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APPLICATION OF THE PROCESSES KINEMATIC SUPPORT AND KINEMATIC GRIP IN WEIGHTLESS CONDITIONS

APLICAÇÃO DOS PROCESSOS DE APOIO CINEMÁTICO E PREENSÃO CINEMÁTICA EM CONDIÇÕES DE INERCIALIDADE

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Abstract
The space industry is increasingly developing its branches in our time. The enormous wealth that the Universe offers is changing people's perception of the category of "wealth". The need for new activities in space imposes new challenges to the designs of spacecraft and their functionality. The space industry will begin with contact, that is, landing, capture and manipulation of small space objects (asteroids). The ability to apply and control the physical processes and phenomena during contact of two bodies in space is of paramount importance for the capture and manipulation of various space objects. In this material, only the physical processes of support and capture will be considered. The connection of robotics and astronautics provides solutions to a number of constructive issues in the kinematic synthesis of future spacecraft intended for the space industry.

Keywords: Space Industry. Asteroid. Support. Grip.

Resumo
A indústria espacial está cada vez mais se expandindo em nossa época. A enorme riqueza que o Universo oferece está mudando a percepção das pessoas sobre o conceito de "riqueza". A necessidade de novas atividades no espaço impõe novos desafios ao projeto das naves espaciais e à sua funcionalidade. A indústria espacial dará início com o contato, ou seja, a aterrissagem, a captura e a manipulação de pequenos objetos espaciais (asteroides). A capacidade de aplicar e controlar os processos e fenômenos físicos durante o contato de dois corpos no espaço é de suma importância para a captura e manipulação de vários objetos espaciais. Neste artigo, serão considerados apenas os processos físicos de suporte e captura. A conexão entre robótica e astronáutica oferece soluções para uma série de questões construtivas na síntese cinemática de futuras espaçonaves destinadas à indústria espacial.

Palavras-chave: *Indústria Espacial. Asteróide. Suporte. Preensão.*

1 INTRODUCTION

The contact of two bodies in space is characterized by many physical phenomena. Among them are landing with its many physical sub-phenomena, support, grip, impact, penetration, sliding, self-centering, etc. Most of them have already been described in publications on the conditions of weightlessness. Support and grip are of great interest due to the fact that with the help of these two physical phenomena two bodies can be temporarily connected for the needs of manipulation [1].

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1.1 Support

The contact between two bodies in the most general case can be considered as a support, which at a given moment in time gives rise to certain types of kinematic phenomena. Kinematic categories (forces, velocities and accelerations) can be constant quantities or time-varying.

Essentially, the support is the point, spot or area of contact between two bodies that are pressed against each other by a force of attraction acting on both bodies. The support can be a point, line, plane, surface or volume (in the case of a fixed support). On Earth, due to the presence of gravity and atmospheric pressure, a huge variety of different types of supports are found in the fauna [2]. Such are:

- Single-point. This is a support in which the contact between the two bodies is a single point or spot, which can be approximated to a single point:
- Two-point. A two-point support, in practice, represents the contact of two bodies along a line in space. In the case of a two-point support, there is a variety in terms of the line. This can be a straight line or a line in space of a higher order:
- Three-point. A three-point support defines a plane of contact in space. This means that the two bodies will contact along a certain plane in space. This plane does not have to be real, it is enough that there are three contact points that do not lie on a straight line:
- Multi-point. A multi-point support is an analogy of a three-point support, in which there are multiple contact points. One of the differences between the two types is that a multi-point support encloses a larger contact area, which can only in a special case be a plane:
- Hybrid. Hybrid support is a combination of support and grip.

When considering a support, one must understand a kinematic structure [3] (independent mechanism). The support, in addition to being an independent mechanism, is always part of a body (global mechanism), where in the process of realizing the support process, this independent support mechanism becomes part of the second body. Thus, there is a kinematic possibility to realize manipulation (controlled movement) between the two bodies.

In practice, the initial data for synthesizing the support in the most general form are:

- the type of force load on the contact area;
- the type of surface of the second body with which contact will be made;
- the type of support;
- the specific manipulative movements that the support must provide in order to optimize the manipulation process.

