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# ASSESSMENT CRITERION OF STRUCTURAL RESOURCES OF FLIGHT SIMULATOR MOTION SYSTEM

**Ua** На засадах врахування особливостей сприйняття пілотом інформації про рух і положення повітряного судна й особливостей просторового пілотування сформульований критерій оцінки використання конструктивних ресурсів динамічних стендів комплексних тренажерів повітряних суден. Розроблений критерій використовувався при розробці систем рухомості комплексних тренажерів літаків Іл-96-300 іТу-204 (Росія, Пензенське конструкторське бюро

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моделювання), Ан-74ТК-200 і Ан-140 (Україна, ДП «Антонов»). Це дало можливість оцінити конструктивні ресурси динамічних стендів і на підґрунті їхнього ефективного використання підвищити якість імітації акселераційних впливів.

**Ru** На основе учета особенностей восприятия пилотом информации о движении и положении воздушного судна и особенностей пространственного пилотирования сформулирован критерий оценки использования конструктивных ресурсов динамических стендов комплексных тренажеров воздушных судов. Разработанный критерий использовался при разработке систем подвижной комплексных тренажеров самолетов Ил-96-300 и ту-204 (Россия, Пензенское конструкторское бюро моделирования), Ан-74ТК-200 и Ан-140 (Украина, ГП «Антонов»). Это дало возможность оценить конструктивные ресурсы динамических стендов и на основе их эффективного использования повысить качество имитации акселерационного воздействий.

## Statement of problem

Flight simulator is an important technical device for solving a set of tasks of flight dynamics, flight performance research and aircraft design, which is practically not solved by other devices, as well as training and retraining of pilots. Although piloting on a flight simulator differs from piloting on an aircraft, their use instead of aircraft has significant advantages. The flight simulators are designed and manufactured by such large enterprises as CAE Electronics (Canada), Thales Training & Simulation (France) and Penza’ Modeling Design Bureau (Russia), and, on the other hand, by such individual aviation enterprises as State Enterprise “Antonov”.

Flight simulator fidelity determines both flight safety and flight regularity and depends on their perfection level and in particular on perfection level of force cueing system - one of the most important components of a flight simulator. In Ukraine, the first six-degrees-of-freedom motion system in the flight simulator of aircraft An-74TK-200 was designed in the mid-nineties. The six-degrees-of-freedom motion system is going to be used in flight simulators of all designed aircraft. So it is very important both to formulate an assessment criterion for evaluating of structural resources of motion systems of aircraft flight simulators and to improve force cueing fidelity on basis of evaluated structural resources.

## Analysis of last achievements and publications

A wide range of technical devices [1, 10, 11, 12] is used for force cueing of whole set of force cues: from vibration stands and vibrators to motion systems and dynamic seats. Modern motion systems able force cueing of low-frequency force cue up to 0,4 g and high-frequency force cue up to 10 Hz and above. Due to this fact they are the main force cueing device and for non-maneuverable aircraft the only technical device of force cueing. For this purpose, a flight simulator compartment is mounted on a mobile basis - motion system. The degree of mobility of motion system is determined by the number of its degrees of freedom.

The design [11] proposed by Stewart (fig. 1) was found to be most effective among proposed designs when using heavy flight compartments of modern non-maneuverable aircraft and the need to provide motion system ranges of linear displacements over 1 m and angular displacements of 25 degrees. It provides a displacement of motion system along six degrees of freedom with less friction, less mass of moving parts, better dynamic characteristics, simpler design, which does not limit inspection through flight compartment canopy.

