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TRANSGRESSION INVESTIGATIONS OF HELICOPTER DYNAMICS

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Abstract

This paper presents a concept of investigating helicopters in limit conditions, as this will make it feasible to estimate dynamic parameters of the system when transgressing admissible limits, and utilizing computer aids, laboratory experiments on a research simulator and flight tests of extreme character.

1. Introduction

The important problem for the safety and development of a designed and operated helicopter construction is its resistance to transgressing admissible limits. This means that the destruction of the system should not occur suddenly, and that the controllability of the system would be preverved, thus making it possible to execute a safety manoeuver. Should, however, a substantial transgression of limits of the system take place, then the survivability of persons on board of the helicopter should be ensured.

The philosophy of designing the construction in such a way is being developed recently, and has already resulted in significant practical benefits, although the investigations are being concentrated on the final phase /effects of transgressing system limits/ pertaining to the process of destruction of the helicopter structure /1/.

The article deals with the problem of development of the phenomena which precede the final phase, including the investigations on the controllability of the system.

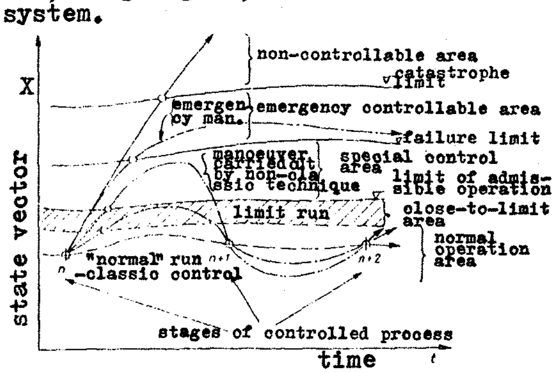
This is for the reason that considerable reserves exist in that area which permit to increase the safety range of operating the helicopter by utilizing informations about the investigations of extreme character. The complementarity of such investigations and the investigations of system destruction should substantially influence the safety level of the helicopter, as well as its operational efficiency.

2. Concept of transgression investigations

To define the area of investigations more specifically it will be helpful to outline the concept of solution for anticipated problems. There are features they share in common contained in the notion of transgression[x/]. For they refer to a process taking place near the limits, situations when limits are exceeded, estimates as to a possibility to return from beyond the limits. Also they embrace the reasons for exceeding limits such as control error, system failure, breaking rules forced by circumstances or deliberate as a result of investigation procedure. Finally they cover cases of unintentional transgression in extreme situations.

Fig.1 illustrates the issue of transgression depicting possible runs of a controlled process which effects phases n, n+1,..., where respective limits and areas could be described as:

- limits and areas of risk - when limit proximity essentially affects the system data so that the way of control has to be modified by this proximity;
- admissible - when having the limit exceeded it is still possible to return to the original process by special way of control with no process changes involved;
- failure - when following limit transgression damage occurs to the system, yet it is possible to interrupt the process safely using emergency control technique at the cost of inability to continue the process as intended before;
- crash - when following limit transgression the system becomes uncontrollable and, if going on, it may destroy the system.



1. Types of control process runs for various cases of transgression.

x/ Lat. transgressio - in narrow meaning: crossing, in a broader sense: crossing boundres, infringing law and regulations, exceeding one's own limits and competence.

Selection and proper arrangement of transgression issues encourage the attempt of transgression as investigation method under limit conditions. Exceeding the following limits, that is transgression, is the best way to discover and to specify the kind and position of those limits. It provides information on either increase or decrease in the intensity of dangerous of transgression and spaces between successive limits.

The introduction of system transgression as investigation method will permit the following:

1. strict establishment of its limits /by confirming or denying their existance,
2. detection of its weak and critical points,
3. reliable estimation of its limit data and adjustment.

Interdisciplinary approach gives a chance to conduct investigations in a proper direction by introducing the elements of control theory, models of operator's actions from engineering psychology as well as description of multi-purpose and multi-phenomena models of control objects. Failure of automatic system control under transgressive conditions contrary to numerous cases of effective system control performed by human operator in such conditions support, due to interdisciplinary approach, a concept of the use of the system anthropomorphic adjustment for transgressive investigations.

The investigations referred to the human-pilot, his extreme capabilities and flexibility of limitations on the one hand and to the machine-helicopter on the other. For investigator, when unaware of all phenomena taking place in the system and neglecting the influence of handling dynamics, becomes arbitrary in selection of critical flight phases, simplifies their models and considers the dynamics of a helicopter as an isolated object.

The investigations concetrated on the course of tasks assigned and operation of the helicopter systems in selected critical flight phases and under overcritical conditions.

A system was developed of transgressive investigations from analyses to experiments coverign:

1. investigations in conventional time on close mathematical models of pilot-helicopter configuration with the use of numerical methods and computer techniques,
2. laboratory investigations on simulator in real time as an intermediate form before going over to the real object,
3. investigation on the real object including helicopter, measure equipment and crew.

In the case of investigations on closed mathematical models the handling model reflecting pilot's decisions and execution is combined with the model of the object or systems operation thus making it possible to investigate the pilot-helicopter system simultaneously.