In the general case, the external load is six-dimensional (three translations and three rotations, that is, three mutually perpendicular forces acting on the body, but not intersecting at one point (1) and three mutually perpendicular moments also acting on the body, their axes of rotation also not intersecting at one point.

$$F_x{}^e = f(t),\ F_y{}^e = f(t),\ F_z{}^e = f(t) \qquad (1)$$

$$M_x{}^e = f(t),\ M_y{}^e = f(t),\ M_z{}^e = f(t) \qquad (2)$$

For convenience in construction, the external load should be transferred to a single point on the first body. An arbitrary point D is chosen on the first body and the external load is transferred to this point.

$$F_{D_x}^e = f(t),\ F_{D_y}^e = f(t),\ F_{D_z}^e = f(t) \qquad (3)$$

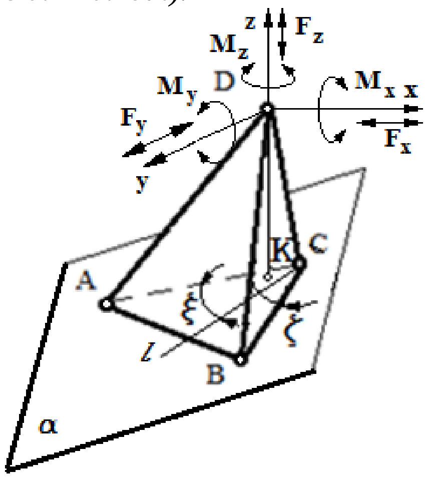
$$M_{D_x}^e = f(t), M_{D_y}^e = f(t), M_{D_z}^e = f(t) \qquad (4)$$

The position of point D in space is absolutely arbitrary [4]. It can be real or unreal, that is, it represents a point where the directrix of forces and moments (2) from the applied external load intersect, but it does not necessarily have a material equivalent. In the kinematic chains of fauna, here on Earth, this is usually the ankle joint [5,6].

As an illustration of the above, in Fig. 1. a diagram of a three-point support loaded at point D and contacting through its side ABC with the plane **a** is shown.

Figure 1

Geometric representation of a three-point support on the plane ***a*** *(in practice this represents a triangular pyramid, whose side ABC can be identified with a plane in space with the help of which the support activity is carried out).*



Thus, the external load concentrated at point D as well as the reducing forces and moments from point D to points A, B, and C cover the entire picture of external influence on the body [7,8]. From which it follows that it is not necessary that the three points (A, B, and C) represent a single unchanging material triangle in time (support triangle).

The three points A, B, and C are points of one body (the body to which the pyramid ABCD belongs), but at the same time, they are also points of the second body (the body to which the plane **a** belongs), as these three points are in practice the points of contact of the two bodies.

In the support process, it is assumed that there is a force that presses the two bodies against each other. Most often, this is the force of gravity, but if the force of gravity is absent or acts repulsively, then support as a physical phenomenon ceases to exist.

1.2 Grip

The entire variety of supports shown in the previous point is also fully valid for the grip. The difference between a support and a grip is that at the support points A, B and C (as was shown, for example, for a three-point support), there are additional mechanisms that implement additional fixed forces at the support points in addition to the support reactions. The fixed forces can be considered as internal to the body to which the pyramid ABCD (3) refers and appear external to the body on the plane a (Fig. 1). And as internal, for one of the bodies, these forces can be easily adjusted in time.

$$\overrightarrow{F^1_{ins.}} = f(t) \qquad (5)$$

Thus, the total compressive force (4) between the two bodies is the sum of the external compressive force $\overrightarrow{F^1_{gravit.}}$ and the internal compressive force $\overrightarrow{F^1_{ins.}(t)}$.

$$\overrightarrow{F^1_{push}}(t) = \overrightarrow{F^1_{ins.}(t)} + \overrightarrow{F^1_{gravit.}} \qquad (6)$$

This shows that even if the external pressure force is zeroed, the internal pressure force from the second body maintains the relationship (5) between the two bodies.

