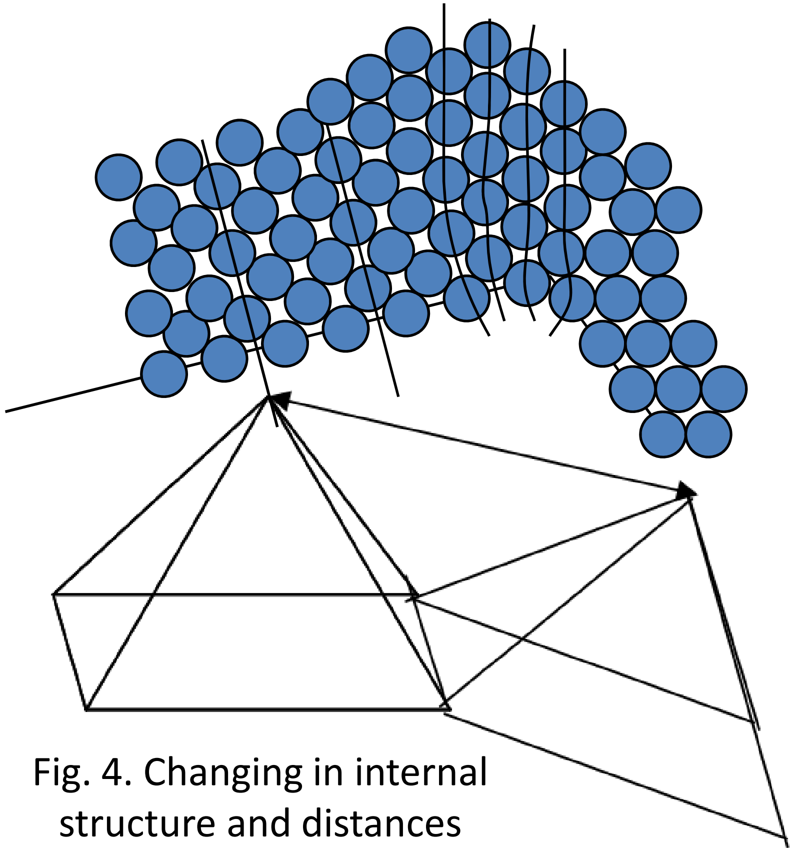


Fig. 4. Changing in internal structure and distances

The estimates of the distances between the particles of a spherical shape

$$D_s \approx (0.07 - 0.6)d$$

Types of structure	Distance between particles for 3 at the base, mcm	Distance between particles for 4 at the base, mcm	Distance between particles for an angle between planes 20°	Maximum distance between particles, mcm
1-4	14	16	17	20
1-3	22	25	31	37

1. Flow under surface particles

The initial data of the numerical model

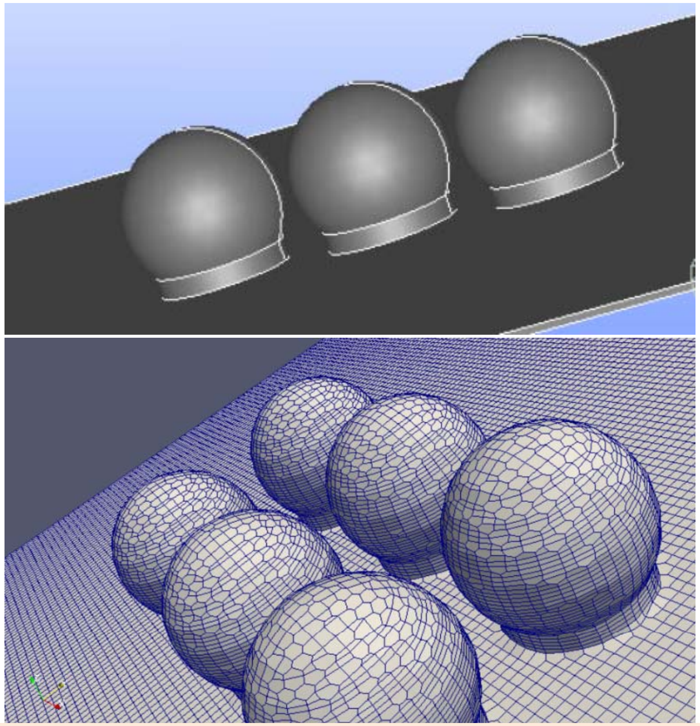
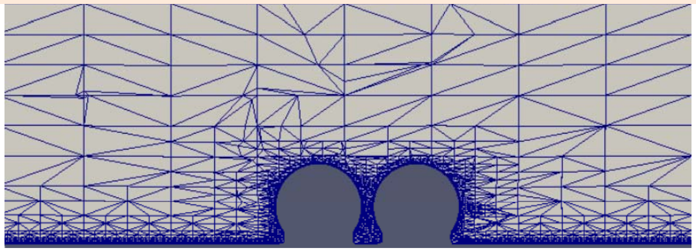


Fig. 5 - 3D surface, surface mesh, 4-level mesh



Hydrodynamic model

$$\nabla \vec{u} = 0$$

$$\frac{\partial \vec{u}}{\partial t} + \nabla \cdot (\vec{u} \otimes \vec{u}) = \nabla \cdot \frac{\hat{\Pi}}{\rho}$$

$$\rho C_v \left(\frac{\partial T}{\partial t} + \nabla \cdot (\vec{u} T) \right) = \nabla \cdot (\lambda \nabla T) + \hat{\Pi} : (\nabla \vec{u})^T$$

μ - dynamic viscosity, ρ- air density,

$\vec{u}$ - vector velocity field,

λ - coefficient of thermal conductivity,

$\hat{\Pi}$ - normal viscous stress tensor,

C_v - specific isochoric heat capacity.

