Airflow visualization during research of large scale vortex flows

Andrey Zamyatin[1], Maxim Grigorev[1,*], Vladimir Rogozin[1], Alexander Zhelannikov[2]

[1]Aircraft Department, Flight Research Institute named after M.M. Gromov, Zhukovsky, Russia
[2]Flight Physics Department, Central Aero-Hydrodynamics Institute named after N.E. Zhukovsky, Zhukovsky, Russia
*corresponding author: grigez@progtech.ru

Abstract Considered in the paper are different types of air flows visualisations which were effectively utilized during research of large scale vortex flows, i.e. flows which are dangerous for flying vehicles of different functions.
Keywords: air flow visualization, wake vortex, flight safety

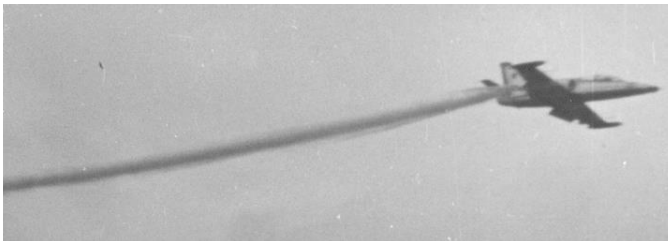
1 Introduction

Development of large scale vortex air flows is inseparably connected with Flying Vehicles (FV) flights. These flows result from lift force creation by FV and thus are inevitable and simultaneously dangerous for other flying aircraft. Especially it concerns the areas in vicinity of airports where there exists a problem of flight safety provision in conditions of possible entering of an aircraft in wake vortices of the other aircraft. Wake vortex safety systems (WVSS) elaboration is rather effective solution of this problem. Wake vortex air flows dangerous for aircraft take-off from and landing on flight deck (FD) of carriers arise over FD and in a wake from moving large ships – aircraft carriers (AC). The problem of wake vortex safety provision is aggravated by invisibility of wake vortex from aircraft or carrier and flight crew don't have any information about location of wake vortex dangerous areas relatively to aircraft-wake generator and it possible influence on the aircraft.
Thus the flight safety provision in conditions when aerodynamic wake vortex is a key factor determining flight safety level is an important scientific-technical problem. The air flows visualization could be both qualitative and quantitative tool for effective investigation of such problems. Air flows visualization could be performed either by application of means making the air flow visible (like smoke generators) or by utilization of math models providing calculation of air masses movement and display of this movement on different indicators (for example on primary flight display in pilot cockpit).

2 Smoke visualization for qualitative assessment of air flows under research

In experimental research carried out in Russia for investigation of the aircraft aerodynamic wake vortex the smoke visualization was used for qualitative evaluation of research of air flows formation and development [1]. Smoke generators were installed on aircraft for durable visualization of air flows areas under investigation (see Figure 1) and on measurement masts for assessment of wake vortices folding in it definite sections (see Figure 2).
Flow visualization by means of masts made it possible to visualize a structure of vortex flows in vortices nuclei in the wake and notice the presence of intensive axial air flows along the vortex axis and also to evaluate the velocity of axial flow (see Figure 3).

