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FACULTY OF MECHANICAL ENGINEERING IN NIŠ

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Niš, April 19 - 20, 2018

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UNIVERSITY OF NIŠ
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PREFACE

More than half a century of tradition, high standards in education of generations of students, modernly equipped classrooms, professional teaching and associate staff, their references and recognisability, position the Faculty of Mechanical Engineering, University of Niš, as the leader in the field of engineering sciences and technologyical sciences, not only on the territory of the Republic of Serbia, but also in the wider region of the Western Balkans.

The proceedings of the 4th International Conference **MECHANICAL ENGINEERING IN XXI CENTURY** appear in the year when the Faculty of Mechanical Engineering, University of Niš, celebrates its fifty eighth anniversary. The Department of Mechanical Engineering of the Faculty of Engineering in Niš was founded on May 18, 1960, and it developed into the Faculty of Mechanical Engineering of the University of Niš in 1971. The Faculty of Mechanical Engineering grew intensely, thus becoming one of the most renowned scientific and educational institutions in the country.

The mission of the Faculty is to organize and conduct academic study programmes and to develop and perform scientific and professional work in the field of engineering sciences and technology. Its vision is to be recognisable in the European and global academic environment in the areas of mechanical engineering and engineering management.

More than 100 teachers and associates, around 45 members of non-teaching staff, as well as numerous teachers and associates from other faculties and from the industry, are working hard every day to accomplish the mission and vision of the Faculty.

The Faculty of Mechanical Engineering, University of Niš, is accredited in compliance with the Law on Higher Education within the scientific and educational field of engineering sciences and technology. It conducts the academic studies of the first degree – undergraduate studies, the second degree – master academic studies, and the third degree – doctoral studies, within the scientific area of mechanical engineering and engineering management.

The Faculty of Mechanical Engineering is a scientific research institution, in addition to being an educational one. There are 11 international scientific research projects within the framework of FP7, TEMPUS, CEEPUS, DAAD, bilateral and cross-border programmes, as well as 24 national scientific research projects, being implemented at the Faculty this year. The participation of teachers and associates from the Faculty in these projects is of utmost importance for their educational and research work and their further career.

The 4th International Conference **MECHANICAL ENGINEERING IN XXI CENTURY** represents a forum for the presentation of latest results, basic and developmental research and application within the topics of:

- Energetics, Energy Efficiency and Process Engineering,
- Mechanical Design, Development and Engineering,
- Mechatronics and Control,
- Production and Information Technologies,
- Traffic Engineering, Transport and Logistics,
- Theoretical and Applied Mechanics and Mathematics,
- Engineering Management,
- Future of work, engineering and professional ethics in the era of globalization.

The Conference will also host the assembly meeting of Serbian Association for the Promotion of Mechanism and Machine Science (SAToMM), as well as the meeting of the National Science Board for Mechanical Engineering and Industry Software, will be held.

One hundred and eight papers, whose authors come from 10 countries, are published in these Proceedings. The papers present the research results of numerous projects financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia, as well as the research results within international projects.

The main goal of the Conference is to bring together researchers from scientific and industrial institutions so that they can present and communicate their newest results, create personal contacts, promote research within the area of mechanical engineering, and stimulate the exchange of results and ideas within the fields encompassed by the Conference.

As Dean of the Faculty of Mechanical Engineering in Niš, I am honoured to greet all participants of the Conference and wish them very successful work.

Dean of the Faculty of Mechanical Engineering,
University of Niš

Prof. Dr Nenad T. Pavlović

Niš, April 2018

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Two Way Coupled Fluid-Structure Interaction Analysis of the Grasshopper Fishing Lure's Movement in the Water Stream

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***Abstract*— The special group of the fishing lures are insect shaped lures that are dragged in the water stream and while dragged they imitate the injured insect swimming in the water stream. The lure is moving both laterally and longitudinally; it is vibrating, making noise and shining in the water – this tricks the fish to attack it and get hooked. The movement, vibration and noise produced by the lure depend on the topology of the lure and the relative speed of the lure in water stream. The modeling and simulation of such a physical process requires an analysis that simultaneously runs structural and fluid-based analysis. The paper is presenting preparation and results of a two-way coupled fluid-structural interaction Ansys analysis applied on a grasshopper lure. The goal is to investigate the deflections of the fishing lure in the water stream.**

***Keywords*— Grasshopper Fishing Lure, Ansys Workbench, Two Way Fluid-Structure Interaction, Displacement**

I. INTRODUCTION

During the last two centuries, line fishing has become more than a pure need for the food resources harvesting – the modern fishing has a goal to use a bait, outfox the fish, enjoy the catch, make a photo of the fish and return it unharmed to the water.