Boundary conditions : $\left.\frac{\partial \vec{u}}{\partial \vec{n}}\right|_{up} = 0, \quad u|_{surf} = 0$

Salome/geometry: streamlined surface
OpenFOAM: rhoPisoCentralFOAM
Grid utility snappyHexMesh with 4 levels
and minimal scale 1e-06 м.
Calculation area size 5000x5000x2000 мкм [7]

[7] Malinovskaya E.A. Numerical simulation of surface flow. Trudy ISP RAN/Proc. ISP RAS, vol. 31, issue 6, 2019. pp. 225-236 (in Russian). DOI:10.15514/ISPRAS-2019-31(5)-15
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2. Airflow near surface particles

Influence of the air flow of a particle in a layer with a change in the distance

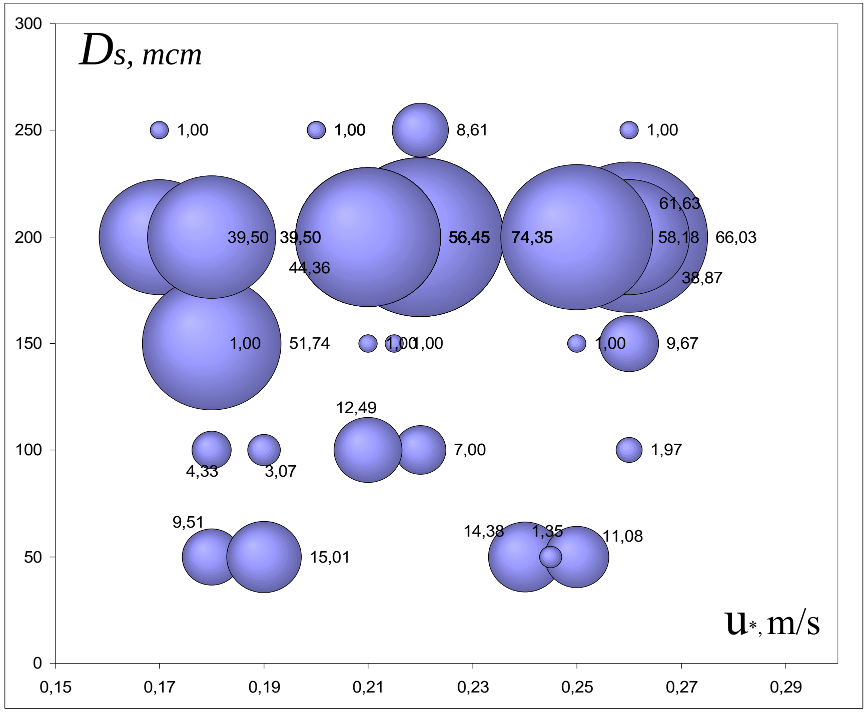

Fig. 6. Evaluation of buoyancy forces (ball sizes) acting on particles in a layer at various values of dynamic velocity and distances between particles

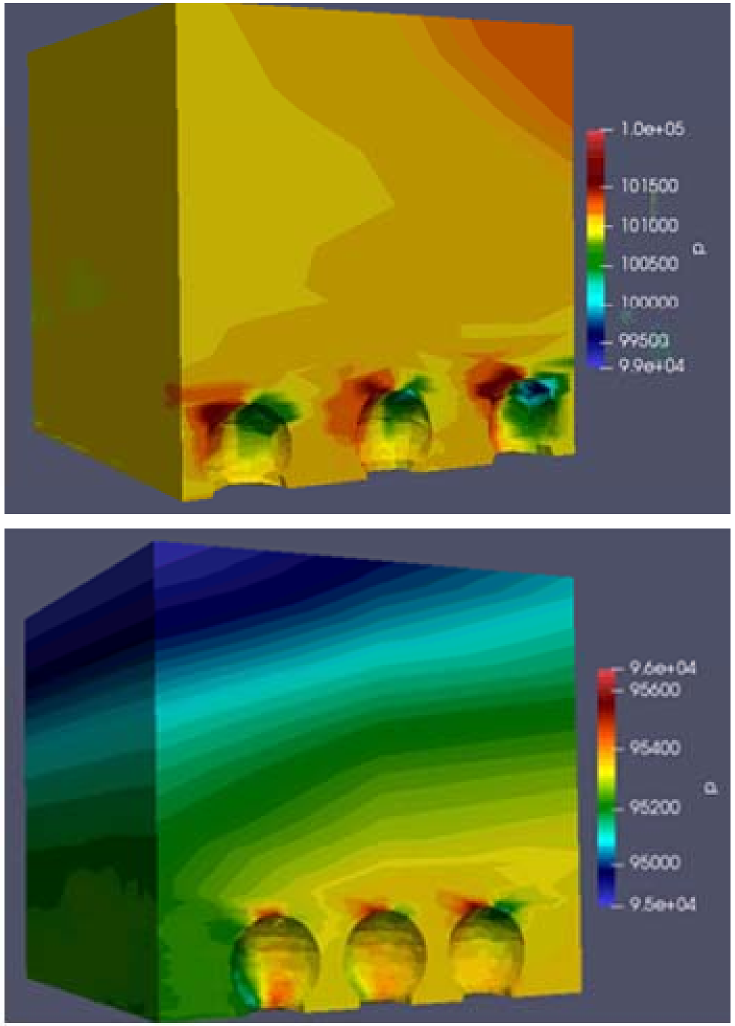

Fig. 7. Pressure field for distances between particle surfaces 100 and 50 μm

Depending on the distance between the particles, the buoyant force acting from the side of the air flow, the critical velocity, and the departure velocity of the particle change

3. Effect of surface structure inhomogeneities

Initial data of the numerical model

With a relative increase in the distance between pairs of particles and a change in the level of the upper surface, the pressure difference between the base and top of the particle increases by 10-30 percents [8].