Tu-124 aircraft



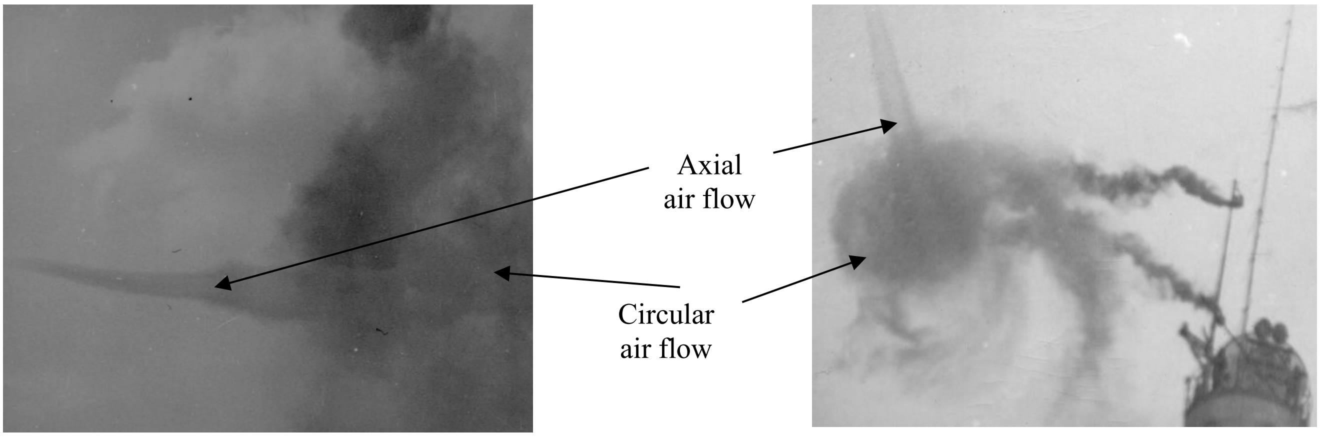
L-39 aircraft

Figure 1. Smoke visualization of wake vortices of Tu-124 and L-39 aircraft

Tu-124 aircraft

L-39 aircraft

Figure 2. Visualization of vortices folding in the wakes of Tu-124 and L-39 aircraft.



L-39 aircraft

Tu-124 aircraft

Figure 3. Visualization of circular and axial air flows in vortices nuclei in the wakes of Tu-124 and L-39 aircraft.

Dangerous disturbed vortex flows arise in the wake from AC and over flight deck. It is not safe for FV to get into these flows during take-off and especially landing on carrier. Location of dangerous areas depends on carrier motion parameters. Both results of air flows measurements and of visualization of air flows over FD of AC are used for evaluation and definition of conditions of safe FV operations on AC. Presented on Figures 4 and 5 are pictures of nose part of AC overflow.

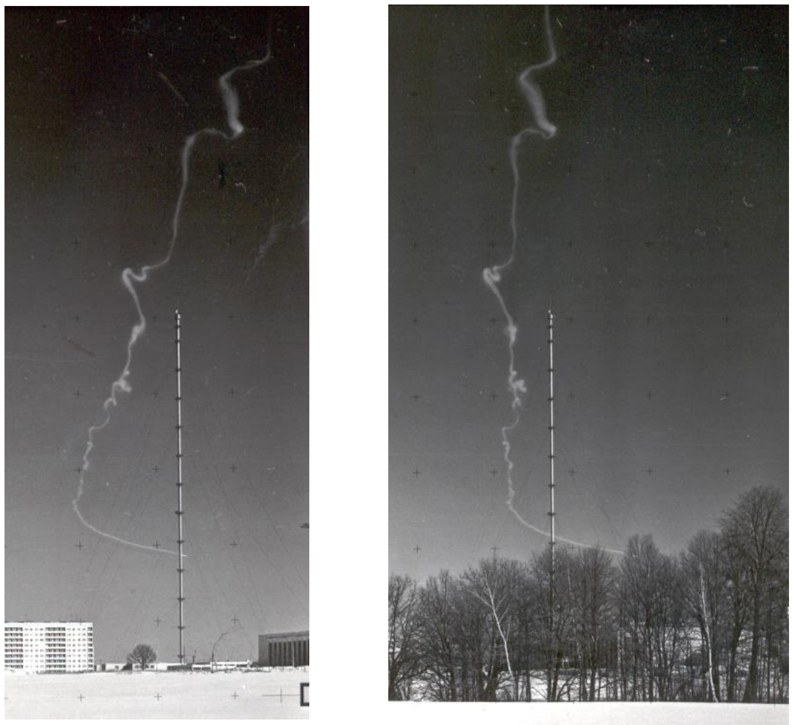
Figure 4. Visualization of nose part of AC overflow. Side view.

Figure 5. Visualization of nose part of AC overflow. Top view.

Formation of large scale vortices is clearly seen. These vortices could be drifted by incident flow on flight deck and helicopters take-off / landing positions and thus create unsafe conditions for take-off / landing operations. Basing on the results of air flows velocities measurements over FD and take-off / landing positions the conditions of AC movement when it is possible to perform safe take-offs and landings of FV on AC. These results and math simulation of take-off / landing flight modes with account of measurements results made it possible to provide a statement on conditions of take-off / landing operations execution from AC under investigation.