A massive group of recreational fisherman use artificial baits for the fish – fishing lures, which imitate the behavior of the natural food of the fish (they imitate insects, amphibians, small mammals or small fish). The lure fishing is quite simple: the lure is cast to the water and dragged by the fishing line. While dragged, the fishing lure spins (partially or fully), dives, vibrates and makes for the fish irritating noise. There are numerous types and shapes of the lures [1-3], with different designs and textures, but this is simply not enough: the trophy fish is too cautions to get caught so easily. Therefore the fishing lure has to be optimized for the fish, water and season of the year, weather and the fisherman.

II. DESING OF THE FISHING LURE

There is no universal fishing lure that can be used for all fish and all fishing circumstances; the fishing lure used for the analysis is a small grasshopper (max. 50 mm long, fig. 1, position 6), the primary target fish is a chub (predatory fish), and the fishing is planned in the shallow and clear river waters during spring and summer [2]. The lure is light – floating or shallow diving, maneuverable, balanced, with a detailed surface texture and with a limited vibration and noise creation. It has the ability to define the intensity of the lateral and longitudinal movement of the lure while fishing by pure adaptation of the fishing lure's dragging speed.

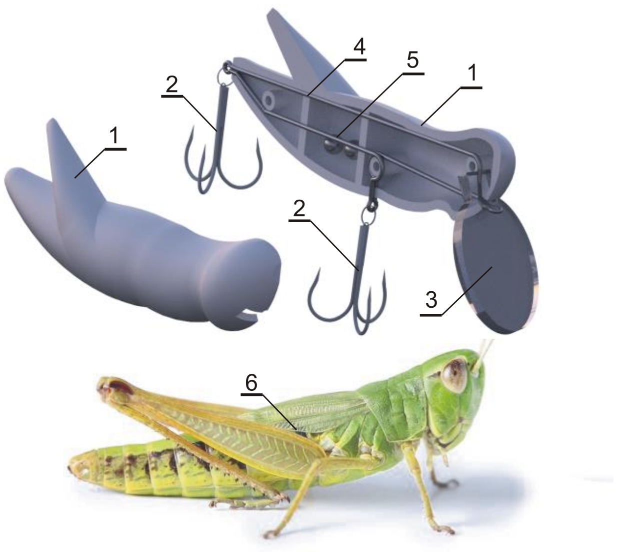

Fig. 1 The Grasshopper: 1) grasshopper lure's body, 2) fishing hooks, 3) diving lip, 4) steel frame of the lure, 5) steel balls inside the vibration chamber, 6) the grasshopper

The shape, size and position of the diving lip in the fishing lure (fig 1, position 3) define the diving depth of the lure, enforce stabile/unstable and controlled/uncontrolled movement of the lure while steel balls inside the vibration chamber (fig. 1, position 5) generate noise and vibration of the lure. Steel balls inside the lure improve/degrade the gyro-stability of the lure, but they always restrain the lure's spin around the longitudinal axis – fishing line [1].

The diving lip on the fishing lure is elliptical (axis: 10 mm×5,6 mm) and it is mounted to the lure at the front side of the grasshopper's head at the angle of α=60° between the horizontal (represented with the fishing line, Fig. 2, position 3) and the diving lip. The diving lip cannot be rotated or translated along the mounting position (what is possible to be done at some state of the art fishing lures [1]).

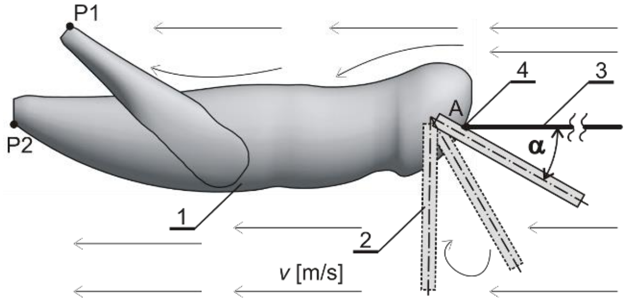

Fig. 2 Location of the diving dip in the fishing lure: 1) fishing lure, 2) diving dip, 3) fishing line, 4) anchor point – A

The fishing line (Fig. 2, position 3) is connected to the lure over only one constraining point located in the middle of the diving dip/ front side of the fishing lure (Fig. 2, position 4)

III. Numerical Simulation of the Fishing Lure Travelling Through the Water Stream

In reality, the fishing lure is dragged by the fishing line trough the water, that is either unmovable or has a positive or negative stream. Regarding on the relative speed of the lure's travel trough the water, the pseudo oscillatory movement of the lure appears in the regimes defined with the lure's topography and the travel/dragging speed. In order to simplify the simulation, it is considered that the lure is restrained in the water flow. Therefore, the simulation is considering the change of the water stream *v* [m/s] to receive the translational response of the fishing lure. The simulation is performed in Ansys Workbench 18.1 environment [4].

A. *Numerical Model*

The numerical model consists of 3 discretized parts: the fishing lure, fishing line and enclosure (Fig. 3).