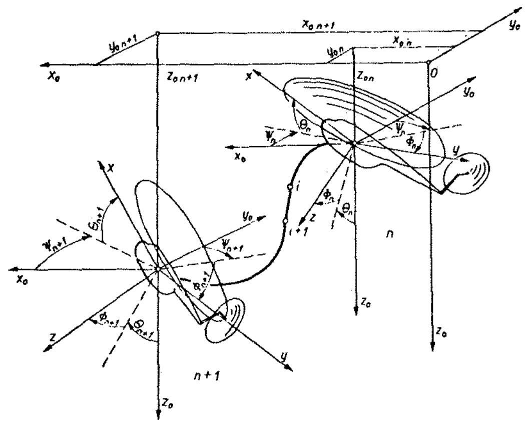
Helicopter simulator of a flexible hybrid-type construction equipped with a stand for ergonomic investigations permits versatile tests of the pilot-helicopter system in real time. The simulator circuit is additionally provided with a model of automatic control based on handling models for investigations in conventional time. This allows to investigate the concept of anthropomorphic auto-pilot and facilitates training of extreme flight conditions using information on transgressive control provided in flight director system.

In order to reduce risk when testing transgressive conditions in flight, alternating investigations are introduced of isolated phases. Empirical simulation of hardly explored phenomena, simulator training and theoretical analyses are used here. They are combined in a uniform program so as to conduct tests as close to the system limit conditions as possible at risk margin not exceeding that involved in conventional investigations.

3. The model of handling-representation of helicopter flight

Any flight assignment can be presented in the form of a flight profile composed of manoeuvre sequence N. Any n-th manoeuvre can be distinguished as flight phase subject to fixed set of rules applying between time t_n up to t_{n+1}. A limited set is available to compose any flight assignment consisting moduli. The moduli, when solved, give solution for an assigmnent provided that the final data of a preceding manoeuvre are introductory data for the following one.

Manoeuvre representation consists in calculation of time runs of alterations in helicopter flight data and in establishment of control function for the assumed rule of manoeuvre execution. For this purpose an inverse assignment is executed in closed model converting the manoeuvre rule into extreme allowable impulses controlling in relation to the ground. Translated into the system connected with helicopter they make it possible to specify necessary control function. The solution is conducted step by step in discrete system. A section of flight assignment of a uniform passage technique /Fig.2 items n and n+1/ is devided into a sequence of constant time sections i, i+1 for the assumed time interval Δt.



2. Diagram of adopted designations for overflight of sector "n".

The development in the models of human behavior starts with psychological investigations of the operator's activities. They have resulted in psychological model revealing the notion of an operational image, that is, internal model.

In the course of the complex control process pilot's anticipation provides information on flight data in the nearest future. Thus it enables him to estimate the difference between the actual and intended levels of state vector and manoeuvre rule indicates the direction of changes in control vector.

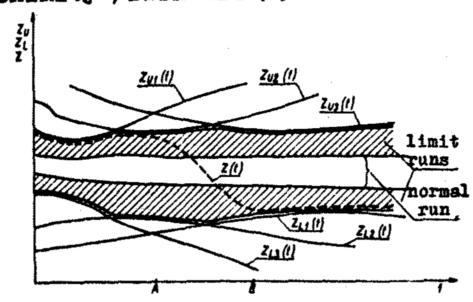
In anthropomorphic handling model feedback and reactions based on pilot's anticipations are parallel elements of the control process. The feedback system fulfils the assignment and stabilizes the system whereas the anticipation system, which is normally intended for more complex problems, serves to establish the intended and flexibly corrected state vector to which feedback system is subjected. According to such an extrapolated run feedback system performs its control function for the nearest moment. Anticipation is a permanent process interfering with control decisions depending on current conditions, position of limits and run of the actual system state vector. For the pilot's mind is involved in anticipation process which is neglected by investigations. This process embraces consequences of intended limit control changes being neither mere projection of ewents nor advancing penetration of disturbance. The basic group of phenomena covered by such an anticipation in limit flights refers to the dynamics of changes in state vector limits and to evaluation of anticipation limit time.

The crucial need to control the system in extreme conditions is to develop the helicopter model control so as to maintain required control run in relation to limitations. This makes it possible to effect different variants of exceedeng limits.

Models of anthropomorphic control fall into several types.

In the first variant of control in limit flight conditions with a provision that the envelope of selected system limits is not exceeded, calculated control impulse Δz_i /target impulse/ must not exceed selected system state limits. This is why in each step and for each element it is necessary to calculate set of upper and lower margins of state vector $\Delta x_{Ui} = x_{Ui} - x_i$ and $\Delta x_{Li} = x_i - x_{Li}$ as well as differential quotients $\Delta D_{ij} = \Delta x^o_j / \Delta z^o_i$ for the assumend individual control impulse Δz^o_i /form relation $Z = GX$ - equations connecting control vector Z with state vector X - a proper change in state vector Δx^o_i can be calculated for Δz^o_i/. Form calculated set of control margins $\Delta z_{ijU} = \Delta x^o_{Ui} / \Delta D_{ij}$ and $\Delta z_{ijL} = \Delta x^o_{Li} / \Delta D_{ij}$ the minimum control margins $\Delta z_j^{U,L}$ min are selected.