3 Utilization of smoke visualization for quantitative assessment of air flows

Stereo photogrammetric survey of the visualized vortex flows in an aircraft wake was utilized for the measurements of coordinates of geometric location of vortex axes and it nuclei sizes at various distances from aircraft. As a result of stereo photogrammetric survey the stereo pairs were obtained (see Figure 6). Stereo pair comprises two shots, made by left and right aerial cameras and accepted after validation procedure. Main criterion for validity of stereo pair was sufficient contrast of the image of the object under research, availability of the image in the field of view of both cameras and synchronism of shooting. Image contrast and presence of the object in the left and right shots were defined visually. Synchronism of shooting was defined via records of signals of opening of a lens of each camera. Data were obtained by precision comparator. These data were used for calculations of spatial coordinates of the object in coordinate system connected to location of left camera. Example of calculation results is presented in Figure 7.



a) b)

Figure 6. Example of stereo pair of the Tu-124 aircraft wake.
a) left camera picture; b) right camera picture

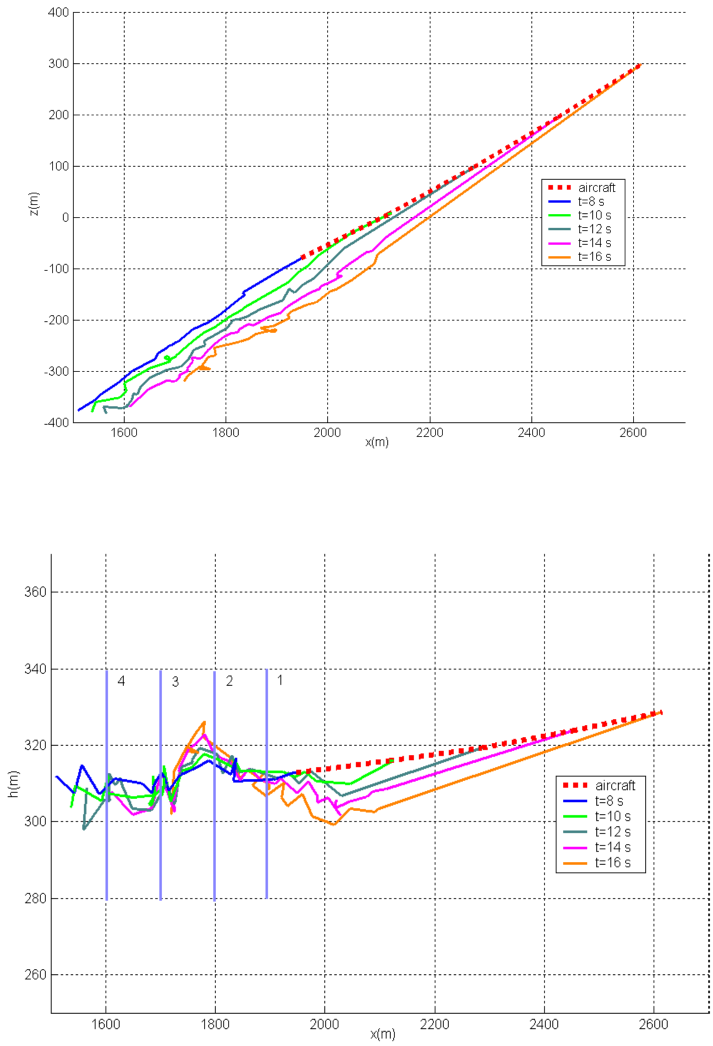


Figure 7. Example of calculations of horizontal and vertical projections of wake and aircraft trajectory.

4 Visualization of vortex flows via math models utilization and it display on indicators

Standards of aircraft separation to provide wake vortex safety are mandatory during cruse flights and at take-off / landing. Especially unpleasant consequences of delays are at take-off / landing flight modes. According to WakeNet Europe data the take-off (landings) delays to provide safe time intervals required by ICAO in European airports constitute 19% of all flight delays. In accordance to the NLR (Netherlands) data mean financial losses for one flight due to such delays are $3000 for ground services and about $800 for airlines.
But at the same time depending on meteorological conditions the dangerous vortex flows in aircraft wake could get out landing and take-off areas at the airfield after considerably less time interval than it is required by regulations what opens potential opportunities to reduce safe time intervals between flights. To determine such situations the prognosis of wake vortex flows development with account of real atmospheric conditions is necessary. Such research also were conducted in Russia in a complex with experimental studies mentioned. For that purpose it were utilized the results of atmospheric parameters measurements obtained on high meteorological mast in Obninsk and math model of wake evolution improved by implementation into it of a model of the surface boundary layer of atmosphere based on Monin-Obuhov theory. By means of this model there were obtained new results on evaluation of safe distance between two particular aircraft in dependence from atmospheric conditions (wind velocity, turbulence level) and it was shown that safe distance strongly varies depending on a state of the atmosphere.
WVSS could be a more precise tool to define safe time intervals between aircraft without reducing of flight safety. This system is also based on dangerous air flows visualization on the display in pilot cockpit and on