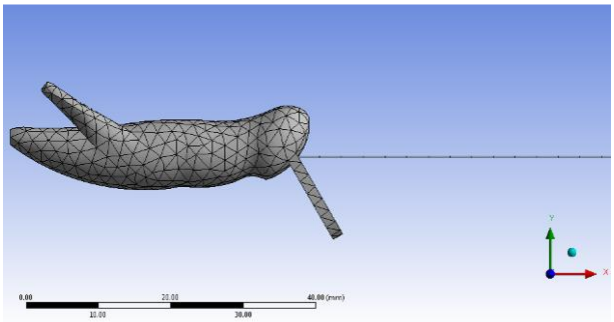

Fig. 3 Discretized fishing lure and fishing line

The lure is modeled/discretized with the 3D-high order Tet10 (SOLID187 [5]) elements while the fishing line was modeled with the beam elements (BEAM188 [6]) and the mesh is stationary. The fishing line has a rounded cross section of 0,25 mm diameter and it is 200 mm long. The fishing lure and the fishing line are connected over a fixed joint (point on curve) while the other side of the fishing line is fully constrained (fixed). The materials used for analysis are PA 6.6 (plastic/nylon with the density of ρ=1150 kg/m^3, Young's Modulus E=3500 MPa, Poisson's Ratio ν=0,4 and Tensile Yield Strength σ_{yield}=85 MPa) used for the fishing lure and FL (steel with the density of ρ=7850 kg/m^3, Young's Modulus E=200000 MPa, Poisson's Ratio ν=0,3 and Tensile Yield Strength σ_{yield}=25 MPa [7]) for the fishing line. The both materials are considered to be ideally elastic.

The enclosure – water is modeled as the non-uniform cube surrounding the fishing lure and the fishing line. Since water has only a minor influence on the fishing line, the enclosure is limited only to the fishing lure (Fig. 4), with the boundary surfaces set 5 mm to 25 mm away from the fishing lure model. The enclose cube's boundaries (named selections) are set as: inlet (+x plane), outlet (–x plane), walls (+y, –y, +z, –z) and as fluid-solid-interface (the set of surfaces that are in contact with the fishing lure).

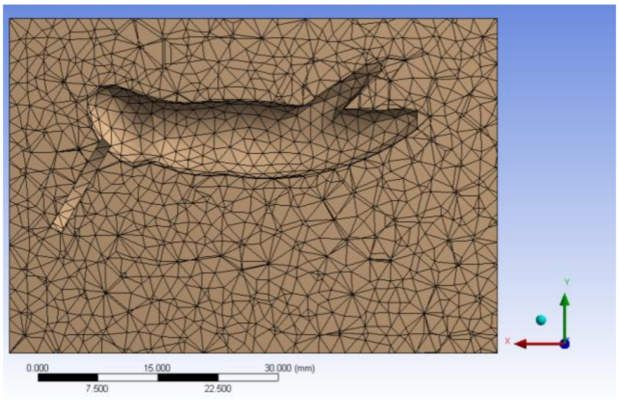

Fig. 4 Discretized enclosure – water (lateral section view)

The water is discretized with the linear 3D Tet4 [8] elements. The mesh is set to be dynamical – the enclosure is being re-meshed after each iteration cycle. The main properties of the water are: density ρ=998,2 kg/m^3 and viscosity η=0,001003 Pas.

B. *Two-Way Coupled Fluid-Structure Interaction Analysis*

Preparation of the model, simulation and analysis of the lure's movement in the water requires understanding the realistic physical process. The lure is attached to the fishing line and it always resists to the water stream. The water stream runs around the fishing lure and due the topology of the lure, the uniform water stream deforms locally (the velocity and pressure). The local changes of the water stream enforce displacement of the lure – it tensions the fishing line and translates/rotates in all 3 directions to reach the meta-stabile or stabile mechanical equilibrium. Such a displacement changes the water stream again, what results in new movement of the fishing lure. Therefore, the process continues and lasts until the water stream runs around the fishing lure or until the stabile mechanical equilibrium is reached.

In such a case, the fluid is interfacing with the solid and the solid is influencing the fluid. Such a case is recognized by the Ansys Workbench as the coupled two-way coupled fluid-structure interaction (FSI) analysis [4]. It is coupling the Transient Structural Analysis – TSA (stress, deformation) of the solids (the fishing lure and fishing line) and the Fluid Flow Analysis – FFA (Fluent) of the fluid – water (Fig. 5) [9].