Kinetic energy of turbulent mixing

$$k = \frac{3}{2}\left(u_{ref} T_i\right)^2$$

u_{ref} is the flow rate, T_i is the turbulence intensity, $\varepsilon = 0.09^{3/4} k^{3/2} l^{-1}$ is the turbulent energy dissipation, $l = 0.07L$ is the mixing length.

$u_{ref} = 0.1$ м·с$^{-1}$, $k = 1 \cdot 10^{-4}$ м^{2}·с$^{-2}$,
$\varepsilon = 0.029$ м^{2}·с$^{-3}$

[8] Malinovskaya E.A. Numerical simulation of surface flow. Trudy ISP RAN/Proc. ISP RAS, vol. 31, issue 6, 2019. pp. 225-236 (in Russian). DOI:10.15514/ISPRAS-2019-31(5)-15
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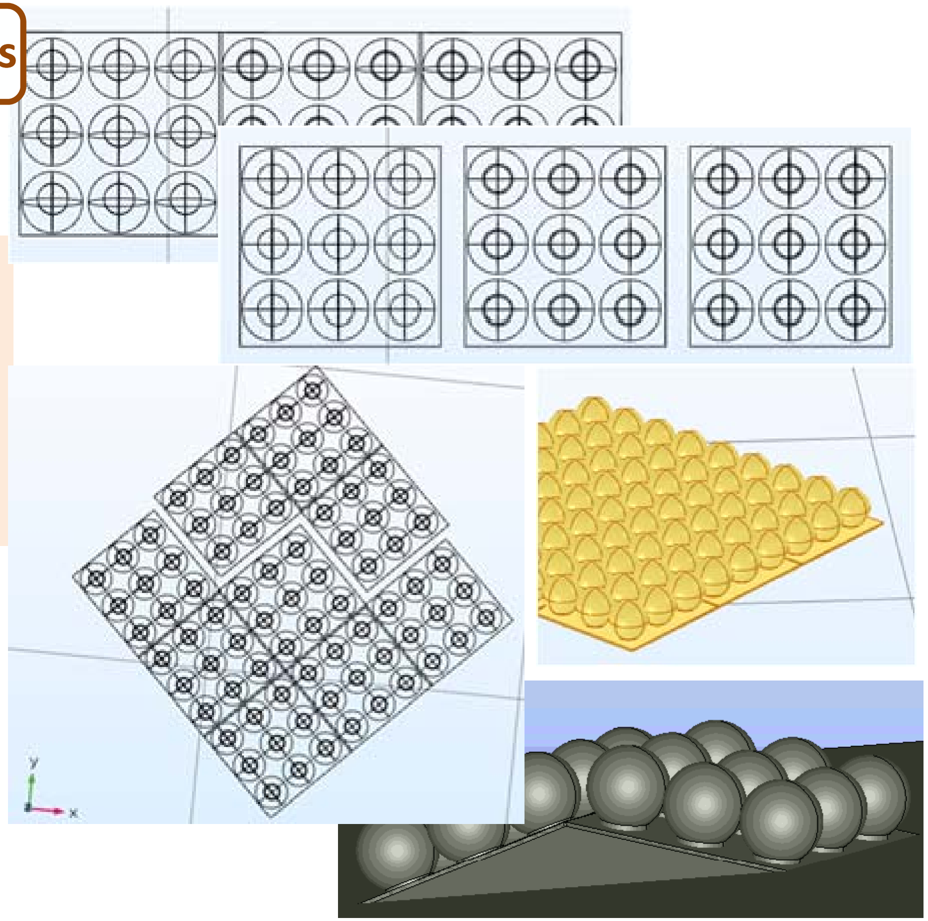
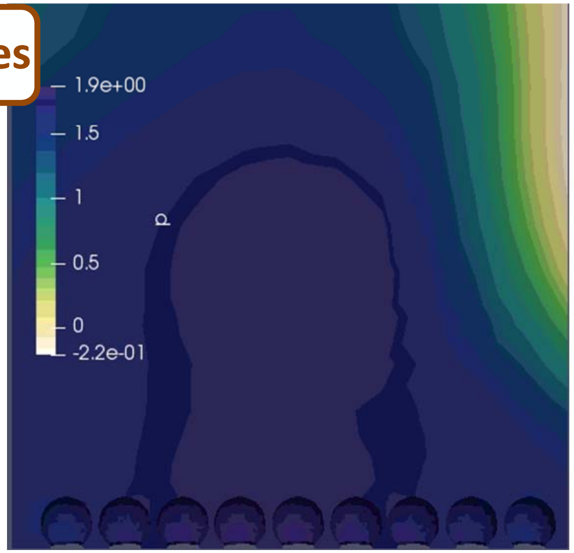


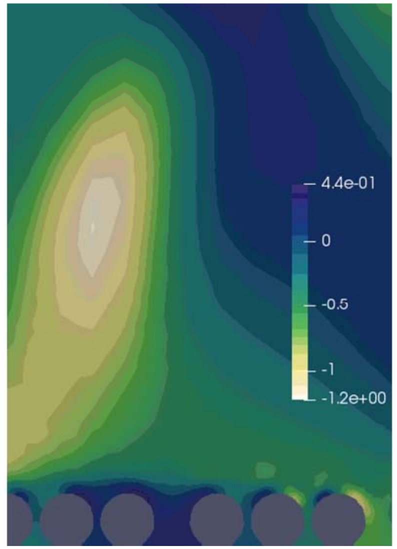
Fig. 8. 3D modeling of the geometry of the streamlined surface (a block of 9 spherical particles, three blocks of particles rotated relative to each other, 9 blocks of particles rotated at an angle of 45 degrees to the direction of air movement, 9 blocks of particles under angle of 45 degrees with a channel inside)