When $\overrightarrow{F^1_{gravit.}}$ = 0, then from formula (4) it follows:

$$\overrightarrow{F^1_{push}}(t) = \overrightarrow{F^1_{ins.}(t)} + 0 \neq 0 \qquad (7)$$

The initial stage of the space industry is believed to start with the capture of asteroids with a predominant polymetallic content and their manipulation. On Earth, the predominant physical phenomenon is the Support, due to the fact that there is an attractive force between the two bodies. In outer space between the spacecraft and the asteroid, in the general case, there is no such attractive force. Therefore, *the physical phenomenon Support in weightlessness cannot be realized. The physical phenomenon Support in outer space is replaced by the physical phenomenon Grip.*

2 PRESENTATION

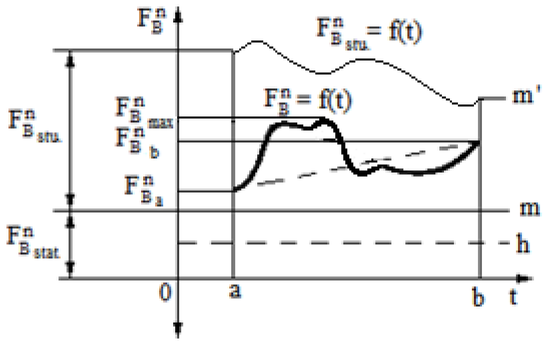
In essence, the support is the point, spot or area of contact between two bodies that are pressed against each other by an attractive force that acts on both bodies. The support can be a point, line, plane, surface or volume (in the case of a clamped support).

In practice, the support is part of one body, and as already noted, it is attached to the other body and becomes part of this other body (with respect to movement).

Fig. 2. shows the graphs of the support force $\overrightarrow{F_B^n} = f(t)$ and the gripping force $\overrightarrow{F_{B_{stu.}}^n} = f(t)$ for the time interval (ab). As can be seen, both quantities are variable and depend on the time *t*.

Figure 2

Example diagram of the location of the support and clamping force for a given time interval



Line m shows the static load, in the physical phenomenon of *Support*, as a result of the external attractive force between the two bodies (as already mentioned, this can be gravity, magnetic force, etc.). Line h is a limiting line in the diagram, reaching which is a critical state for the support process. It is clearly seen that the dynamic processes in the support process additionally load the system.

If the graph $\overrightarrow{F_B^n} = f(t)$ acquires values below the abscissa axis (that is, $\overrightarrow{F_B^n} = f(t)$ becomes negative at a given moment), then the support process breaks down and the bodies separate.

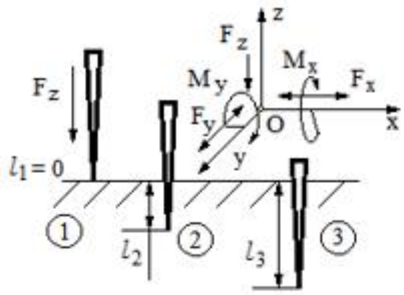
In a grip, there is an additional force $\overrightarrow{F_{B_{stu.}}^n}$ due to the grip (curve m'), in addition to the static force $\overrightarrow{F_{B_{stat.}}^n}$ of attraction between the two bodies (line m). The grip force is internal to the system of the two bodies, and is also a function of time $\overrightarrow{F_{B_{stu.}}^n} = f(t)$ and can be controlled. The sum of the two forces $\overrightarrow{F_{B_{stat.}}^n} + \overrightarrow{F_{B_{stu.}}^n}(t) = \overrightarrow{F_{B_{grip}}^n}(t)$ gives the grip force, where $\overrightarrow{F_{B_{grip}}^n}(t) > \overrightarrow{F_B^n}(t)$.

2.1 Single point support and grip

This is a support where the contact between the two bodies is a single point or spot that can be approximated to a single point.

Figure 3

In crustaceans, limbs with a single point of support, which can easily be converted into a grip, are most often found



a)

b)

In the single-point support shown in Fig. 3. position 1. the first body is shown as a wedge contacting the second body at a single point pressed against each other, only by the force $\overrightarrow{F_z}$. It can be seen that this is an unstable connection of the first class and for its strengthening it is necessary to apply additional mechanisms.