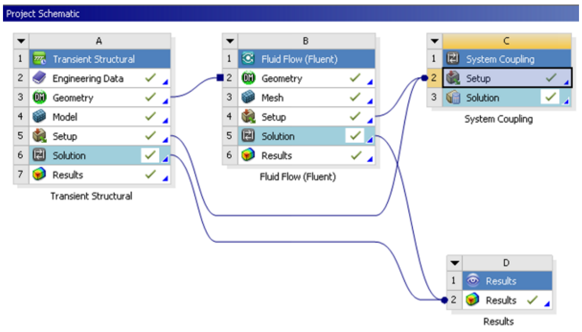

Fig. 5 The Ansys Workbench Coupled FSI Analysis – the project schematic

Both the TSA and FFA share the same geometry consisting of the fishing lure, fishing line and water around the fishing line and fishing lure. The TSA Model uses the geometry of the fishing line and fishing lure while the water is suppressed. On the other hand, the FFA Model uses only the water geometry and the fishing lure and the fishing line are suppressed.

The TSA Setup, beside common structural settings, requires use of the Fluid Solid Interface loading (set to all surfaces/faces of the fishing lure, fig. 6) and the use of the APDL Command to activate initial stress-deformation of the solids (e.g. elastic strain defined over the INISTATE command). This APDL is required to stabilize the numerical model at the first time step of analysis.

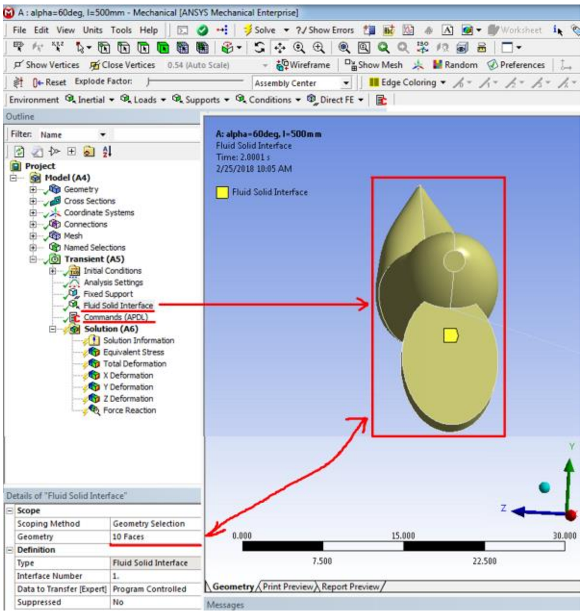

Fig. 6 The TSA – Fluid-Structure Interaction loads and APDL Command

It is necessary to set only 1 calculation step in the settings (otherwise the coupling analysis will not work). All other analysis settings concerning time/time step are unimportant because the coupling settings overrides them all [10, 11].

The FFA Setup is slightly more complex than the TSA Setup. It is mandatory to set:
General→Transient Analysis; Models→Viscous→k-epsilon (2 eqn)→Realizable→Scalable Wall Functions; Materials→Fluid→Water-Liquid; Cell Zone Conditions→Select Water Liquid; Boundary Conditions→it is necessary to set Inlet (Fig. 7), Outlet, Walls and Fluid Interior. The boundary layer of water flowing around the fishing lure, that is necessary for more precise capture of local pressure drops, has been neglected.

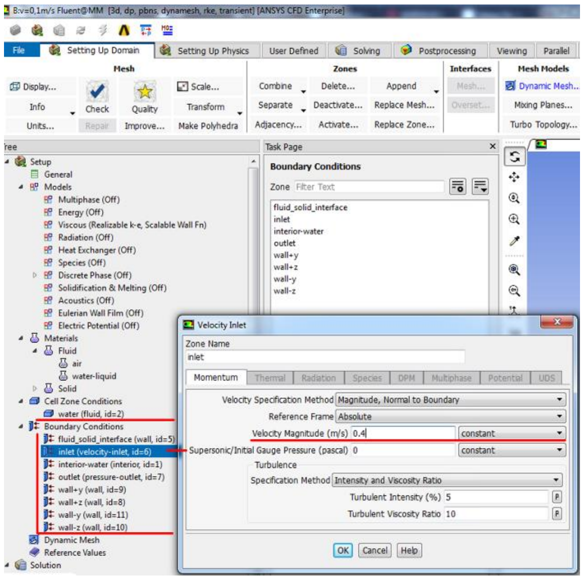

Fig. 7 The FFA – Boundary Conditions, Inlet Settings, water stream v=0,4 m/s

Dynamic Mesh→Smoothing→Settings→Diffusion→Diffusion Parameter→2; Dynamic Mesh→Dynamic Mesh Zones→Walls, Inlet, Outlet (Stationary), Fluid Solid Interface (coupled), Interior (dynamic), shown in Fig. 8.

