RESPONSE OF CARGO TO ACCIDENTAL COLLISION OF TRANSPORT AIRPLANE AGAINST TAKE-OFF AND LANDING RUNWAY

A.I.Abakumov, N.N.Gerdyukov, P.N.Nizovtsev, S.A.Novikov,
V.G.Sergienko, V.A.Sinitsyn

All-Russia Research Institute of Experimental Physics, Sarov, Nizhni Novgorod region, Russia

ABSTRACT

The problems of providing safety during transportation of hazardous cargoes containing radioactive, explosive and similar materials are in the center of attention when arranging transportation of such cargoes by all types of transport. The special place during solution of this problem is taken by researches of behavior of such cargoes in the environments of transport accidents.

Authors of the paper give description of the numerical-experimental method for determination of cargo response to collision of airplane against a take-off and landing runway (TOLR) at emergency landing basing on results of experiments performed by the method of reversed impact at gasdynamical shock test bench.

Results of analysis of the information obtained in experiments with simplified models of AN-26 airplane fuselage fragment (scales 1:5, 1:10) with cargo models fastened in them are presented. For the analysis, the package of applied codes DRAKON-3D/S [1] was used.

The information obtained in rather simple and cheap experiments can be used for improvement of safety of airtransportations that is especially important for cargoes containing risky and hazardous substances.

INTRODUCTION

Availability of the reliable information about behavior of a transport airplane and transported cargoes in abnormal situations, for example at emergency landing, allows correctly to choose measures to protect cargo and to provide safety of its transportation with account for accidental effects. The direct experiments with various variants of emergency landing of an airplane are very complicated and expensive. Probably, first full-scale experiments on study of accidents at take-off and landing were performed by NASA in 1956 [2]. During experiment, the airplane was led through radio and moved along TOLR by guidings with the help of its engine. Its velocity was damped at collision against obstacles simulating an accident. The airplane flew above a cavity in TOLR and hit by its nose against oblique surface of a bulk hill. The experiments have shown that the emergency landing at small angles of collision of an airplane and ground with its subsequent sliding results in moderate damages, and overload caused in fuselage are not too great.

In 1984 for the first time in research air practice in USA a full-scale experiment was performed with an emergency landing of remotely controlled airplane Boeing-7202 [3]. At this experiment, the landing weight of the airplane was 87 t, horizontal velocity was ~76 m/s. The fuselage hit ground by its forward part with the slope angle for dive of 2.5° at vertical velocity of reduction of the airplane weights center of masses of 3.66 m/s (the chassis was removed). To the moment of stop moving on ground the airplane moved for 415 m (with average longitudinal acceleration of ~14 m/s^2). The results of the analysis of peak accelerations of the airplane floor in this experiment have shown that the vertical overloads along fuselage length vary rather significantly: from 15 near to the airplane nose, up to 2.5-3 – at distance of 25-27 m from the nose cowl. The peak values of horizontal overloads along fuselage length (excluding its nose destroyed part) were actually kept constant in limits 2-2.5.

At the stage of revealing of the basic regularities of behavior of the plane and cargo at emergency landing, it is more preferable to obtain the required information in cheaper experiments with simplified and reduced models and fragments of airplane. The experiments, where the behavior of tested object (TO) is studied at collision against an obstacle are usually performed either by the method of direct impact or the method of reversed impact. In the first case, the TO is accelerated up to required velocity and is impacted by specified way against a stationary barrier, in the second - TO is fixed unmovable, and up barrier or its fragment is accelerated up to required velocity and is impacted against TO by specified way. The experiments with direct impact are more complicated and less informative than with reversed impact, since it is much more difficult to get information from gauges set at a movable object than to make this procedure with stationary object. For these reasons, when developing Work Plan for ISTC Project ¹990 "Study of Airframe and Cargo Mechanical Response at Accident Impact of Transport Airplane to Take-off and Landing Runway (experiments with fragments of the airplane)" (the Project efforts were initiated by Sandia National Laboratories, USA, the collaborator is Dr. Richard E. Smith), it was decided to perform experiments by the method of reversed impact at gasdynamic test bench. As a prototype of the test object, the transport airplane AN-26 was chosen. Beside of experimental researches, in these efforts we performed calculation researches of TO response to impact against a take-off and landing runway (TOLR) with the help of the package of applied codes DRAKON-3D/S developed in VNIIEF. Some results obtained under the framework of ISTC Project ¹990 are presented in this paper.