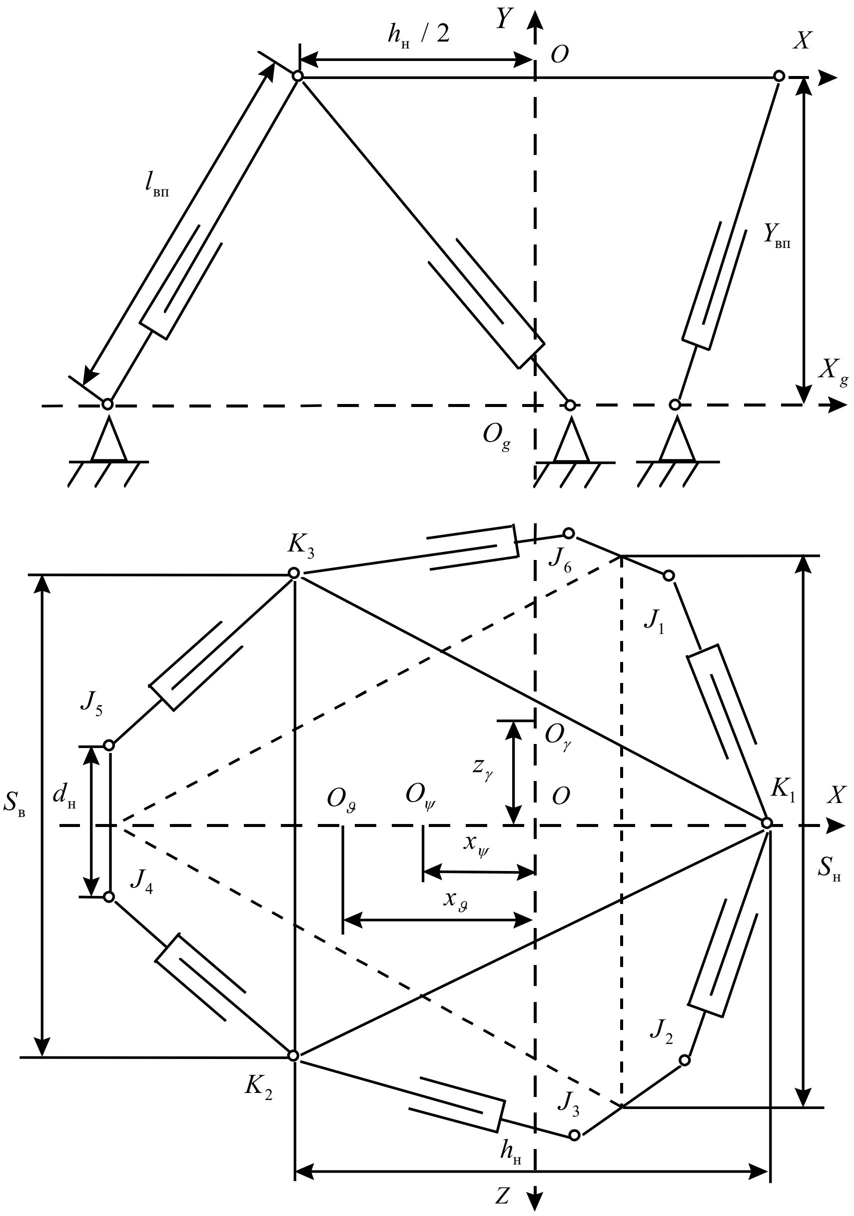

Fig. 1. Kinematic diagram of six-degrees-of-freedom motion system

Many investigations [1 – 9] of force cueing were conducted in order to increase an efficiency of flight simulators.

## Formulation of purpose

One of the most important factors determining the force cueing fidelity on flight simulator is a jack length. Actuality of determining of required jack length is caused with both requirements of improving of force cuing fidelity and reducing of motion system cost. On the one hand, the required jack length is main factor in determining of operating ranges of motion system displacement. Therefore, it should be sufficient for force cueing as close as possible to perception of real force cues. On the other hand, a motion system is expensive. Increasing of jack length leads to a sharp increase of technical difficulties and cost of motion system. So jack length should not be too large. It should be noted that increasing of jack length is not an obvious and sufficient condition for high fidelity of force cueing, since this reduces stiffness of motion system structure, and even with narrowing of permissible range of changes of motion system performances, it is not always possible to maintain a force cueing fidelity. Therefore, a jack length should not be too large.

## Presentation of basic material

According to approach of theoretical mechanics a totality of kinematically possible motions of motion system is given in a form of area $\tilde{U}$ of possible positions of motion system in the n-dimensional space of n composite coordinates.