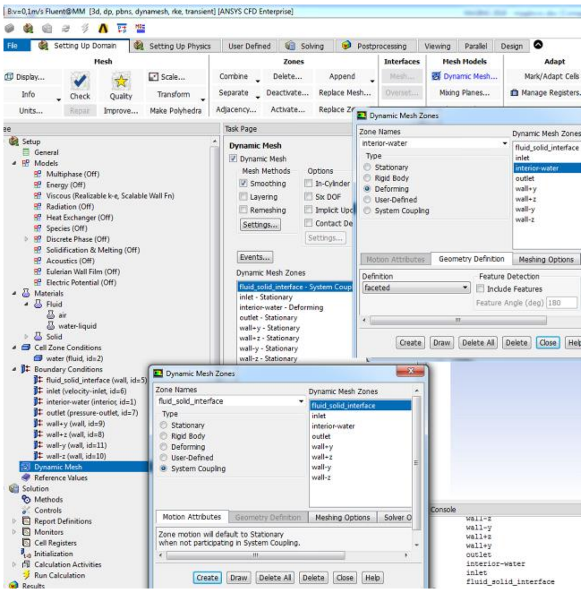

Fig. 8 The FFA – Dynamic Mesh

Method→Solution Methods→Scheme→Coupled; Initialization→Initialize.

All other settings are optional or semi-optional since coupling overrides almost all of them.

The Coupling Setup (Fig. 9) requires connecting the TSA and FFA: it is necessary to make the data transfer from TSA to SA and vice versa. It is done over the Fluid Structure Interface: the TSA delivers incremental displacement to the FFA while FFA delivers forces to the TSA. After setting the time step (due to the convergence issues it is necessary, in many cases, to set very small values, e.g. Δt=0,0001 s), end time (smaller than one given in TSA) and min/max iterations the coupling setup is done.

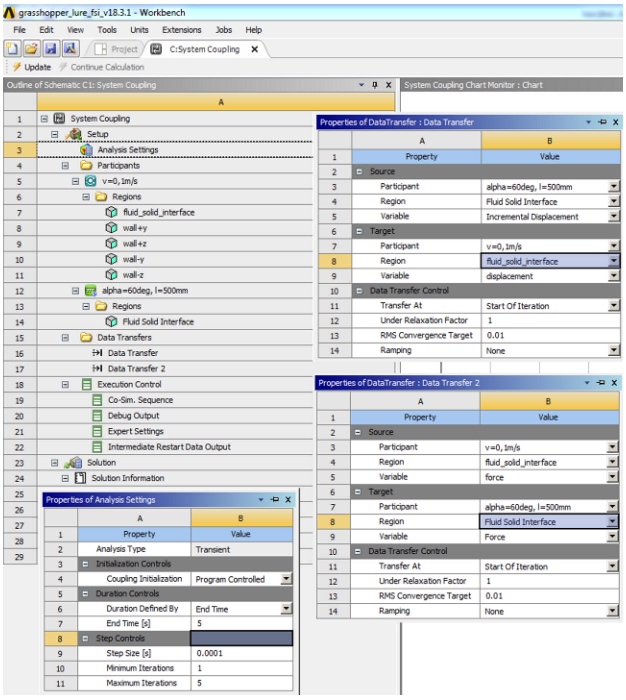

Fig. 9 The Coupling Setup – Settings

Unfortunately, solving the coupling system, even for relatively small numerical models (e.g. less than 100000 elements and less than 200000 nodes) is extremely slow – TSA and FFA have to converge, and afterwards data transfer from TSA to FFA and data transfer from FFA to TSA, as well.

IV. Results and Discussion

The coupled analysis has been ran for five different water streams (0,3; 0,35; 0,37; 0,4 and 0,5 m/s), analysing the first 5 seconds of water flow. The results have been showed only for three characteristic points on the fishing lure (A, P1 and P2, shown in figure 2), with absolute coordinates in mm: A (36,817; 3,3084; 0), P1 (4,0915; 15,549; 0), P2 (-0,95601; 6,8278; 0)). The results are presented considering global coordinate system (given in figures 2, 4, 6 and 10) where: –*x* direction is the direction of the water stream (flow) – longitudinal direction, –*y* is the (vertical lateral) direction of the gravity (the gravity has been neglected) and the *z* direction is (horizontal) lateral.

There are some notations that have to be taken into consideration while checking the results:

1. The results show intensive oscillatory behaviour of the fishing lure in the water stream.
2. The TSA model has received initial (before the first iteration) artificial pre-loading defined as the constant elastic strain of 10^{-8} mm/m for all the elements in the model. This was a necessity for the proper numerical constraining and numerical stability of the coupled model. Therefore, after achieved convergence at the first time step, the model is „resting" from the initial loading. Also, the TSA model is being calculated first without concern on FFA model what gives non realistic results. Considering both reasons, the first 0,5 s of the analysis should be neglected.