EXPERIMENTAL SET-UP

As tested objects we used simplified and reduced (scales 1:10 and 1:5) models of a fragment of the cargo compartment of fuselage of transport airplane AN-26 with a weight model of cargo fastened in it. Figure 1 shows schematically TO (scale 1:10) in section. TO is a thin-walled (thickness of a wall is 1mm) cylinder made of aluminum alloy D16 (density – 2.8 g/cm^2, Young' s modulus – 72 Gpa, yield strength – 300 Mpa)supported from within by five ribs, which are simulators of frames. It contains also a simulator of floor as an aluminum plate having thickness of 1mm attached to the cylinder by screws and supported from the side of the TO bottom by aluminum partitions based on the frames. The simulator of floor is screwed to the weight model of transported cargo, which is a rectangular steel plate with weight of 1kg (the weight of the typical cargo is accepted as 1 t). The basic sizes of TO are specified in fig. 1.

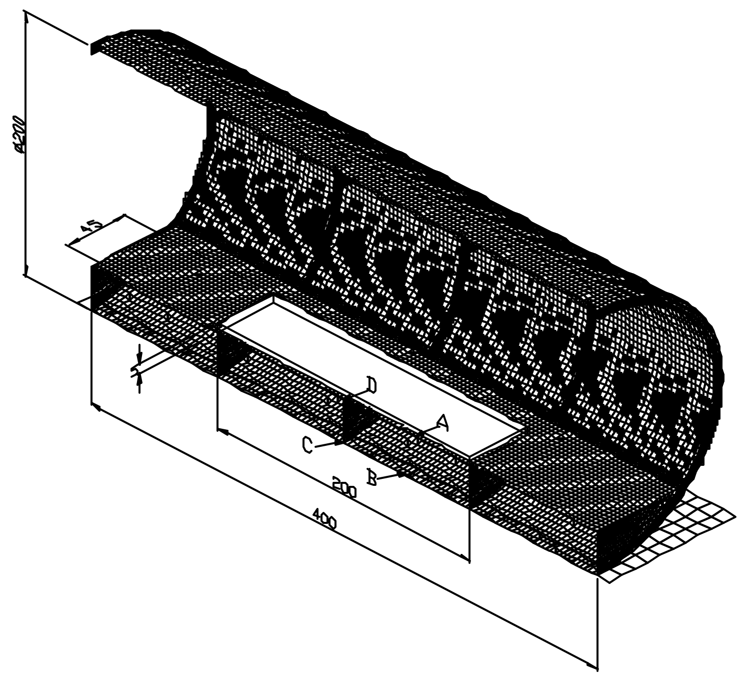

Figure 1, The Scheme of TO (Scale 1:10)

O (scale 1:5) differed from the previous that a little in design, and its housing was made of aluminum alloy AMg-6, which has insignificantly distinguishes from alloy D16 in strength characteristics. The basic difference of TO of various scales in design was that the larger object has weight model of cargo fastened not to floor, but with one end of dynamometer plate, the other end was fastened by screws to the floor. Besides, the cargo model in this case was positioned in the frames fastened to the floor allowing cargo to move along the TO axis, but preventing cargo to leave floor in the perpendicular direction. The weight of cargo model was equal 8 kg. TO with scale 1:5 in section is schematically shown in fig. 2.

In the experiments the response of model of fragment of the cargo compartment of the transport airplane AN-26 fuselage and weight model of cargo fastened in it for collision with TOLR model was determined. The collision conditions (characteristics of accidental landing), specified by collaborator were the following: landing velocity 100m/s, the velocity vector is directed at angle of 30î to TOLR, airplane tangage of 0î, the chassis are not released, landing to a concrete strip.