The following ranges of motion system displacements are required for force cueing:

- along longitudinal, vertical and lateral degrees of freedom $x_{\min} = y_{\min} = z_{\min}$ =0,4 m;
- along the roll $\gamma_{\min}$ = 3,5 deg;
- along both the roll and the lateral degree of freedom $\gamma_{\Sigma \min}$ = 10 deg;
- along the yaw $\psi_{\min}$ = 4 degrees;
- along both the pitch and the longitudinal degree of freedom $\vartheta_{\min}$ = 9 deg.

Space of possible positions of motion system $\tilde{U}$ is very limited due to economic and technical limitations. Due to this the approach on the basis of theoretical mechanics is not effective. So according to calculation it is necessary to have motion system with more 2 m length jacks (up to 10 m). Except necessity to decide some complicated technical problems this approach is very expensive. For effective decision problem it is important to identify factors influencing on structural resource of motion system for its analysis and design of motion system.

Available structural resources of motion system are used inefficiently in traditional methods of force cueing along several degrees of freedom simultaneously. Motion systems with larger lengths of jacks are used for improvement of force cueing fidelity. This is economically inexpedient. Problem of force cueing fidelity along all six degrees of freedom coordinated with real force cue includes two components:

- taking into account peculiarities of both appearance of force cues caused by spatial aircraft displacement and their force cueing;
- taking into account of structural resources of motion system.

The conducted studies have showed that a human has only one decision making channel, through which all information is gradually passed, and that in process of multichannel control, a human works as a single channel regulator with sequential switching attention. This factor, as well as a presence of minimum intervals between occurrence of perceived force cue, is based on use of force cueing priorities scheme in terms of degrees of freedom: force cues along linear degrees of freedom are considered as independent of each other and force cueing is carried out in this way.

As special significance for piloting an aircraft motion along pitch has an absolute force cueing priority and is carried out under any conditions. Only both the aircraft pitch and the force cue along yaw are force cueing compatible with force cue along the longitudinal degree of freedom. Only both the aircraft pitch and the force cue along the roll are force cueing compatible with force cue along the vertical degree of freedom. Only both the aircraft pitch and the force cue along roll and yaw are force cueing compatible with force cue along the lateral degree of freedom.

According to this a geometric meaning of problem is reduced to insertion of three parallelepipeds into a space of possible positions of motion system $\tilde{U}$ in turn, namely:

- a parallelepiped $\tilde{P}_{\vartheta 1}$ whose edge lengths are equal to working ranges of motion system displacements along the longitudinal degree of freedom, pitch and yaw $\tilde{P}_{\vartheta 1}=\left\{(x,\vartheta,\psi)\middle|-x^*\le x\le x^*,-\vartheta^*\le\vartheta\le\vartheta^*,-\psi^*\le\psi\le\psi^*\right\}$, where $x^*,x,\vartheta^*,\vartheta,\psi^*,\psi$ are working displacement ranges and motion system displacements along the longitudinal degree of freedom, pitch, yaw respectively;
- a parallelepiped $\tilde{P}_{\vartheta 2}$ whose edge lengths are equal to working ranges of motion system displacements along the vertical degree of freedom, pitch and roll $\tilde{P}_{\vartheta 2}=\left\{(y,\vartheta,\gamma)\middle|-y^*\le y\le y^*,-\vartheta^*\le\vartheta\le\vartheta^*,-\gamma^*\le\gamma\le\gamma^*\right\}$, where $y^*,y,\gamma^*,\gamma$ are working displacement ranges and motion system displacements along the vertical degree of freedom and roll respectively;
- a hyperparallelepiped $\tilde{P}_{\vartheta 3}$ whose edge lengths are equal to working ranges of motion system displacements along the lateral degree of freedom, pitching, yaw and roll $\tilde{P}_{\vartheta 3}=\left\{(z,\vartheta,\gamma_\Sigma,\psi)\middle|-z^*\le z\le z^*,-\vartheta^*\le\vartheta\le\vartheta^*,-\gamma_\Sigma^*\le\gamma_\Sigma\le\gamma_\Sigma^*,-\psi^*\le\psi\le\psi^*\right\}$,

where $z^*, z, \gamma_\Sigma^*, \gamma_\Sigma$ are working displacement range and motion system displacement along both the lateral degree of freedom and the roll and static force cueing along the lateral degree of freedom respectively.