The conditions $|\Delta z_j| \leq |\Delta z_j^{U,L} \text{ min}|$ when fulfilled make it possible to secure the objective within system capabilities and to fly "along limits" without exceeding them. The principle of limit run between allowable limits have been presented in Fig.3 where z_{U1}, z_{L1}, z_{U2}, z_{L2}, z_{U3}, z_{L3} depict envelopes of top and bottom limit control impulses for the handling model - index 1, helicopter - 2 and environment - 3. On section AB control run $z/t/$ is effected for the condition $|\Delta z_j| \leq |\Delta z_j^{U,L} \text{ min}|$, the remaining area corresponding to $|\Delta z_j| = |\Delta z_j^{U,L} \text{ min}|$. Shaded area indicates the area where flying and control are considerably affected by limit proximity /risk area/.



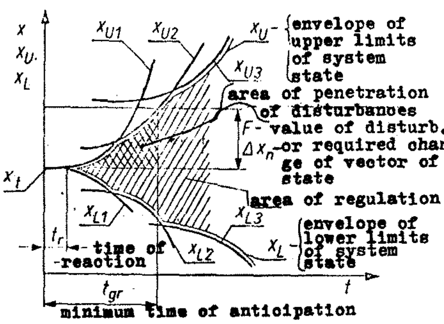
3. Diagram of a limit run.

The second type of control deals with the models of exceeding limits. Having a problem of control along limits developed it is possible, at any time, to exceed the limits. They can be exceeded either by intentional control according to the rule corresponding to structural capabilities of the system element and assambly.

Also it is possible by changing the environmental conditions.

The third type is advance control. The handling model represents the process of complex decisions concerning flight program check /evaluation of performed manoeuvre and passage to another flight phase/, detection of system failure and serious distrubances and, as a results, proper modifications in flight program /alteration in ΔX_n/ and the way of its execution. Any decision as to the choice of flight program modification when approaching serious disturbances or inentional change in control vector requires an adequate representation in the model of anticipation process.

Therefore, it is necessary to calculate extreme possibility of changes in adjustment range so as to penetrate the area in which the process will continue in the nearest future. At the same time some features of extreme changes in adjustment range have to be taken into consideration /Fig.4/.



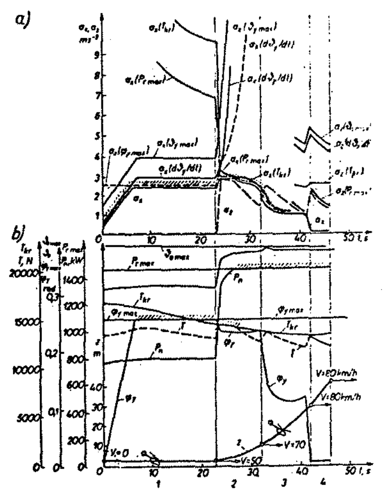
4. Variation of system regulation range according to time elapse from the moment of intervention of control system.

Disturbance magnitude should be converted into magnitude of necessary change in state vector ΔX. Thus a premise is obtained to estimate to moment being a starting point of the control system reaction to compensate disturbance. To do this, it is necessary to estimate time which passes from the onset of the system action using limit control capabilities up to the moment when alteration in adjustment range equals disturbance magnitude ΔX_n. This time is limit time indicated in Fig.4 as t_{gr}. Symbols $X_{U1}, X_{L1}, X_{U2}, X_{L2}, X_{U3}, X_{L3}$ refer to top and bottom limits system state /model of control system, object and environment/.

All the elementary control actions to cause required change in state vector ΔX are mostly anticipation - type control processes. The handling model then represents characteristic way of handling including action impulse ΔZ_a which initiates alteration in state vector into required direction and advance counteraction of controls ΔZ_k to impede movement so that the required level of alteration in state vector ΔX could be achieved.

The fourth variant of anthropomorphic type control deals with decisions to modify flight assignment if, for instance, an unexpected failure occurs to the system. Unlike static type decision processes /as known from literature/, those processes must be synchronized with flight dynamics due to considerable time limitations. The pilot then is forced to modify flight program by selecting the ready flight procedures. The heuristics of assignment structure like this have to be mastered by the pilot to be employed automatically. Making a model in such a case consists in selection of a proper sequence run. Having a proper assignment structure selected, the decision sequence is focused on selection of dynamic data for respective sequences.

Fig.5 illustrates the functioning of feedback circuit while in successive manoeuvres the system compensates the error of the current and target state vector without exceeding the limits imposed.



5. Illustration of flight solution "along limitations" on the example of a normal take-off of the helicopter: a - function of control impulses, b - run of change of parameters of system state.

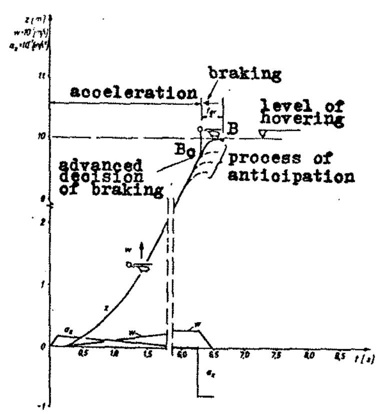
The assignment, it was provided, had to be effected to the assumed flight program using the limit system capabilities. The limitations assumed were: the use of maximum engine power $P_{r\,max}$ and maximum thrust T_{kr} /stream stall/ when maintaining the limit control data $/d\vartheta_o/dt/_{max}$, $/d\vartheta_y/dt/_{max}$ and $\varphi_{y\,max}$. Flight program has been presented in Fig.5 as a set of altitude - airspeed combinations at the end of each flight phase. They have been indicated on a curve z/t/.