At positions 2 and 3, part of the first body (conical wedge) has penetrated the second body, respectively at depths l_2 and l_3, thus forming a clamped connection. Thus, a 4th class connection is realized between the two bodies (shown in the upper part of the diagram).. The connections of positions 2 and 3 are significantly more stable than position 1. The magnitudes of the clamped forces in these cases depend on the geometric dimensions of the clamped support, namely the depths l_2 and l_3, the solid angle at which the penetration of one body into the other occurs, and other characteristics.

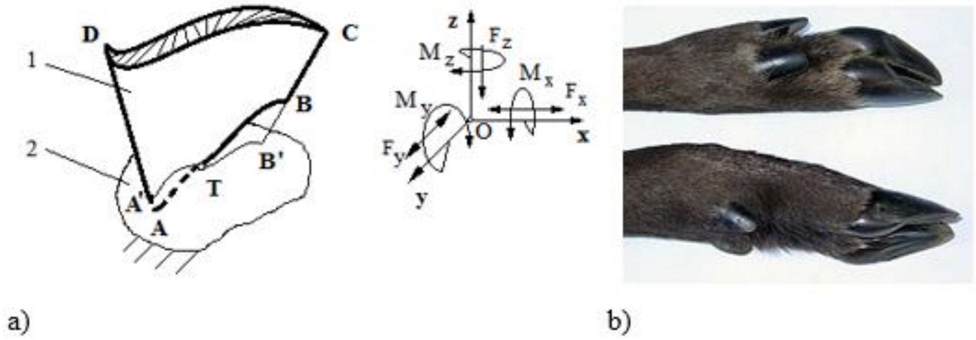
2.2 Two-point support and grip

A two-point support, in practice, is a contact of two bodies along a line in space (the curve A‘B‘, Fig. 4., a).). In particular, this line can be straight. A two-point support or grip is a methodologically separate, transitional support or grip between a one-point and a three-point support or grip, which find great application in practice.

In the two-point support, the first signs of the physical phenomenon of *self-centering* are observed. This is a phenomenon in which the first contact of the two bodies, usually, is realized at a given point, after which the support process continues, through the physical phenomenon of self-centering, until a second point comes into contact and the two contact points form the two-point support, although the line drawn by the two points is not real. The two contact points may be real points of a real three-dimensional line of a higher degree, but the fact that only two points of this line are in contact turns the support into a two-point support.

Figure 4

In artiodactyls, there is a paired variant of two-point support



The body 1 shown in Fig. 4. is a spatial wedge-shaped body ABCD, with edges DA, AB and BC being sharp, and DC is a cross-section showing the volume of the body. The support process is reduced to overlapping the line AB of body 1 with the line A‘B‘ of body 2. In this case, it is a question of creating only and only support reactions between the two bodies along the line of contact.

When body 1 has partially penetrated body 2 along the line A‘T (Fig. 4. a)) at a depth A‘A, it is already a question of grip and in addition to support reactions along the line of contact, there are also stuck forces in the penetration zone AA‘T. As can be seen from the possible gripping forces between the single-point grip and the linear grip, there are all three mutually perpendicular moments of resistance forces.

As an example from Earth's nature, there are a number of living creatures in the fauna that at some point in their gait use the linear support and grip (Fig. 4. c) of the legs of an artiodactyl, where the lines of primary contact are clearly visible.

3 THREE-POINT SUPPORT AND GRIP

In the introductory part, as an example, the three-point support was considered, in part. In this section, the three-point support and grip will be explained in more detail. In practice, the three-point support is a mechanism that establishes contact between two bodies along a plane. This plane is in most cases virtual (introduced for methodological reasons), and the contact itself is realized at three contact points, but a large part of the forces and their components lie or intersect this plane at a certain angle.

3.1 Three-point support

A three-point support is a plane support and is a geometric-mechanical element of kinematic systems. The three-point support is the first support listed above that is an independently stable mechanical unit. This is due to the minimal requirements of geometric laws for defining a plane in space, which in turn can characterize an entire body.