The basis for evaluation of structural resources of motion system is their permissible displacement, calculated according to accepted priority scheme of force cueing along degrees of freedom. Along the linear degrees of freedom the structural resources of motion system can be estimated with dependences of permissible linear displacements of motion system along the longitudinal $\bar{x}(\vartheta)$, vertical $\bar{y}(\vartheta)$ and lateral $\bar{z}(\vartheta)$ degrees of freedom from the pitch angle, calculated on the basis of accepted priority scheme of force cueing along degrees of freedom:

$$\bar{x}(\vartheta) \to \max_{L_\text{j},\psi,\vartheta} x;\left(L_\text{j} \in \Omega_l; -\vartheta^* \le \vartheta \le \vartheta^*; -\psi^* \le \psi \le \psi^*\right),$$

$$\bar{y}(\vartheta) \to \max_{L_\text{j},\psi,\vartheta} y;\left(L_\text{j} \in \Omega_l; -\vartheta^* \le \vartheta \le \vartheta^*; -\gamma^* \le \gamma \le \gamma^*\right),$$

$$\bar{z}(\vartheta) \to \max_{L_\text{j},\gamma_\Sigma,\psi,\vartheta} z;\left(L_\text{j} \in \Omega_l; -\vartheta^* \le \vartheta \le \vartheta^*; -\gamma_\Sigma^* \le \gamma_\Sigma \le \gamma_\Sigma^*; -\psi^* \le \psi \le \psi^*\right),$$

where $L_\text{j}$ is length of jacks,

$\Omega_l$ is applicable domain of length of jacks.

The calculated dependences of admissible displacements along the longitudinal, vertical and lateral degrees of freedom from the angle of pitch of motion system with 1,5 m jacks are shown in Figure 5. The structural resources of motion system along degrees of freedom are used irrationally.

The structural resource is determined by disagreement between the permissible displacement of the motion system with 1,5 m jacks (fig. 2, fig. 3 and fig. 4, curves 1) and the working displacement range of the motion system (fig. 2, fig. 3 and fig. 4, curves 3) for the same degree of freedom.

Thus, the positive vertical displacement of the motion system , which corresponds to the limited negative value of pitch working range, is less than other permissible vertical displacements of the motion system, and it defines the operating range of the motion system displacement along the vertical degree of freedom. Similar relations along other degrees of freedom. In particular, the working displacement range of the motion system along the pitch is determined by the permissible displacements of the motion system along the lateral degree of freedom. There is an unused structural resource of the motion system along both the longitudinal and vertical degrees of freedom.

At the maximum use of structural resources of motion system (fig. 2, fig. 3 and fig. 4, curves 1), the admissible positive $\bar{y}^+$ and negative $\bar{y}^-$ vertical displacements corresponding to the limited negative $-\vartheta^*$ and positive $\vartheta^*$ values of the working range of the motion system pitch are almost equal.