In control sequence from stick displacements to helicopter displacements, causes and effects are subject to the following scheme:

$/\delta_o, \delta_x/ \to /\vartheta_o, \vartheta_y/ \to /a_{zo}, a_{xo}/ \to /a_z, a_x/ \to /V_z, V_x/ \to /z, x/$ where: δ_o - displacement of collective pitch lever, δ_x - stick displacement in the plane of symmetry, ϑ_o, ϑ_y - displacement of control disc /collective and cyclical inclination pitch/, a_{zo}, a_{xo} - accelerations in helicopter system as immediate /non inertial/ result of control action, a_z, a_x - transposition of accelerations into system connected with the ground, V_x, V_z, x, z - airspeed and displacements of helicopter as a result of acceleration effect in time. Accordingly a_z and a_x accelerations have been assumed as input control impulses in the model, the remaining data have been calculated.

Fig.5a shows control impulses run. It occurs that the minimum impulses a_x or a_z are assumed as limit values. Fig.5b illustrates entrance in the following limit ranges of respective helicopter assemblies /1 - flight with maximum pitching, 2 - initially flight close to stall conditions and then at the engine maximum power, 3 and 4 - flight with maximum power/.

The effect of predictive system in the handling model is illustrated in Fig.6 for fast elevation to spot hovering at intended altitude /typical NOE - "nap-of-the-earth" - manoeuvre /5//. In a simple single-parameter vertical helicopter movement the elements to be considered are introductory vertical acceleration and subsequent speed reduction so as to maintain hovering at 10 m above the ground.



6. Example of functioning of prediction circuit in the manoeuver of helicopter vertical jump.

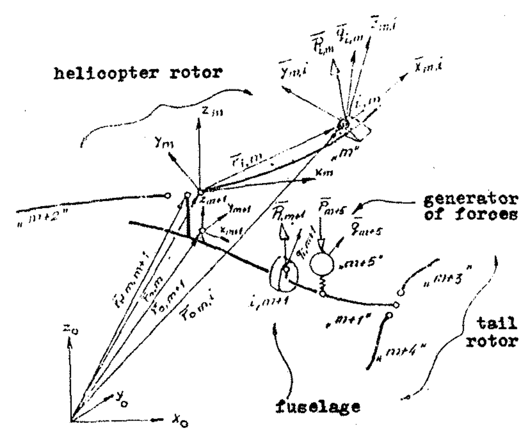
In order to establish the starting point for braking vertical movement it is necessary to calculate the lower limit of system adjustment for each step /Fig.4/. The advance control action /point B_o in Fig.6/ for time t_{gr} permitted, with the accuracy of numeric solution, to brake climbing speed at required altitude of 10 m /point B/.

4. Dynamics of multi-element discrete helicopter structure

A helicopter model was developed in the form of multi-element discrete structures such as: rotor blades, fuselage structure, models of exciting force generators /e.g. drive, elements of active or passive vibration isolation/, connected to one another by joints /e.g. blade attachment joints/. The dynamics of the whole system was solved by means of systems of equations of motion corresponding to each sub-system. The systems of equations were next connected with equations of constraints.

It is assumed that the wole system is moving unsteadily in relation to inertial system connected with the ground x_o, y_o, z_o and is subject to deformations evaluated in system x_m, y_m, z_m which are connected with selected sub-systems to which due to their digitizing local system $\bar{x}_{m,i}, \bar{y}_{m,i}, \bar{z}_{m,i}$ are assigned in each i-th point of the concentrated element state vector.

Fig.7 illustrates mutual interrelations between the system element in generalized coordinates, where q is generalized displacements, P is generalized force, $\bar{r}_o$ is positional vector of coordinates system of m-th element, $\bar{r}_{wm,m+1}$ is positional vector of joint connecting elements m and m+1, $\bar{r}_{m,i}$ is positional vector of i-th discrete point in the system connected with m-th element.



7. Diagram of connections of the structure of deformable elements of the helicopter.

Equations of motion for m-th assembly in generalized coordinates following left-sided separation of linear elements assume the form: $M\ddot{q} + \Lambda\dot{q} + Cq = P/t/$, where M is inertia matrix, Λ is suppression matrix, C is stiffness matrix, P/t/ is generalized force being a non-linear function of aerodynamic loads, kinematic and force inputs resulting from joint reaction, gravity forces, control and friction loads and force generator inputs of equipment installed on the helicopter.

The solution of this system of coupled equations representing non-linear relations of the helicopter dynamics is extremely difficult. Modal coordinates, when introduced, make it possible to obtain for the system of n degrees of freedom n independent differential equations of a single degree of freedom. And this is one of efficient means to solve the system. Each equation in modal coordinates was solved using Runge-Kutt fourth-order method.

Uniform air flow round the helicopter is disturbed by velocity field induced by a system of wakes generated by the helicopter rotors /main rotor and tail rotor/, lifting areas /wings, stabilizers/, fuselage flow round and atmosphere turbulence.