The experiments were carried out at gasdynamics stands of the gun type with accelerating compartments of diameter of 357 mm ("small" stand) and diameter of 792 mm

Tests of TO of scale 1:10 were carried out with models simpler than TO of scale 1:5 and in more simplified statement. The experiments were carried out using the "small" stand. In these experiments a model of TOLR fragment as a piece of a steel pipe (the diameter of 219 mm, length of 534 mm) with steel caps welded to its end faces (disks with thickness 20 of mm, diameter of 356 mm) was accelerated at gasdynamic stand up to velocity of 50m/s and impacted against TO placed at its trajectory. The TOLR simulator weight was equal 43 kg. The velocity vector was directed

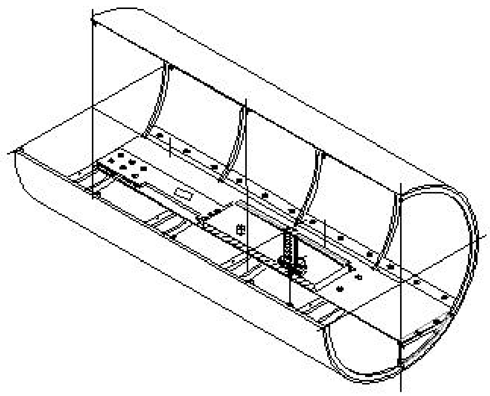

Figure 2, The Scheme of TO (Scale 1:5)

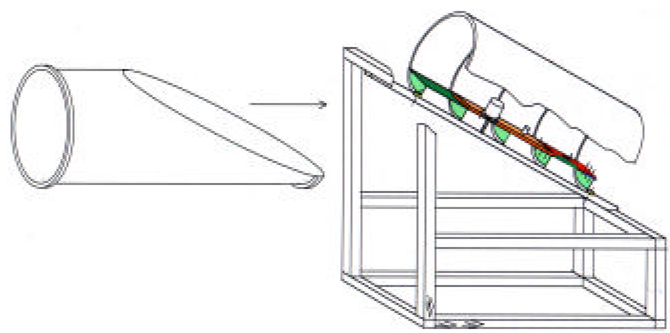

Figure3, The Scheme of Experimental Set-up

perpendicularly to longitudinal axis of TO, its value was equal to value of vertical component of the specified landing velocity of the plane. The experiments with model 1:10 were carried out with the purpose of adaptation of DRAKON-3D/S technique for the calculated description of response of the model-simulator of airplane fuselage fragment and cargo mod fastened in it to collision against a barrier. Besides, in these experiments the technology of realization of tests at the gasdynamic stand was fulfilled.

The experiments with models of fuselage fragment 1:5 were carried out at the "large" stand. In these experiments, the emergency landing with given conditions of collision against TOLR was simulated. The performance of given conditions of collision was reached due to use of the special impactor-simulator of TOLR fragment. It was made of a piece of a steel pipe (diameter of 738 mm, length of 1200 mm) with caps welded to end faces (the caps were disks with diameter of 787 mm, thickness of 8 mm). On the one hand pipe with a part of cap was cut at angle 30° to the axis in such a manner that there was a segment of cap of height 10cm left, the pipe cavity up to an edge was blocked by scraps of boards, then on a plane of an edge the concreting by a layer of about 4mm was made. The concreted surface carefully was leveled. Weight of impactors used in experiment with model 1:5 was in limits 370-390 kg.

Before experiment, the TO was placed at special wooden support on the way of motion of TOLR fragment model motion at distance of about 2 m from barrel edge of accelerating compartment of the gasdynamic stand. To obtain the required parameters of collision in experiment, the TO was placed so that angle between TO axis and axis of the accelerating compartment of the stand was equal 30°. Then generatrix of the cylinder was parallel to the plane of oblique section of TOLR fragment model (tangage 0°), and the angle between TO axis and the direction of TOLR fragment model velocity vector was equal 30°. The bottom end of TO was located 2-3 cm higher than the bottom point of the plane of oblique section of TOLR fragment model, that allowed at TO-TOLR collision and subsequent sliding of TO on TOLR to take the most of length of the plane of oblique section of TOLR fragment model The experimental set-up is schematically depicted in figure 3.