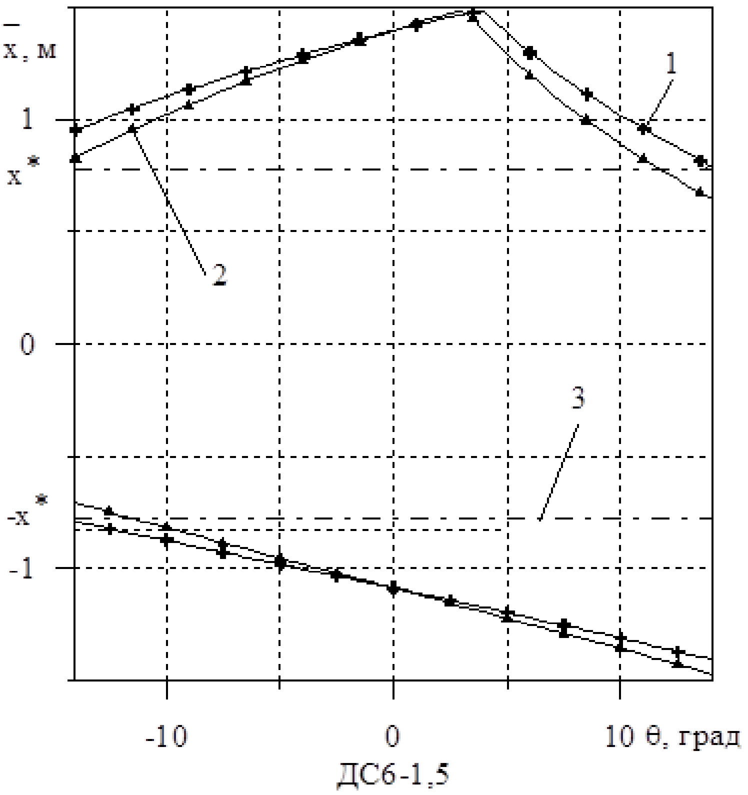

Fig. 2. Permissible motion system displacements in effective (1), traditional (2) force cueing and maximum working ranges of motion system displacements (3) along the longitudinal degree of freedom

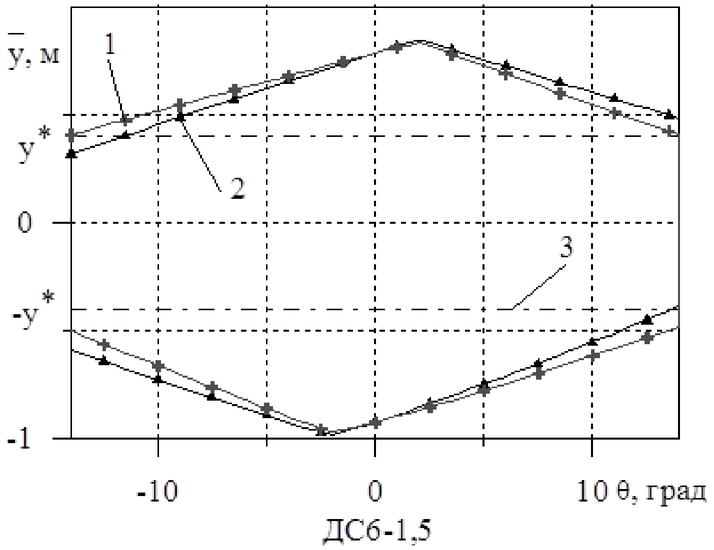

Fig. 3. Permissible motion system displacements in effective (1), traditional (2) force cueing and maximum working ranges of motion system displacements (3) along the vertical degree of freedom