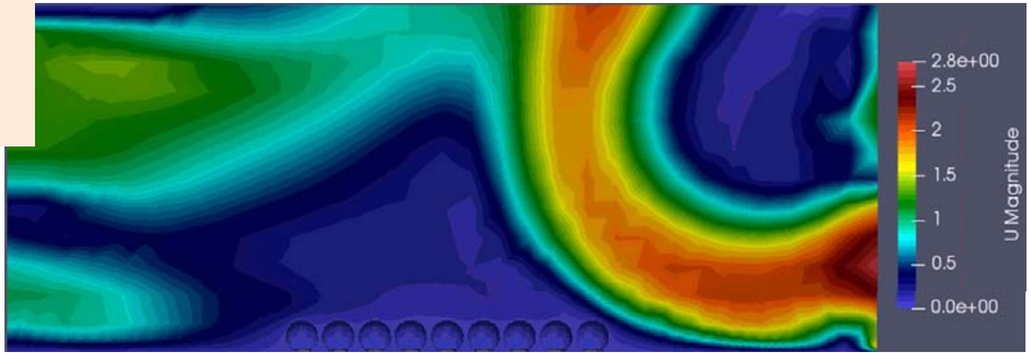
3. Effect of surface structure inhomogeneities

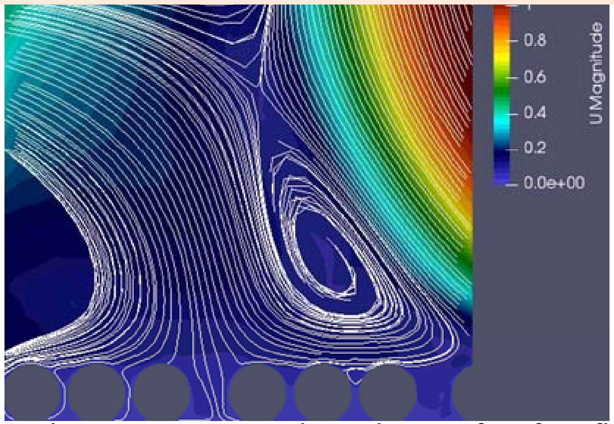
Changing the distance in a layer

There is a slowdown in the flow near the particles and outside their acceleration region. The inhomogeneities realized by increasing the distance between the blocks accelerate the flow, and also contribute to its twisting, areas of pressure decrease above the surface appear [7].