To determine TO response to collision with TOLR in experiment with TO 1:10 with the help of electrocontact gauges, the cross displacement of the weight model of cargo and TO bottom was measured during collision, and with the help of piezoaccelerometers - acceleration of cargo model in the direction of impact. In experiments with models 1:5, the above-mentioned measurements were added with measurements made by foil tensoresistive gauges of dynamometer strain, and the cargo acceleration was measured in two directions: along the longitudinal axis of TO and perpendicular to the floor plane.

EXPERIMENTAL RESULTS

In test with TO 1:10 the TOLR fragment model was accelerated at “small” gasdynamic stand up to velocity 50 m/s and impacted against model of fuselage fragment perpendicularly to its longitudinal axis, thus with the help of the electrocontact gauge we measured the mutual displacement of the TO bottom and weight model of cargo attached to the floor at collision. By piezoaccelerometers mounted at cargo model, we measured cargo acceleration in the direction of impact. The experimental results as the diagrams “displacement-time” and “acceleration-time” are given in the diagrams 1 and 2. At TO observation after test, it was revealed that at impact it had large plastic strains, therefore the TO bottom adjoined to the floor, and the upper part of the fuselage model was so bent that the cross section of the model took the form similar to numeral 8 put on a side.

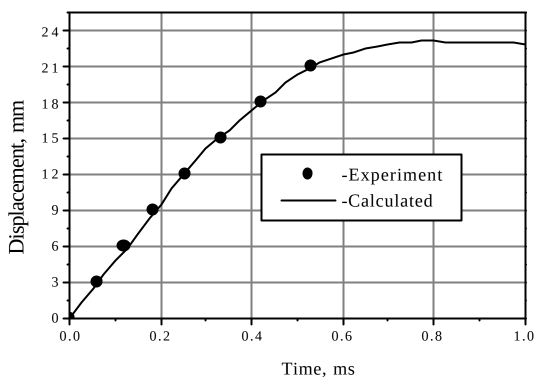

Chart 1, Time Dependence of Cargo Displacement Along Normal Line to Surface of Impactor cut (Small Model).

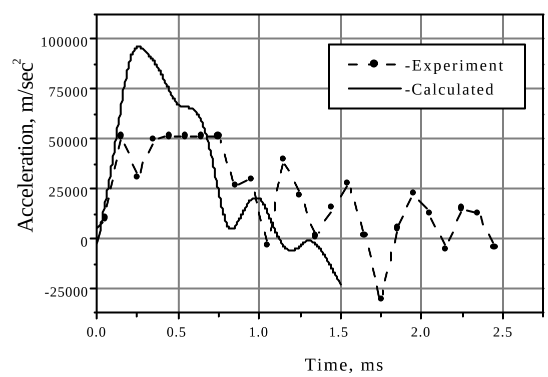

Chart 2, Time Dependence of Cargo Acceleration of Construction Impact

With TO 1:5 three experiments at “large” gasdynamic stand were carried out. In the experiments, the emergency landing was simulated, when the velocity vector is directed at angle 30$\hat{\imath}$ to TOLR surface, airplane tangage is equal 0$\hat{\imath}$. The velocity of collision of TO with TOLR fragment model was 96 m/s, 85 m/s and 97 m/s in consecutive experiments. In the first two experiments there was floor separation from fuselage (the screws of fastening were cut off). In the third experiment, the fastening was strengthened and resisted impact. In the tests we measured mutual displacement of TO bottom and cargo model, the strain of dynamometer in the direction of longitudinal axis of TO,, which was used to control effort effecting on cargo model during collision of TO and TOLR and the subsequent sliding of TO on TOLR, TO acceleration in the direction of its longitudinal axis and in the direction perpendicular to TOLR surface. The part of results obtained in the third experiment is presented in diagrams 3, 4 and 5 as dependencies "dynamometer strain - time", "cargo displacement regarding TO bottom - time" and "cargo acceleration in the direction of longitudinal axis of TO - time". Observation of TO after experiment showed that its strain in this experiment in character was similar to strain of TO 1:10, but there were also significant distinctions associated with various character of loading (perpendicularly to longitudinal axis in the first case and at angle 30̂ to the longitudinal axis in the second case). In particular, the strain from the side of impactor approach was significantly higher than from the opposite side. It is associated with activity of inertial forces during the TO-TOLR collision and further deceleration action at its sliding on concrete surface of TOLR.