the screen of air traffic control staff. This visualization is realized on the base of math models. Short conceptual description of such system is presented below.
Utilizing computational software system the FV constantly performs calculations of it wake vortex characteristics and transmits the data of it wake. All aircraft nearby receive the data on dangerous area of wake vortex on their system of warning of approaching to wake vortex. These data are displayed on head-up display in pilot cockpit. Besides, audio warning about approaching to dangerous area of wake vortex is also possible. Operation of onboard part of the WVSS could be integrated with other aircraft systems, for example with traffic collision avoidance system (TCAS). Block diagram of WVSS operation is presented in Figure 8.

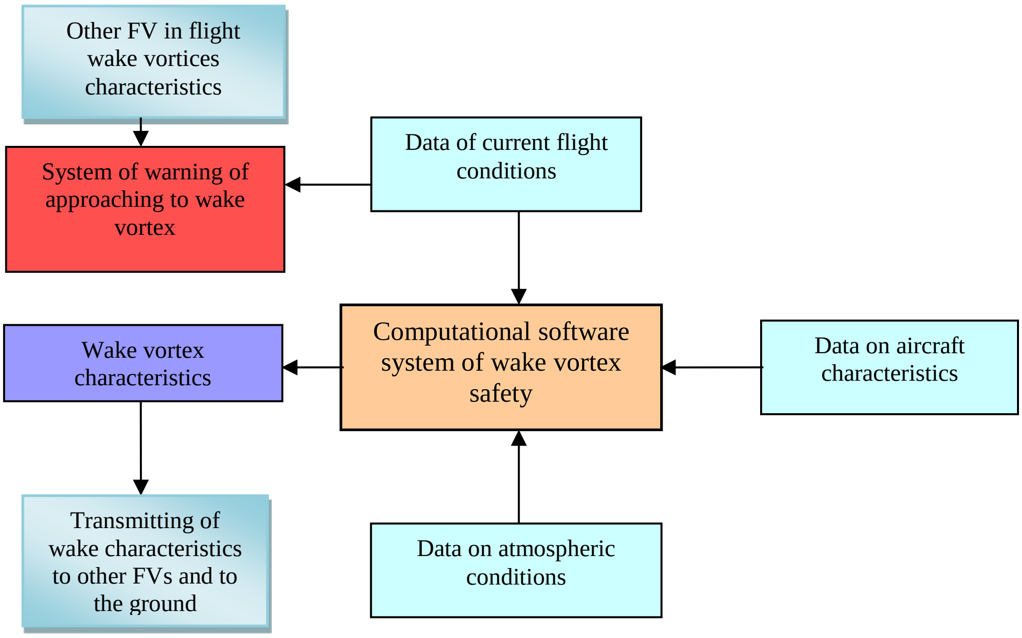


Figure 9. Block diagram of WVSS operation.

5. Conclusions

Thus conditions and means of provision of sufficiently high degree of flight safety at take-off / landing flight modes are defined as a result of conducted in Russia, including application of visualization, researches of large scale vortex flows, i.e. flows which are dangerous for various FVs. Collected data are valuable basis for development of experimental data bases on flight safety and also for testing and tuning of numerical calculation techniques.

References

[1] Zamyatin A.N., Vyshinsky V.V., Sudakov G.G. (2006) Theoretical and experimental research of evolution of wake vortex behind aircraft flying in atmospheric boundary layer. *Journal Air Fleet Technology, vol. 3-4.*

[2] Babkin V.I., Belotserkovsky, A.S., Zamyatin, A.N., et. al., (2008) Wake vortex flight safety systems for airplanes. Nauka, Moskow.

[3] Zamyatin A.N., Grigorev M.A., Rogozin V.V., Zhelannikov A.I. (2014) Mathematical Model of Aircraft Wake Vortices Development for Take-off/Landing Phases for Wake Vortex Safety Systems. In: Proceeding of the 29th Congress of the International Council of the Aeronautical Sciences. Saint-Petersburg, Russia, 7-12 September 2014.

[4] Zamyatin A.N., Zhelannikov A.I. (2015) Computational software system for wake vortex safety system. Russian Federation Certificate on state registration of computer software № 2015614783.