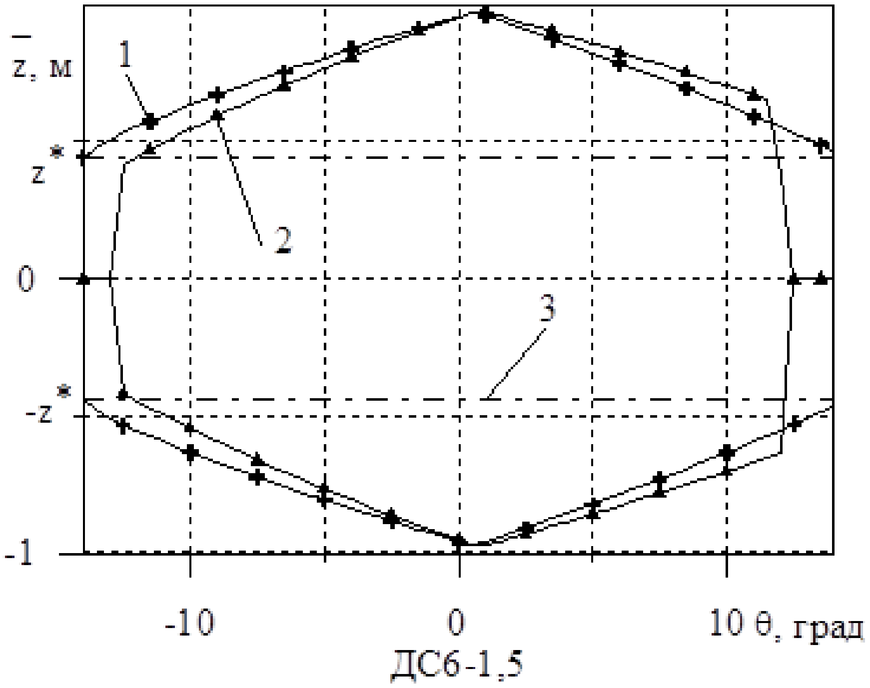

Fig. 4. Permissible motion system displacements in effective (1), traditional (2) force cueing and maximum working ranges of motion system displacements (3) along the lateral degree of freedom

Almost equal negative and positive permissible displacements of motion system with a lateral degree of freedom corresponding to limited negative and positive values of motion system pitch working range. Thus, at maximum use of structural motion system resources, it is possible to obtain larger working ranges of motion system displacement (fig. 2, fig. 3 and fig. 4, curves 3).

It is desirable that the structural resource of motion system was used in full and the permissible displacements was equal to the value of the appropriate working displacement ranges. Criterion for evaluating structural resources of the motion system along the longitudinal, vertical, lateral degrees of freedom are calculated by the formula

$$J=\int_{-\vartheta^*}^{\vartheta^*}\left|\bar{x}(\vartheta)-x^*\right|^2 d\vartheta+\int_{-\vartheta}^{\vartheta}\left|\bar{y}(\vartheta)-y^*\right|^2 d\vartheta+\int_{-\vartheta}^{\vartheta}\left|\bar{z}(\vartheta)-z^*\right|^2 d\vartheta .$$

## Conclusion

After evaluation of structural resources of motion systems it is necessary to develop method of use of untapped structural resources for improving force cueing fidelity.

## Reference

1. *Александров В.В., Садовничий В.А., Чугунов О.Д.* Математические задачи динамической имитации полета. – М.: МГУ. – 1986. – 181 с.
2. *Базилевский А.Н., Гузий А.Н. Мо*делирование поля информации в авиационных тренажерах. – К.: Общество "Знание" УССР. – 1975. – 55 с.
3. *Ashworth Billy R., McKissick Burnell T., Parrish Russell V.* Effect of Motion Base and g-Seat on Simulator Pilot Performance // NASA Technical Paper 2247, 1984. – 23 p.
4. *Borah, J., Young, L.R. and Curry, R.E.* Sensory Mechanism Modeling, AFHRL-TR-77-70, October 1977 – 89 p.
5. *Bray, Richard S.* Visual and Motion Cueing in Helicopter Simulation, AGARD Flight Simulation, AGARD-CP-408, September 1975 – 19 p.
6. *Bussolari S.R., Young L.R., Lee A.T.* The Use of Vestibular Models for Design and Evaluation of Flight Simulator Motion// Collect. Techn. Pap. "AIAA Flight Simul. Technol. Conf. and Exhib.", Boston, Aug. 14-16, 1989. – Washington (D.C.). – 1989. – p. 86-93.
7. *Cardullo M. Frank et al* A System Approach to the Perception of Motion in Flight Simulators// Proceedings of 50 Years Flight Simul. Conf, Sess. 2. – Buckingham. – 1979. – p. 95-102.
8. *Gum Don R.* Modeling of the human force and motion-sensing mechanisms, AFHRL –TR – 72 – 54, 1973 – 92 p.
9. *Hall, J.R.* The Need for Platform Motion in Modern Piloted Flight Training Simulators, Tech Memo FM 35, Royal Aerospace Establishment, Bedford, UK, October 1989. – 16 p.
10. *Heintzman Richard J.* Determination of Force Cueing Requirements for Tactical Combat Flight Training Devices // SIMTEC, Inc. 10364 Battleview Parkway Manassas, ASC-TR-97-5001, February 1996 – 153 p.
11. *Stewart D.* A Platform with Six Degrees of Freedom// Aircraft Engineering. – 1966. – v. 38. – № 4. – p. 30-35.
12. *Valverde Horace H.* Flight Simulators. A Review of the Research and Development // AMRL – TR – 68 – 97, July 1968 – 140 p.