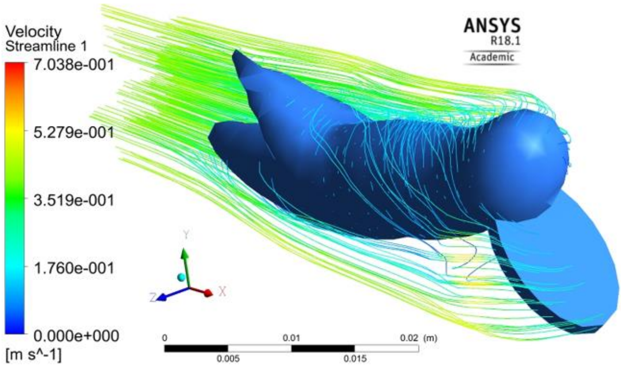

Fig. 10 The velocity/streamline for *v*=0,5 m/s

The fishing lure and the fishing line are initially set to have collinear (horizontal) axes. However, the water stream is forcing the lure to dive (in –y direction) to reach natural fluid-mechanic equilibrium position, regardless on speed of the water flow. The „equilibrium" position is reached after 0,5 s to 1,5 s for all water streams and afterwards (in time interval 1,0 s to 5,0 s) the fishing lure is in the stabile dynamic influence of the water stream.

The relative diving depth of the selected points (A, P1 and P2) for the case when water stream is *v*=0,3 m/s is given in figure 11.

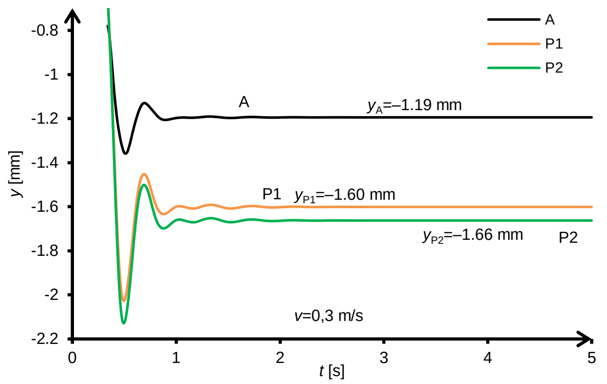

Fig. 11 The relative displacements of points A, P1 and P2 in the *y*-direction for the water stream of *v*=0,3 m/s

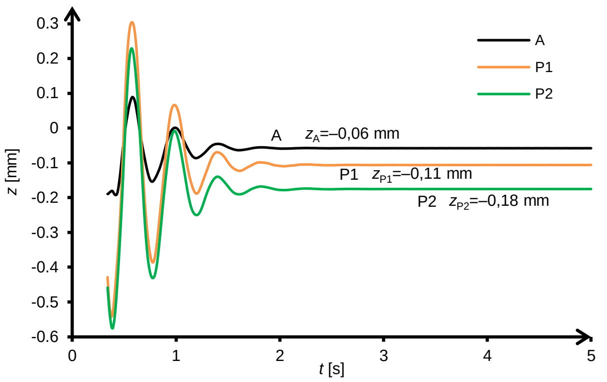

Fig. 12 The relative displacements of points A, P1 and P2 in the *z*-direction for the water stream of *v*=0,3 m/s

Comparing the initial *y* coordinates of points A, P1, and P2 and appropriate relative displacements of points in *y*-direction in steady water stream (y_A, y_{P1}, y_{P2}), it can be observed that the lure as is diving, but the points P1 and P2 (the back side of the lure) dive app. 0,5 mm more than the point A (the front side of the lure). The water stream is too slow to initiate oscillatory movement of the fishing lure what results in constant relative displacement of the points in z-direction (Fig. 12). The existence of the lures deflection in –z-direction is (z_A, z_{P1}, z_{P2} different from 0, Fig. 11) is induced by ununiformed distribution of the lure's mass, what is the product of the solid discretization-meshing and numerical calculus.

The water stream of v=0,35 m/s induces a bit deeper diving of the fishing lure (Fig. 13) than with water stream of 0,30 m/s. The backside of the fishing lure goes deeper than the front side, as well. The diving depth is not constant anymore but slightly oscillatory.

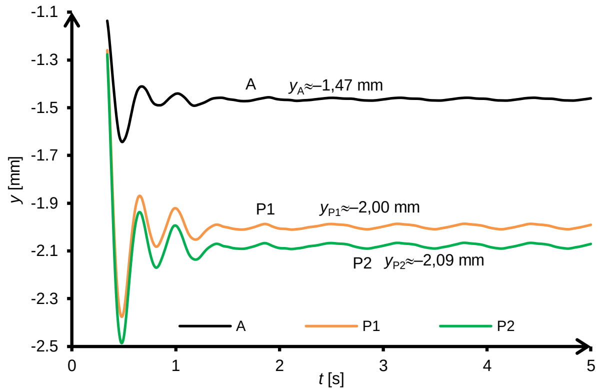

Fig. 13 The relative displacements of points A, P1 and P2 in the y-direction for the water stream of v=0,35 m/s

The lure deflects in ±z direction with a frequency of f_z≈2Hz (Fig. 14) and the deflection of the points is: z_A (z_{Amin}=–0,08 mm; z_{Amax}= 0,05 mm), z_{P1} (z_{P1min}=–0,04 mm; z_{P1max}= 0,41 mm) and z_{P2} (z_{P2min}=–0,08 mm; z_{P2max}= 0,32 mm).