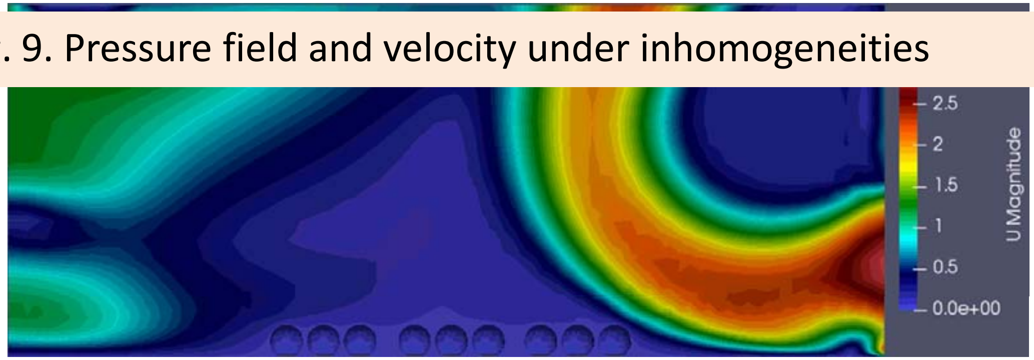


Fig. 9. Pressure field and velocity under inhomogeneities

[7] Malinovskaya E.A. Numerical simulation of surface flow. Trudy ISP RAN/Proc. ISP RAS, vol. 31, issue 6, 2019. pp. 225-236 (in Russian). DOI:10.15514/ISPRAS-2019-31(5)-15
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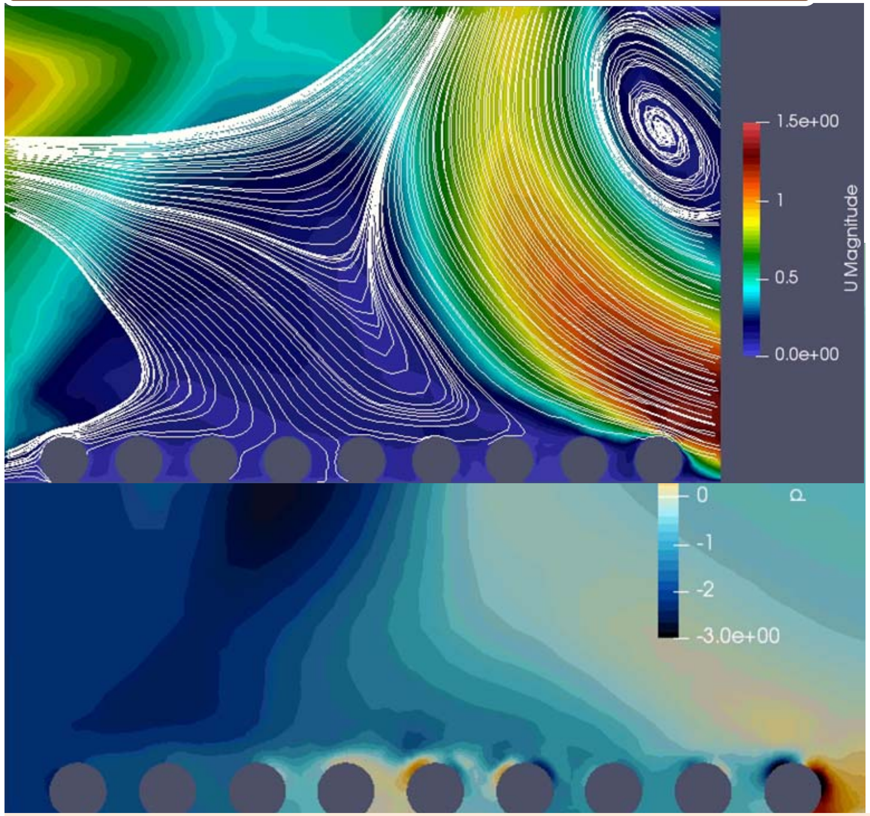
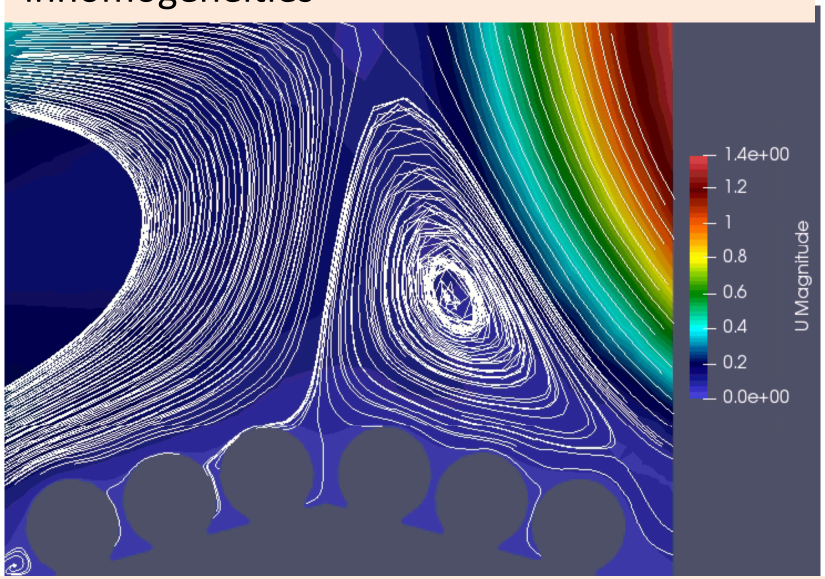
3. Effect of surface structure inhomogeneities

Changing the orientation of structure blocks



Change the inclination of surface planes

Fig. 10. Pressure field and velocity under inhomogeneities



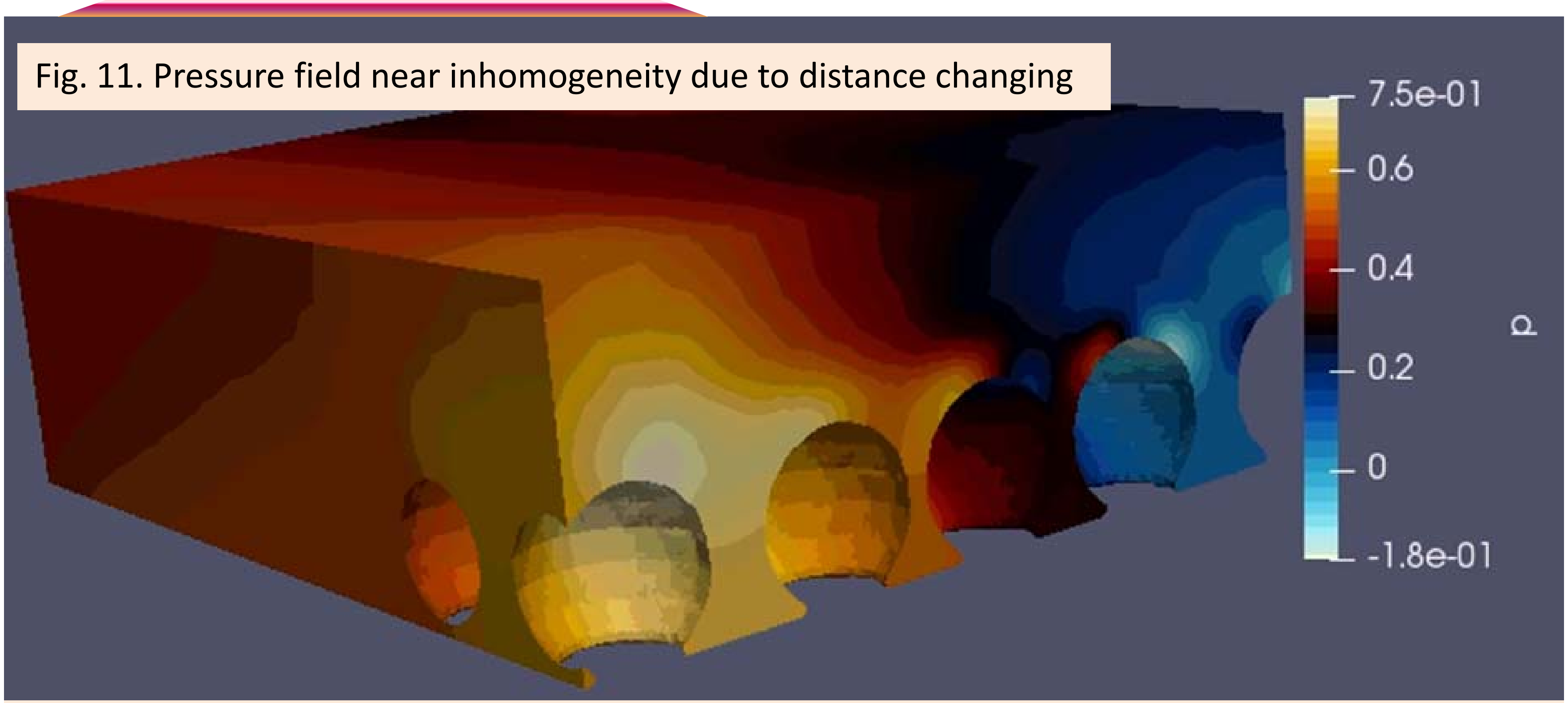
When flowing around particles collected on two blocks, the planes of which are inclined to each other at an angle (Fig. 7), the highest pressure value is noted at the top of the structure, which leads to the appearance of a horizontal pressure difference spreading the particles in different directions [7].