By definition from geometry*, any three points in space that do not lie on a straight line determine a plane in space.*

Each three-point support must be understood as an independent mechanism (kinematic structure). A three-point support, in addition to being an independent mechanism, is always part of a body or another mechanism.

In general, in mechanics, a three-point support is considered as a triangular pyramid with height KD (Fig. 1.), where point D is the top of the pyramid above the plane defined by the three contact points A, B and C, which in practice represent points of the two bodies.

Point D can be real or unreal in the real construction of the support. It is an extremely important point, since the external load of the two bodies is concentrated in it, as well as the center of rotation in the self-centering effect of the connection.

An example of a real point D is when there is a differential gear mechanism with bevel gears connecting the support triangle to the manipulation system. In this case, point D is located in the center of the axis connecting the two satellite gears.

An unreal point D is observed in cases where it is not part of a given machine element. This is the case when the connecting mechanism between the support triangle and the manipulation system is, for example, the mechanism known as the "Steward Platform". In this case, point D is between the machine elements and has no material expression.

Finding the support reactions at the support points is a classic task for finding support reactions, as functions of position and time. The most important thing here is to study these support reaction functions for the existence of regions of the parameter intervals in which any of the components of the support reactions can be zeroed or acquire a negative value. In these intervals, the support reactions actually repel the second body. So, when these components are zeroed or become negative, the physical phenomenon of support cannot be realized.

3.2 Three-point grip

The component of the support reactions, which is along the normal to the plane **a**, plays a great role. This component ensures the pressing of the support triangle ABC to the plane **a**.

Fig. 2 shows a graph of how the force $\overrightarrow{F_B^n}(t)$ changes in the interval (a, b) above the line *m* (line *m* is a limit line of the minimum values of the force $\overrightarrow{F_B^n}(t)$), which shows the change in the normal reaction at point B, as a result of the external load. It is clearly seen that in the time interval (a,b), dynamic processes additionally load the system. The line *h* is a constructive limiting line in the diagram, reaching which is a critical state for the support process. If the process in which the force $\overrightarrow{F_B^n}(t)$ becomes negative. That is, at this moment a separation of point B from the plane **a** is observed. This process interrupts the support process in the interval (a, b).

If there is a possibility that the components of the support reactions that press the three-point support to the plane a are zeroed, even for a short time, the support cannot be realized, in this case, resort is made to the synthesis of a three-point grip. During the grip, the support reactions can acquire different values, without limitation, whether they are positive, negative or zeroed.

The forces at the support points A, B and C during the grip increase in comparison with the forces at the same points at the support. The grip adds stuck forces at the support points, therefore equations (1) take the form:

$$F_B^n = f\left(F_D^e + F_{A_{\text{зап.}}}^e\right) \qquad (8)$$

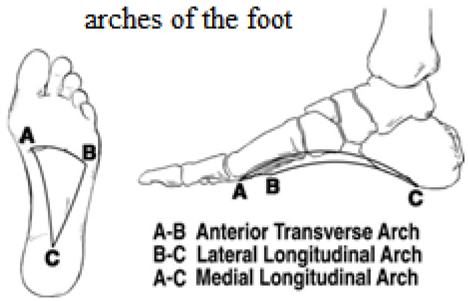
$$M_B = f\left(M_D^e + M_{A_{\text{зап.}}}^e\right) \qquad (9)$$

The clamping forces are not due to external forces, they are due to the kinematic movement of the three-point grip and its effect on the second body. This shows that the clamping forces depend on the design solution of the three-point grip. That is, the magnitude of $\overrightarrow{F_{B_{\text{зап.}}}^n}$ can be set by the designer. Thus, the line m from Fig. 1., is moved in height, to position m', due to the increase in the forces from the grip. In practice, the grip forces exceed the support reactions in absolute value, which fully guarantees the gripping process.

In many cases, the complex kinematics of the human foot, purely methodologically, can be reduced to a three-point support with partial gripping devices.