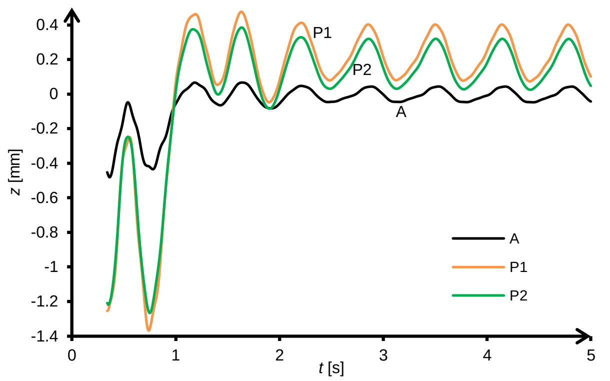

Fig. 14 The relative displacements of points A, P1 and P2 in the z-direction for the water stream of v=0,35 m/s

The water stream of v=0,4 m/s enforces oscillatory and more deeper diving of the lure (Fig. 15). The diving depth of the points varies between y_A (y_{Amin}=–2,51 mm; y_{Amax}=–1,76 mm), y_{P1} (y_{P1min}=–3,52 mm; y_{P1max}=–2,42 mm) and y_{P2} (y_{P2min}=–3,60 mm; y_{P2max}=–2,47 mm) and frequency of f_y≈10Hz. The lure deflects in ±z direction with a frequency of f_z≈10Hz (Fig. 16) and the deflection of the points is: z_A (z_{Amin}=–1,47 mm; z_{Amax}= 1,67 mm), z_{P1} (z_{P1min}=–3,34 mm; z_{P1max}= 3,48 mm) and z_{P2} (z_{P2min}=–1,60 mm; z_{P2max}= 1,70 mm).

The water stream of v=0,5 m/s enforces highly oscillatory and more deeper diving of the lure (Fig. 17). The frequency of oscillations is f_y≈11Hz while the diving amplitude varies between 1mm to 2,5 mm.

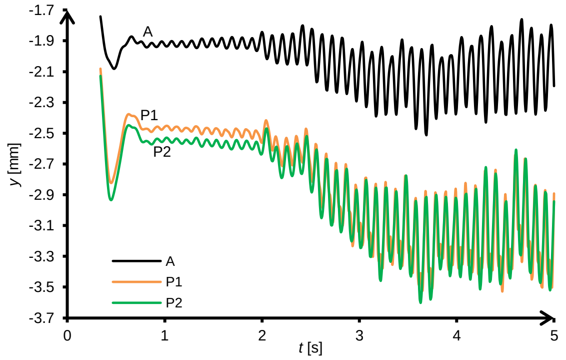

Fig. 15 The relative displacements of points A, P1 and P2 in the y-direction for the water stream of v=0,4 m/s

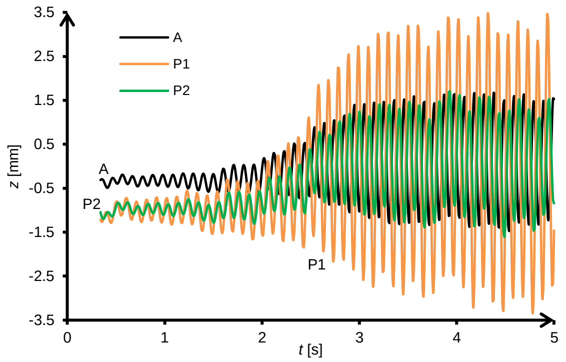

Fig. 16 The relative displacements of points A, P1 and P2 in the z-direction for the water stream of v=0,4 m/s

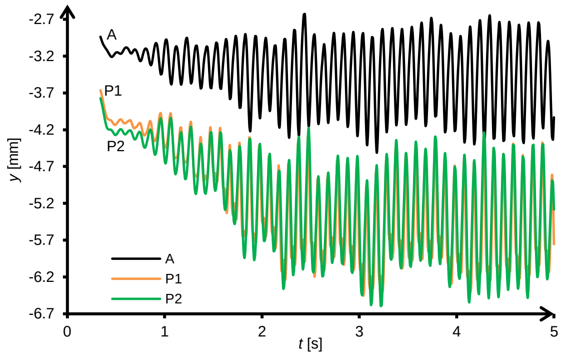

Fig. 17 The relative displacements of points A, P1 and P2 in the y-direction for the water stream of v=0,5 m/s

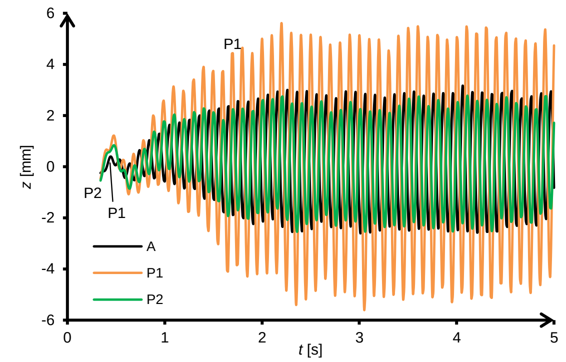

Fig. 18 The relative displacements of points A, P1 and P2 in the z-direction for the water stream of v=0,5 m/s

The deflection in ±z direction is more intensive than for the lower water streams: the frequency is f_z≈11Hz (comparing to 10 Hz for 0,4 m/s), but the amplitudes of point deflections are much higher (from 1 mm to 10 mm, Fig. 18).