[7] Malinovskaya E.A. Numerical simulation of surface flow. Trudy ISP RAN/Proc. ISP RAS, vol. 31, issue 6, 2019. pp. 225-236 (in Russian).

DOI:10.15514/ISPRAS-2019-31(5)-15

3. Effect of surface structure inhomogeneities

Fig. 11. Pressure field near inhomogeneity due to distance changing



All these factors indicate that the sand surface under the constant influence of the wind is an alternation of quasiregular regions in which the surplus of the pressure difference above and below the particle prevails over gravity. As a result, areas with different probability of wind drift appear, due to which, in particular, the occurrence of aeolian ripples occurs [7].

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4. Aolian structures

1 step: $x(t_0,z_0) \rightarrow x(t_1,z_0) = k \cdot x(t_0,z_0)$

2 step: $x(t_1,z_0) \rightarrow x(t_2,z_0) = k^2 \cdot x(t_0,z_0)$

$x(t_1,z_1) \rightarrow x(t_2,z_1) = x(t_1,z_1) - k \cdot \left(x(t_1,z_1) - x(t_1,z_0)\right)$

3 step: $x(t_2,z_0) \rightarrow x(t_3,z_0) = k^3 \cdot x(t_0,z_0)$

$x(t_2,z_1) \rightarrow x(t_3,z_1) = x(t_2,z_1) - k \cdot \left(x(t_2,z_1) - x(t_2,z_0)\right)$

$x(t_2,z_2) \rightarrow x(t_3,z_2) = x(t_2,z_2) - k \cdot \left(x(t_2,z_2) - x(t_2,z_1)\right)$

i step: $x(t_{i-1},z_0) \rightarrow x(t_i,z_0) = k^i \cdot x(t_0,z_0)$

$x(t_{i-1},z_1) \rightarrow x(t_i,z_1) = x(t_{i-1},z_1) - k \cdot \left(x(t_{i-1},z_1) - x(t_{i-1},z_0)\right)$

$x(t_{i-1},z_j) \rightarrow x(t_i,z_j) = x(t_{i-1},z_j) - k \cdot \left(x(t_{i-1},z_j) - x(t_{i-1},z_{j-1})\right)$

$x(t_0,z_0)$ is leeward length at initial time
k is coefficient determining the change in layer length at each step
$\langle r \rangle$ is an average particle radius,
t_p is an average particle rise time above the surface

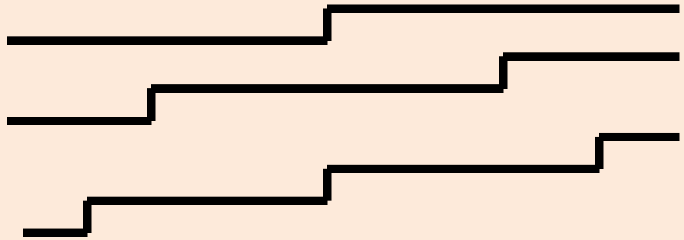


Fig. 12. The lines of the windward slope when solving equations of change in the length of the layers

For the model of the formation of the windward slope, taking into account the linear change in the critical velocity with height, we note the corresponding real angles of inclination of the surface [8]

Estimates of the balance of detached and falling particles

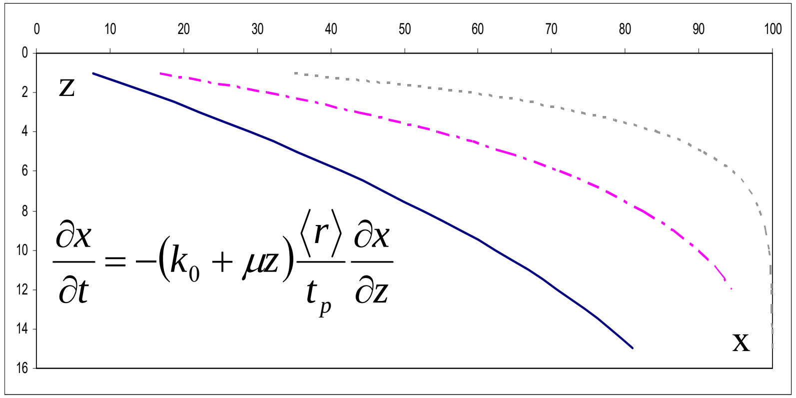


Fig. 13. windward slope line

$k = const$		$k = k_0 + \mu z$		
k	Windward Slope	k_0	μ	Windward Slope
0,9	3	0,95	0,08	5,7
0,8	2,1	0,9	0,09	6
		0,9	0,1	7,1
		0,8	0,08	4,2
		0,7	0,08	3,6

One of two possible
- increase in critical dynamic speed u_{*k} when moving up the windward slope;
- increase in roughness and resistance closer to the top

[8] Malinovskaya E.A. Model of the windward slope formation of the eolian relief form. Izvestiya, Atmospheric and Oceanic Physics. 2019. V.55(2). 88-95 https://doi.org/10.31857/S0002-351555286-95

4. Aeolian structures

Dune cannot be considered as a monolithic homogeneous structure. This is a medium consisting of whose properties are different for its various parts, which, in particular, is associated with the peculiarities of laying particles on the surface.