Figure 5

The human foot can also be considered as a three-point support.



4 MULTIPOINT SUPPORT AND GRIP

The multipoint support is an analogy of the three-point support, the difference between the two types is that the multipoint support encloses a larger contact area, which can only be a plane in a special case. In the case of the multipoint support, the support triangle from Fig. 1 is transformed into a spatial polygon, which can only be assumed to be a plane in very rare cases. Unlike the three-point support, which always describes a plane in space, the multipoint support adjusts itself according to the terrain of the second body.

The self-centering effect, which is noticeably observed in the three-point support, in the multi-point support its importance decreases, since the support points contact the surface of the second body independently, being located in the three-dimensional space according to the contact surface.

Application of a multi-point support is applied when there is a result of an analysis of the support reactions and it is established that there are serious overloads in separate zones of the support. In these cases, an additional point or points of contact are created in order to redistribute the efforts from the support reactions. In this way, the multi-point support contacts a larger area than the three-point support and creates conditions for better regulation of the efforts.

Multi-point grip is a very good solution in terms of possibilities for grip between two bodies in any situation (in the presence or absence of an attractive force, in the presence of large amplitudes of the normal support reactions or in increasing the probability of a secure grip of the given grip mechanism, etc.).

Figure 6

Drawings of the feet of birds using multi-point support and grip. 1. Lark – support. 2. Pheasant – mainly support. 3. Eagle – grip. 4. Owl – grip.

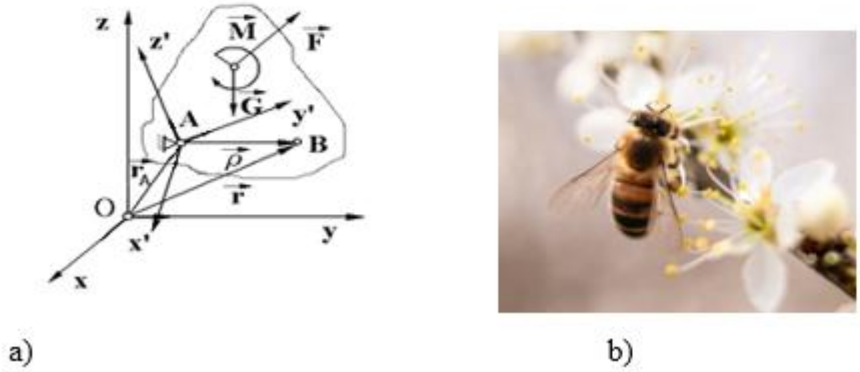
5 HYBRID SUPPORT WITH GRIP

In order to be able to deduce the need for a hybrid support with grip, it is necessary to perform a force analysis of the action of all external forces acting on the two contact bodies. The possible external loads shown above on the different types of supports and grips concentrated at one point are variable in time in the general case. For the demonstration of the method, it is assumed that the attractive force is a constant value (this can be approximated for the conditions of the Earth for a certain segment of altitude), that is, $\vec{G}$ = const.

In the sources, the position of a rigid body is approximated by the position of a triangle. The task can be significantly simplified if the locomotion method is used to perform force analysis. In this case, one body is represented by a segment (AB)¯ Fig.7. a). This segment represents a bridge between two manipulators (legs), with the help of which locomotion is performed. It is extremely characteristic in the field of kinematic synthesis of locomotion kinematic systems and is called - bridge.

Figure 7

Determining the position of a rigid body in space



To determine the position of a rigid body, the above-mentioned bridge segment is used $\overline{AB}$ (the position of the bridge segment is assumed to be parallel to the abscissa axis, and the xOy plane is the surface of the second body) in space and the coordinate system $Oxyz$ associated with the second body is introduced. The movable coordinate system $Ax'y'z'$ associated with the first body is also introduced, with the rotation pole at point A as its center. The first body, under the influence of the external dynamo $\vec{F}\vec{M}$, performs a movement relative to the second body, which can be calculated from these two coordinate systems. In addition to the dynamo $\vec{F}\vec{M}$, the figure also shows the force of gravity $\vec{G}$ (the attractive force for both bodies, in this case on Earth), which is also part of the external load on the first body. In Fig. 7. b) the bridge segment can be illustrated as part of the bee's body, and the second body is the branch and the flower on which it has perched. During its locomotion, the bee assumes different positions relative to the flower, but the force of attraction is always in one direction and in the different positions, the bee uses different methods of contact.