Velocity field generated by rotary wake depends on wake geometry which is shaped due to the way of its creation and deformation in disturbed medium caused by all disturbing factores. The whirling surfaces induce velocity field V/x,y,z,t/ solved by integration according to Biot and Savart rule.

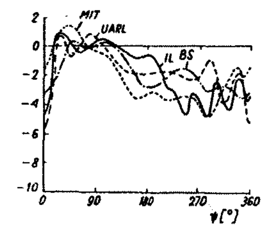
Results of investigations of the helicopter dynamics under transgressive conditions can only be reliable if the model is tested in well-controlled circumstances close to limit ones and especially carefully are checked those phenomena /model fragments/ which are essential to the system behaviour when exceeding limits. Below is presented the outline of verifications, global and partial alike, of the system model by comparison with methods use by world's leading helicopter manufactures, flight tests and by comparison of numeric solutions with analytical solutions.

Studies /2 and 3/ deal with comparison of calculation methods developed by the world's leading helicopter manufacturers of which methods provided in /3/ are considered the most advanced ones. The rotor hypothetical data provided in /2 and 3/ have been calculated using the method described here in order to verify the data.

In order to estimate the methods an extreme case has been selected with stream stall on returning blade and compressibility phenomena on attacking blade /$M_{1,90^o}$ = 0,9/ and at particular rotor position against the air flow round. It has been assumed for high flight speed /μ = 0,33/ that shaft inclination against the stream is $\alpha_w = 0$.

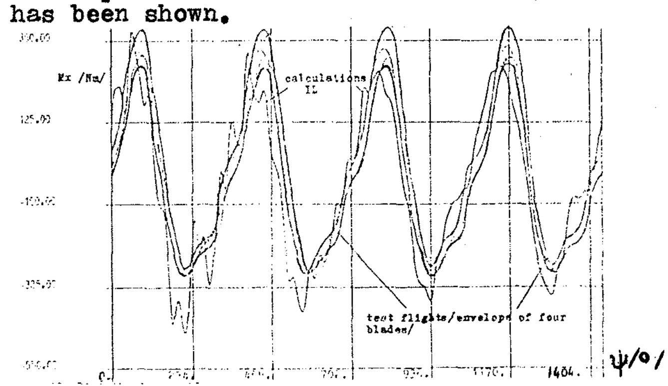
Flexural loads reveal conformability for all methods /2/. Deformations and torsional loads as much more sensitive indicator of the method quality show considerable discrepancy from one result to another. Good uniformity of results have been attained for improved methods /3/, including IL method /Fig.8/, where codes of respective companies assumed in diagrams for different calculation methods:

MIT - Massachusetts Institute of Technology
UARL - United Aircraft Research Laboratories
BS - Boeing Stall Method
IL - Aeronautical Institute /Poland/



8. Distributions of blade tip torsional deflexion with relation to the azimuth; comparison of methods /3/ and IL.

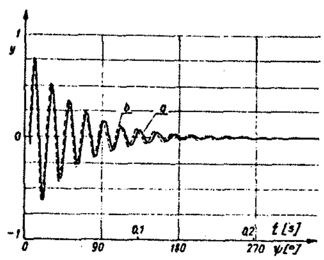
Using IL method calculations were made for the cases tested in flight. The results are shown in Fig.9. In the drawing distribution of torque moment affecting helicopter blade root in steady flight has been shown.



9. Distribution of blade twisting moments at the blade root. Rotor of ACR type, horizontal flight, V = 140 km/h. Comparison of results of the flight tests with the result of calculations. Visible is the decay of initial conditions for the second torsional form /about the 8-th harmonic/, through about 2.5 of rotor revolution.

This verification of calculations and tests is of particular significance for it concerns low torsional stiffness blade type ACR /4/. Extreme sensitivity of calculation results, in particular for torsional deformation, to method errors /even slight/ and errors in data set for the rotors of this type with simultaneous conformity of calculation results and test results testifies to positive method verification.

For various frequencies of blade excitation and various suppressions the results of numeric program solutions have been compared analytical solution of function type $y = Ae^{\lambda t}\cos\bar{\nu}\omega t$. Fig.10 shows comparison of solutions for suppression $\lambda = 25$ at frequency $\bar{\nu} = 18$ for solution step $\Delta\psi = 5^{o}$. Calculation results are not practically different from accurate solution to $\bar{\nu} = 18$ for $\Delta\psi = 5^{o}$. Greater conformity /strict coincidence of numeric and analytical results/ is obtained with decreased step $\Delta\psi = 2.5^{o}$.



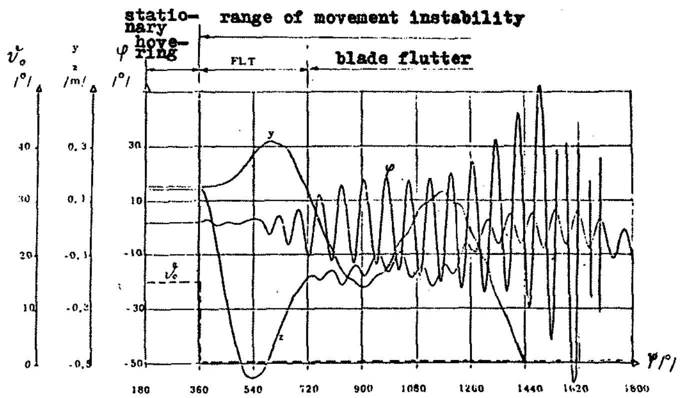
10. Inspection of the correctness of the solution of the differential equations system of blade movement; a - numerical solution /IL/, b - analytical solution.