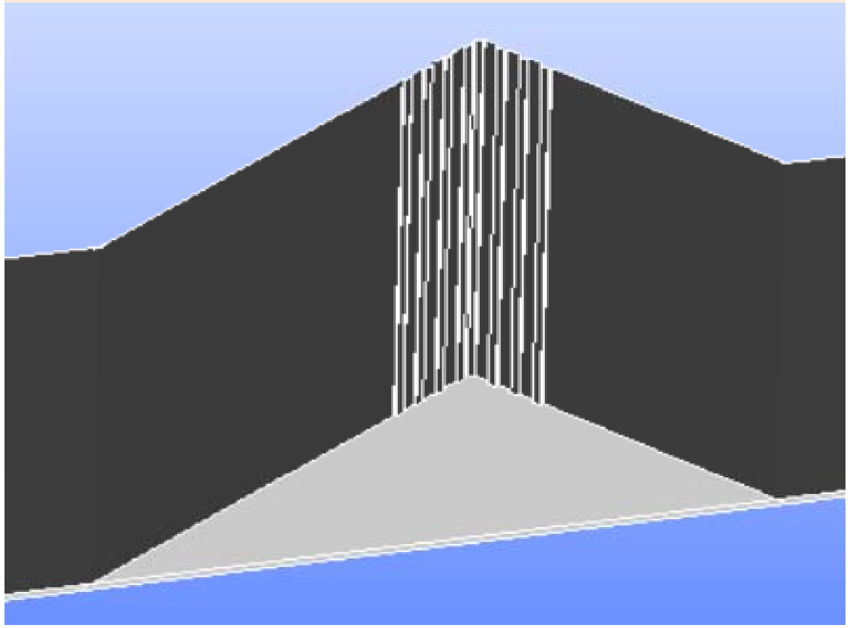


Fig. 14. Geometry with surface furrows

Initial data of the numerical model

$u_{ref} = 3.5$ m·s^{-1}, $k = 0.4$ m^2·s^{-2},
$\varepsilon = 2.0 \cdot 10^2$ m^2·s^{-3}

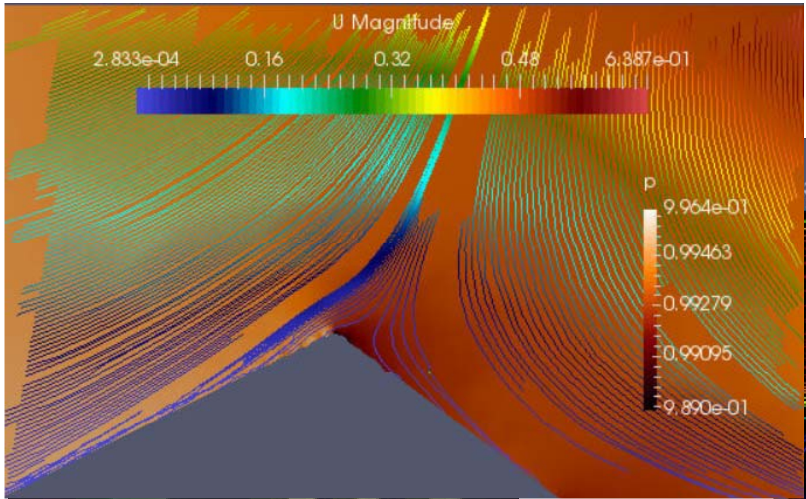
Salome/geometry: streamlined surface
OpenFOAM: rhoPisoCentralFOAM

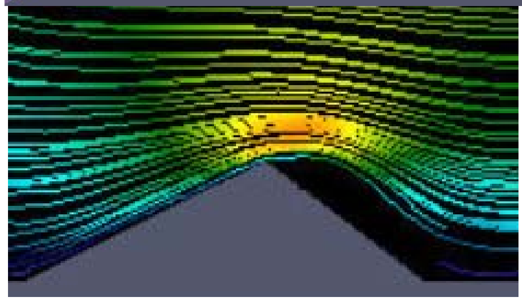
The critical velocity increases when moving up the windward slope of the dune [9]. This phenomenon is possibly associated with the influence of ripples on the air flow. The flow around of the micro-ripples with a height of 0.1-1 mm was considered for air flow velocity of 2-4 m/s at a height of 1-2 cm [8, 9].