With the help of VNIIEF package of the applied codes (PAC) DRAKON-3D/S intended to solve in three-dimensional statement the problems of non-stationary deformation of constructions consisting of branching shell elements and undeformable solid bodies. At contact interaction of shell elements among themselves and with solid bodies, the calculation description of TO response to collision with TOLR model was made. The calculations were performed with account for friction at contact of the surface of the construction (aluminum) against the surface of impactor cut (concrete). The friction coefficient was assumed as 0.3 [4]. The calculated scheme of TO construction 1:10 is given in figure 1 , calculated scheme of TO construction 1:5- in figure 4 Some results of calculations for illustration are given in the diagrams 1-5 together with experimental results.

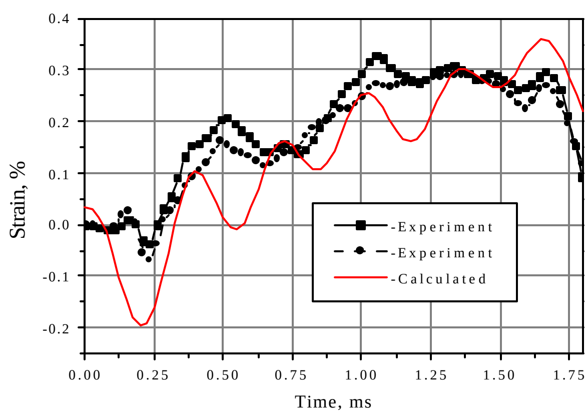

Chart 3, Time Dependence of Longitudinal Strain at Dynamometer.

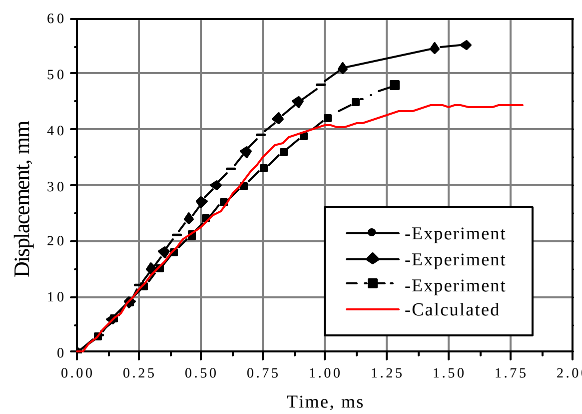

Chart4, Time Dependence of Cargo Displacement Along Normal Line to Surface of Impactor cut (Large Model).

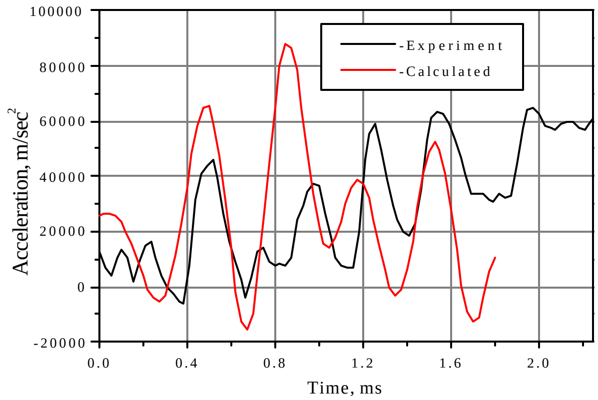

Chart 5, Time Dependence of Cargo Acceleration
in Direction Perpendicular to the Floor Plane .

Comparison of experimental results with data of calculation for TO 1:10 in value of change of distance between points A and B and acceleration in point C (see figure 1) is given in diagrams 1 and 2. In the diagrams, one can see that the results of calculation are in good agreement with experimental data. The significant disagreement between the calculated value and the peak value measured in experiment is, probably, caused by an error made in specification of measured interval of accelerations in the experiment. This resulted in loss of information at value of acceleration exceeding 50000 m/s^2. Nevertheless, in the diagram 2, one can see good agreement in character of change of cargo acceleration in time.