5. Examples of investigations of transgression nature

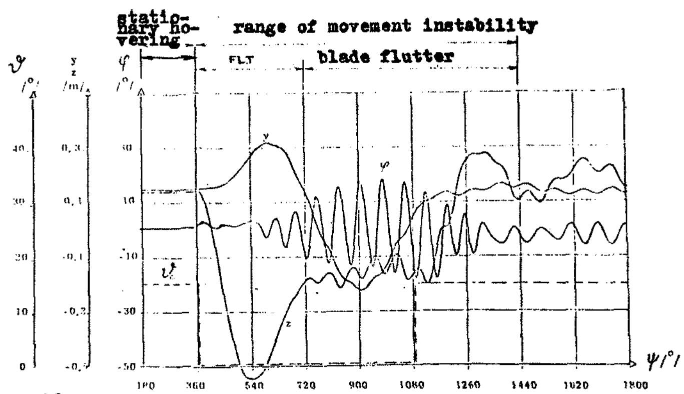
As examples of transgression type investigations below are given the following: by means of an accurate simulation model - simulation investigations of aeroelastic problems of hingeless rotor, injuries of tail rotor blades and sailing of the blade; in flight-maneouvers after failure of power plant.

The first example pertains to a hingeless rotor, wherein by/inertialess/ reducing the collective pitch, a limit chord instability of FLT /Flap-Lag-Torsion/ type was initially introduced, and next, the limit of the divergent flutter of the blade was exceeded /Fig.11/. The investigations of the possibility by means of re-increasing the collective pitch are illustrated in Fig.12.

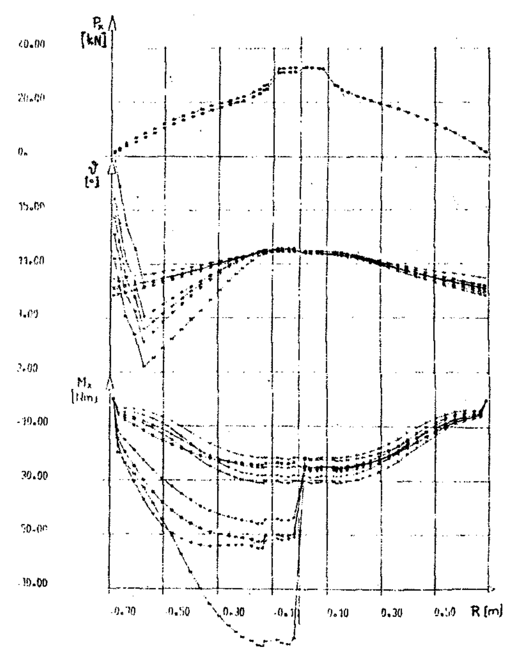
The second example deals with investigations of two-blades teetering tail rotor, in the ewent of one blade's tip being damaged. Those cases are concerned with investigating the consequences of rotor damage which may cause exceeding of the limit of a respective type /Fig.1/. The results of changes in the condition of the system when the blade tip has been injured on about 15% of length, with loss of mass and bending of the trailing section, are displayed in Fig.13.



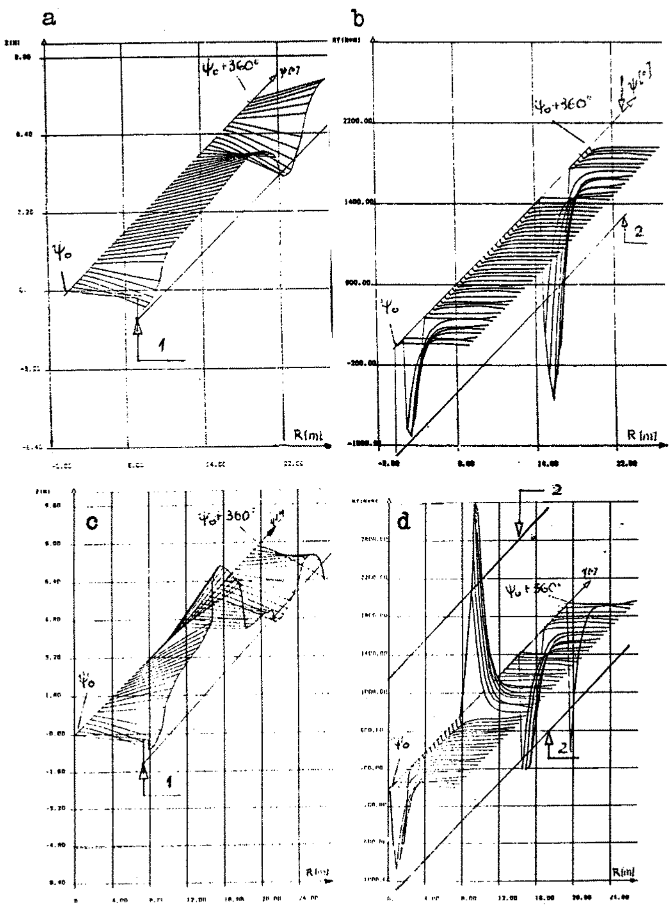
11. Transgression of aeroelastic instability of the hingeless rotor /blade flutter/ caussed by a substantial reduction of the collective pitch.