- If the directrix of the gravity force $\vec{G}$ is directed towards the segment $\overline{AB}$ and intersects it, then this is a normal support.
- If the directrix of the gravity force $\vec{G}$ is not perpendicular and does not intersect the segment $\overline{AB}$, then an additional torque will act on the segment. In this case, a hybrid support with a grip is needed.
- If the directrix of the gravity force $\vec{G}$ is perpendicular and intersects the segment $\overline{AB}$, then this case also requires a hybrid support with a grip.
- If the directrix of the gravity force $\vec{G}$ is directed opposite to the segment $\overline{AB}$, intersects it, or has such a component, then only a grip is needed.

In the listed variants of the positions of the two bodies relative to the attractive force $\vec{G}$, the capabilities of the support and the grip are used to varying degrees. With a full force analysis of the behavior of external forces, it is possible to specify the input parameters for the synthesis of the support and the grip. The hybrid support with grip is a universal kinematic mechanism allowing the realization of a secure contact between the two bodies in different situations. This characterizes the hybrid support with grip as a universal support, both in conditions where there is a pressing force between the two contacting bodies, and when such a force does not exist.

6 CONCLUSION

The launch of the space industry will place extremely high demands on the designs of future spacecraft and their power units. The pursuit and capture of certain space bodies (asteroids) requires the management of physical phenomena associated with enormous efforts, the impact of which cannot be ignored. This requires a very good study of the physical processes that would occur in weightlessness.

The development of mechanics in the direction of the synthesis of three-point, multi-point and hybrid supports and grips, provides an opportunity for the development of landing, manipulation and locomotion on space bodies without gravitational forces.

The structural design of spacecraft created for the space industry begins with the types of supports and grips. This is especially important in the development of the space industry, where contact with space bodies is inevitable.

Here on Earth, in the fauna (insects, birds, etc.), which land on flowers, trees, climb them, often in the opposite direction of the action of gravity *the force of attraction), have limbs ending in hybrid supports. This shows the accuracy of the conceptual approach for the constructive synthesis of supports and grips. The study of the movement of the external load on the support, respectively the grip at point D, gives an unambiguous answer which of the types of supports or grips are suitable for the specific case.

REFERENCES

Gomes, M. W. et al. A five-link 2D brachioting ape model with life-like motions and no energy cost. *Theoretical and Applied Mechanics*. Ithaca: Cornell University, 2004.

Iliev, M. *Trajectory planning for manipulation systems with multiple degrees of freedom*. Plovdiv, 1998.

Li, B.; Holstein, H. Recognition of human periodic motion: a frequency domain approach. In: *16th International Conference on Pattern Recognition Proceedings*, v. 1, p. 311–314, 2002.

Madarász, J. Disponível em: *https://mek.oszk.hu/00500/00550/html/madar-09.htm*. Acesso em: 4 jun. 2025.

Sinilkov, P. *Analytical synthesis of mechanisms for the limbs of legged mobile robots*. In: *21st International Conference on Robotics and Mechatronics: Proceedings of the Scientific and Technical Council on Mechanical Engineering*. Varna, 19–21 set. 2011. ISSN 1310-3946.

Sinilkov, P. *Opportunities for creating industry outside Earth*. In: *S.E.S.*. Sofia, 22–25 out. 2024. p. 146–151. ISSN 2603-3313.

Sinilkov, P. *Synthesis of legged mobile mechanisms*. Tese de doutorado na área profissional 5.1 Mechanical Engineering, especialidade científica Robots and Manipulators. Sofia, 30 mar. 2015.

Stefanov, T. *Design of control systems with variable structure*. Sofia: Tekhnika, 1986.

Wisse, M. *Essentials of dynamic walking*. 2004.