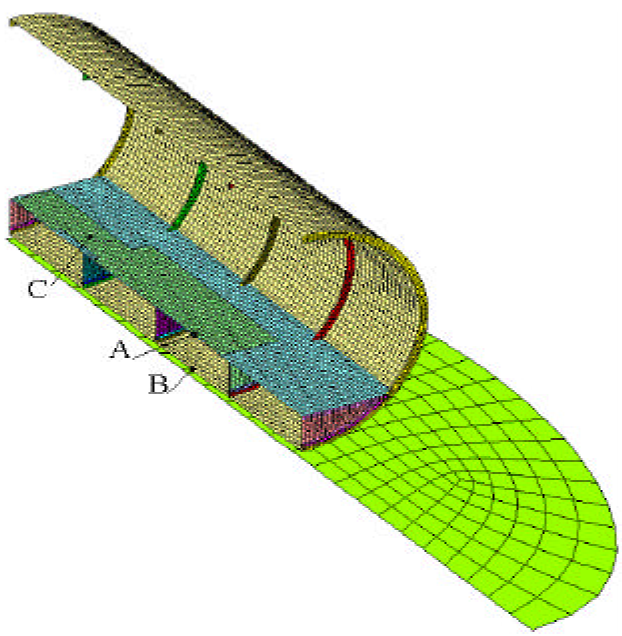

Figure 4, The Calculated Scheme of TO (Scale 1:5)

Thus, the comparison of calculated and experimental results allows to speak about possibility of rather correct modeling of the process of collision of considered construction with undeformed mass in the variant, when the construction is loaded perpendicularly to the longitudinal axis.

The comparison of experimental results with data of calculation for TO 1:5 is given in diagrams 3, 4 and 5. Time dependencies of cargo displacement along the normal line to the collision surface (distance between points A and B, see figure 4) obtained by calculation and recorded in three experiments are presented in diagram 3. The character of change of dynamometer strain recorded in the third experiment is close to that obtained in calculation in point C, the figure 4 that one can see in diagram 4. Probably, by variation of friction coefficient value, one can achieve better agreement between calculation results and experimental data. It is possible to note also the satisfactory conformity of the cargo acceleration along the normal line to the impactor surface measured in the third experiment and that obtained by calculation. It can be seen in diagram 5.

SUMMARY

Results of experimental and calculation research of response of scale models of transport airplane fuselage fragment with cargo model fastened in it to emergency impact against TOLR model allow to speak that experiments by the method of reversed impact enables to determine in rather simple experiments the response of these models to effect of loading simulating an emergency impact against TOLR. It is still early to speak about possibility of transference of results of such researches to full-scale constructions, but it is possible with confidence to speak about possibility of determination in such researches the comparative efficiency of these or those constructive solutions aimed to improve resistance of airplane construction, and, especially, transported cargo to effect of emergency loading. The testing technique requires further perfection. To reduce influence of the scale factor on TO behavior, it is necessary to increase scale of researched models.

The authors express sincere gratitude to Dr. Richard E. Smith, who is collaborator of ISTC Project №990, within the framework of which the presented researches were made, for constant attention to our efforts and assistance.

REFERENCES

[1] A.I. Abakumov, P.N. Nizovtzev, A.V. Pevnitzky, V.P. Solovyov "Program Pacage DRAKON for Calculations of Elasto-Plastic Flows under Shock-Wave Loading in Two- and Three-Dimansional Statement", Reports of International Conference IV Zababakhin Scientific Readings. Snezhinsk, Chelyabinsk reg. October, 16 – 20, 1995.

[2] "Transport Airplane Crash Loads", NASA, Preprint № 772 (Institute of the Aeronautical Sciences, E, 64th St. New York), 27-30, 1958.

[3] H.G. McComb-jun., R.G. Tomson, R.J. Age "Study of dynamics of constructions at modeling of aircrash of full-scale transport airplane ", translated by A.B. Dzheremievsky. Aerokosmicheskaya tekhnika. M., "Mir", №3, 1988.

[4] N.N. Gerdyukov, A.G. Ioilev, S.A. Novikov. " Determination of dynamical friction coefficient of sandy soil ", PMTF, Novosibirsk, №4, 185 – 187, 1995.