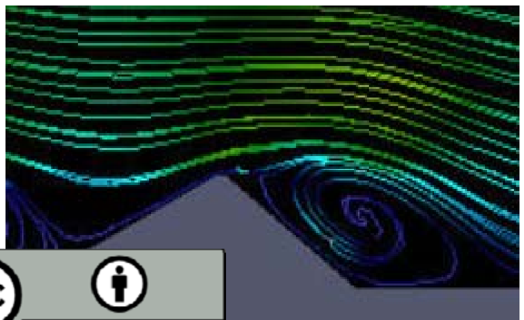
[8] Malinovskaya E.A. Model of the windward slope formation of the eolian relief form. Izvestiya, Atmospheric and Oceanic Physics. 2019. V.55(2). 88-95 https://doi.org/10.31857/S0002-351555286-95
[9] Malinovskaya E. A., Chkhetiani O. G. Modeling of near-surface flows over an aeolian relief //IOP Conference Series: Earth and Environmental Science. – IOP Publishing, 2019. – T. 386. – №. 1. – C. 012030. https://doi.org/10.1088/1755-1315/386/1/012030

4. Aeolian structures

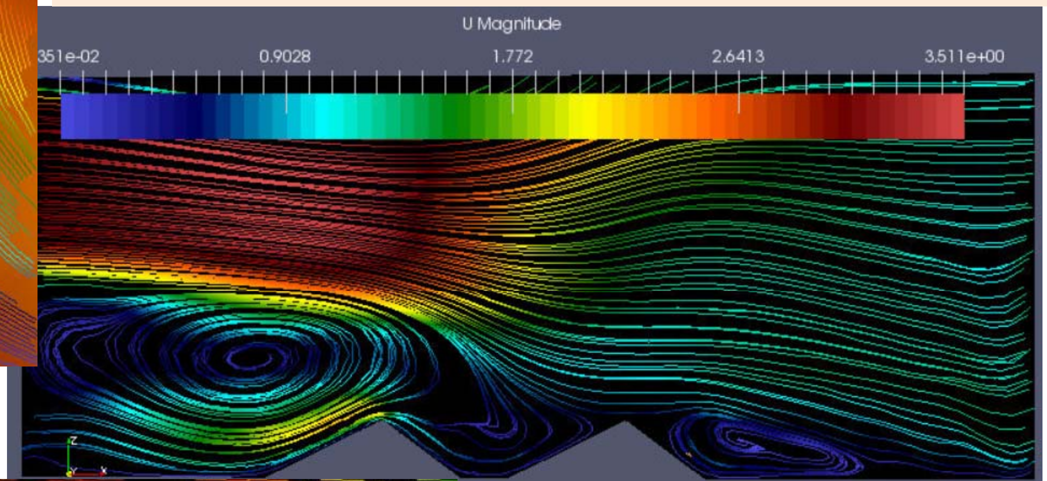
Comparison of the flow pattern with and without discontinuities at the top of a ripple

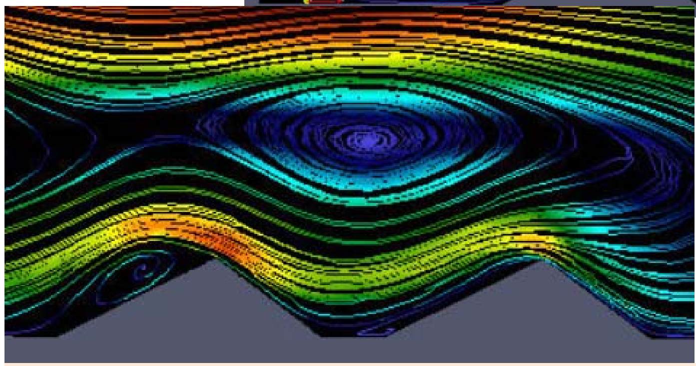






- The addition of supplementary elements of inhomogenity at the apex near the rough surface of the streamlined aeolian structure leads to a displacement of the separation point of the ascending flows.
- We have a change in the length of the recirculation zone and the time intervals of the strengthening of the wind at the apex.





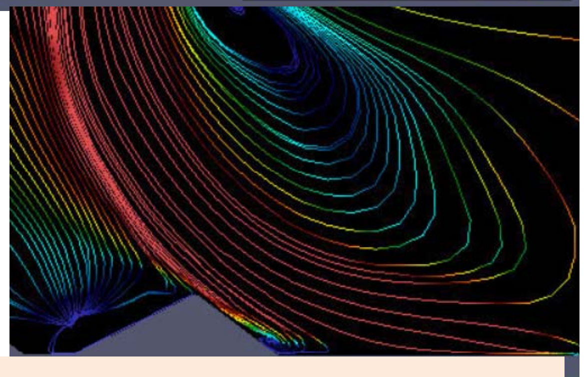


Fig. 15. Flow around microtowing with furrows on the surface

Conclusion

- The initial velocity of particle at separation from the layer grows with the pressure difference on opposite sides that is determined the lifting force. The relative increase is about 10% for the inhomogenity area.
- The appearance of inhomogeneities in the initial structure may arises due to changing the angle between the planes of the surfaces leads to increase in the flow velocity and a decrease in pressure at separation from the inflection area of surface.
- Inhomogeneities that arise due to an increase in the distance between the surfaces of individual particles or when the angle of inclination of the plane changes, affect the local change in the pressure difference by 10-30%.
- All these factors indicate that the sand surface under the constant influence of the wind is an alternation of quasiregular regions in which the surplus of the pressure difference above and below the particle prevails over gravity. As a result, areas with different probability of wind drift appear, due to which, in particular, the occurrence of aeolian ripples occurs.
- The model of the formation of the windward slope gives the corresponding real angles of inclination of the windward surface if it is accounted the linear change in the critical velocity with height. This may be due to increase in roughness and resistance closer to the top.
- The addition of supplementary elements of inhomogeneity at the apex near the rough surface of the streamlined aeolian structure leads to a displacement of the separation point of the ascending flows. We have a change in the length of the recirculation zone and the time intervals of the strengthening of the wind at the apex.

References

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Thank you for your attention!

Any questions ?

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