12. Trangression of aeroelastic instability of the hingeless rotor blade in result of the reduction of the collective pitch and return into the ranges of stability of movement of the blade which is subject to violent flutter /Fig.11/ by re-increasing the collective pitch to initial value.



13. Distributions along the radius and with relation to the azimuth: Px - of centrifugal force ϑ - of pitch angle, Mx - of torsion moment. Mark symbols of azimuth every 45° in sequence:

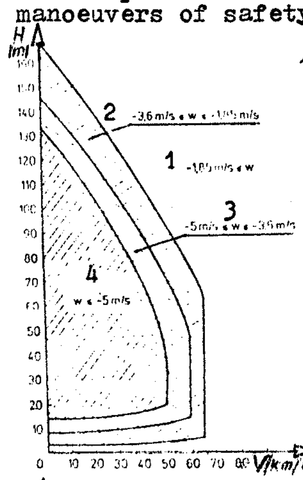


14. Investigations of sailing of the blade. Distribution along the radius and with relation to the azimuth: a,c - deflection of the blade z/m/, b,d - bending moment out of plane My /Nm/; a,b - wind w = 15 m/s; c,d - wind w = 30 m/s; ψ_o - relative direction of the wind onflow. 1-level of tail boom, 2 - limit of value of bending moment.

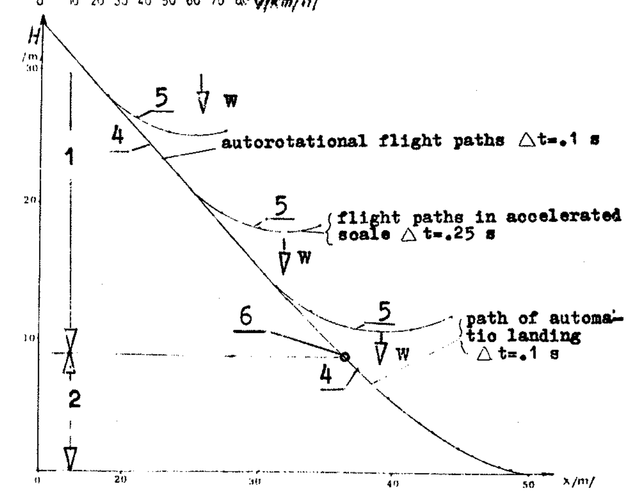
The third example is displayed in Fig.14 where are shown the results of investigations of sailing of the blade during starting of helicopter rotor with angular velocity $\omega = 0.05\omega_{nom}$, where the velocity of level wind has been selected as the escalating medium for limits transgression. Successive limits concern deflection of the blade tip /to the tail boom/ and the values of bending moment of the blade root following impact against the limiters which restrict blade movement. The target of the investigations is the assessment of the controllability of the process in order to avoid the collision of the blade with the tail boom by adjusting the relative direction of the wind onflow, the position of the control system, or else by introducing proper design approaches /lifting the angle of the blade back-up/.

Investigations of pilot-helicopter configuration in conditions of power plant failure include tests concerning determination of limits of safety zones where it is feasible to safely carry out landing manoeuvers or to continue flight after failure of the power plant, the so-called HV zone /"height-velocity" - due to their determination in co-ordinates altitude - velocity/, tests of interrupted take-off in result of power plant failure, and cases of power plant failure during operations performed by a helicopter in hovering flight, and at low air speeds /rescue work and flying crane operations/.

Fig.15 shows the safety zones which it is necessary to obtain, by employing the method of successive repeating for determing the optimal manoeuvers of safety for various initial conditions at the moment of failure. In order to get well acquainted with the stereotype of dynamical control of the helicopter, following power plant failure, for various initial conditions of its occurring, it is necessary to train the individual phases of flight and the complete manoeuvers of safety on a simulator.



15. Types of limits of zones HV /equivalent of Fig.1/. As the criterium adopted was the admissible landing speed /example for heavy lift helicopter - failure of two engines/. Zones: 1 - soft landing, 2 - hard landing, 3 - admissible crash landing, 4 - area of catastrophe.

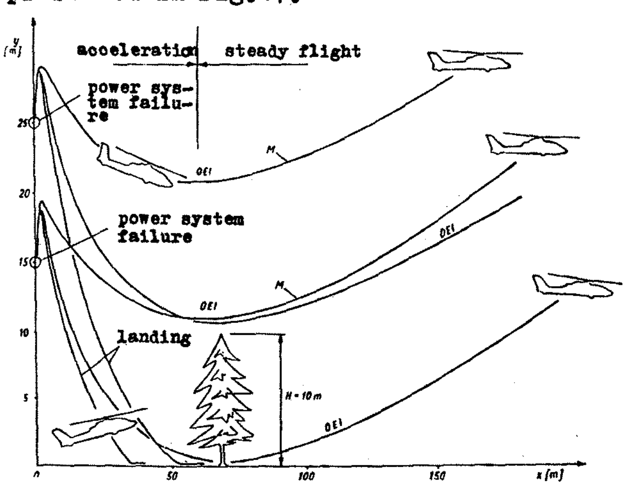


16. Illustration of anticipation processes and automatic landing on the diagram of helicopter autorotational landing flight paths. 1 - autorotational descent, 2 - flare, 3 - manual control, 4 - solution in real time, 5 - solution in accelerated time /limit flight path/, 6 - decision point for beginning of flare, w - admissible landing speed.