The force delivered by the water stream to the fishing lure (over the Fluid Solid Interface) is rather small (Fig. 19). The reasons are that the lure is connected to the elastic fishing line that captures the resistance force and the lure is free to move in the water so the water stream does not deform the lure or stresses it intensively (Fig. 20).

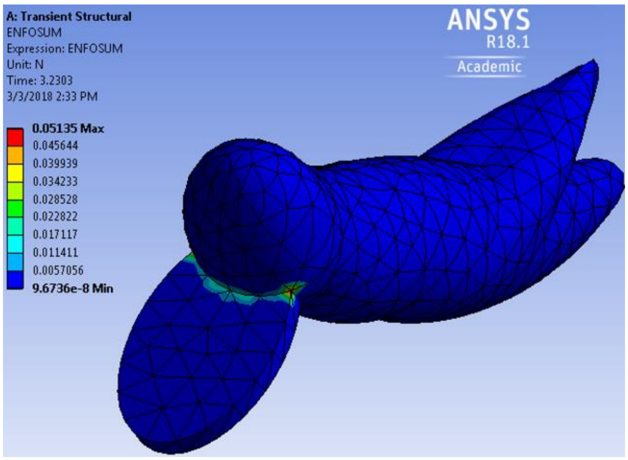

Fig. 19 The intensity of the forces delivered to the fishing lure by the water stream of *v*=0,5 m/s

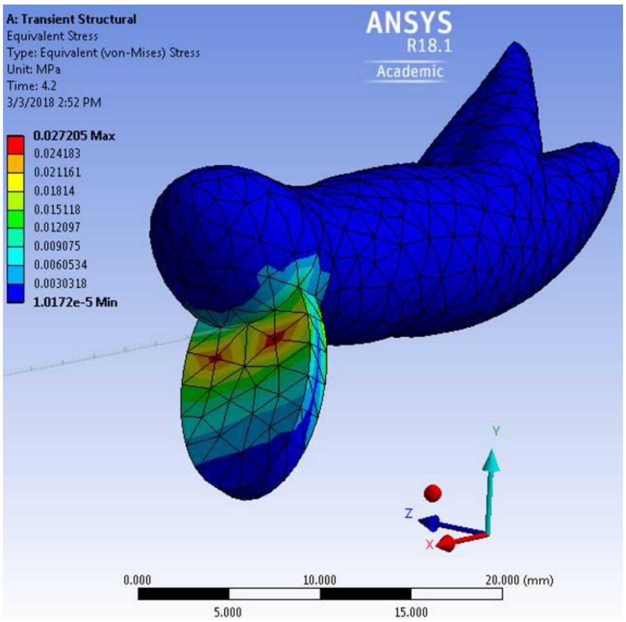

Fig. 20 The equivalent stress in the fishing lure enforced by the water stream of *v*=0,5 m/s

The fishing line does not receive loading from the water stream but only from the fishing lure while restrains it. Therefore, the fishing line is always under pure tension.

V. Conclusions

The coupled FSI analysis of the proposed grasshopper lure shows that the model starts to oscillate in the water flow faster than 0,3 m/s. It is not investigated what is the critical water stream where oscillatory movement of the lure appears but at the 0,37 m/s grasshopper lure oscillates both in lateral horizontal and vertical directions with 2 Hz. With the rise of the water flow, the frequency rises, as well, and at water stream of 0,5 m/s it reaches 11 Hz.

The rise of the water stream's intensity induces diving of the fishing lure and the greatest diving has been recorded for the 0,5 m/s. However, the diving is not uniform – the back side of the lure is diving deeper than the front side of the lure. The maximal diving depth of the complete lure is app. 10 mm what classifies the fishing lure as shallow diving.

Deflection of the fishing lure in lateral direction (z-axis) is intensive if the water stream is 0,35 m/s or higher. The fishing lure deflects maximally 10 mm for the water stream of 0,5 m/s what is the maximal expected water stream in the river. Higher water streams might induce larger deflections and higher oscillation frequencies what might lead to unstable travel of the fishing lure. As a result of such a travel the fish might not be intrigued to attack the lure – it might get scared and swim away from the lure.

Further research will be focused on boundary water streams, improvement of the fluid-flow model and diving lip – the size, shape and position in the fishing lure.

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