Successively selecting the initial conditions of altitude and the rapidity of failure occurrence, and performing the safety manoeuver of landing or departure, it is possible to determine the zone limiting points. Utilizing the circuit of anticipation for investigation the limit possibilities of the system, as well as the circuit of automatic control /see Fig.16/ it is feasible to relatively easily determine and master the technique of pilotage in the more difficult limit phases.

By carrying out a transgression by means of a simulation model, and next on an investigation simulator, it is possible to estimate the position of successive zone limits in order to estimate their reciprocal position, as well as simulation area, and also time reserves and the degree of risk cumulation which influence the process of making decisions, and selecting the type of safety manoeuver.

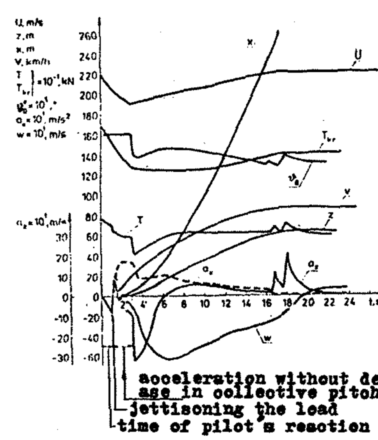
Similar problems are encountered when investigating interrupted take-offs of a helicopter the power failure. The article only points to the estimation of effectiveness of pilotage technique modification in the course of such a take-off. The classic failure /considerable lowering of flight path/, do not warrant an adequate level of flight safety, and this reason it is suggested to modify the technique of take-off, consisting in increasing the rate of clim in the initial phase and fly away, following engine failure, by applying the technique of minimum rotor revolution /lesser lowering of flight path/. The illustration of comparing the classic technique with the modified one of vertical take-off /in the example without utilization of rotor energy in the phase of vertical climb/ is presented in Fig.17.



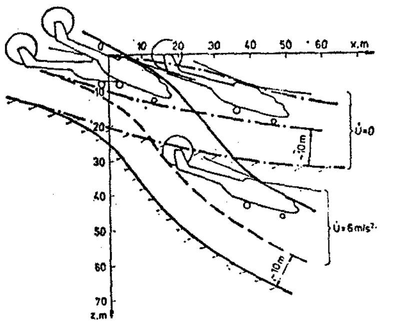
17. Influence of modofication of handling technique on flight path during interrupted vertical take-off M - modified technique.

The effectiveness of introducing limit simulation investigations is illustrated by the results of modyfying the pilotage technique of emergency manoeuver after power plant failure of the helicopter when performing flying crane operations. When applying classic technique, the helicopter being initially violently lowered, after reduction of the collective pitch, requires much free space, already occupied by the assembly stand and appliances, as well as by the dropped load, previously hoisted, and by miscellaneous objects in the surroundings. It is, therefore, indicated to search for new techniques of carrying out safety manoeuvers in order to reduce this area.

Fig.18 shows the procedure of changing the flight parameters in the function of time with one engine inoperative /failure/ by means of a modified technique of flight /first acceleration, then correction of the collective pitch/ witch speeding up the r.p.m. at the rate of $dU/dt = 2\ m/s^2$ /tip rotor speed $U = \omega R$/. An estimation of the possibility of colliding with obstacles has displayed in Fig.19. Visible are substantially magnified /as compared with classic method/ the areas in which the presence of obstacles does not imperil flight safety.



18. The course of alterations in helicopter system data following failure of one engine by a modified handling technique.



19. Flight paths of the helicopter following failure of one engine by a modified handling technique.

6. Summary

The offered hypothesis of introducing transgressive investigations of helicopters is intended to evaluate, after passing through the system limits, the development of dangerous phenomena, as well as the means of attenuating their effects by appropriate controlling or by introduction of design modifications.

The advantages resulting from utilizing the accurate information image - obtained by the aforementioned means - about the anticipated states of the system, of extreme character, of a designed or operated helicopter, may be significant particularly when new design approaches and unconventional techniques of control are being introduced.

Utilization of simulation aid and model extrapolation of the system state for overextreme conditions, considerably reduces the costs and risks involved in flight tests of limit character.

Bibliography

1. G.A.O.Davies, J.Morton, Structural impact and crashworthiness, Vol.1, Vol.2, London, 1984
2. R.H.Ormiston, Comparison of several methods for predicting loads on a hypothetical rotor, J.A.H.Soc., October 1974
3. W.Johnson, Comparison of three methods for calculation of helicopter rotor blade loading and stresses due to stall, NASA TN D-7833, November 1974
4. R.H.Blackwell and D.J.Markley, The aeroelastically conformable rotor concept, J.A.H.Soc. July 1979
5. H.L.Kelley, and R.J.Pegg and R.A.Champine, Flying quality factors currently limiting helicopter nap-of-the earth menoeuverability as identified by flight investigation, NASA TN D-4931, December 1968.