TRANSPORT SYSTEMS

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AUTOMATION OF TECHNOLOGY OF AIR-TO-AIR REFUELING REGIONAL AIRCRAFT

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Abstract—*Here are considered benefits of airlift using a phase in-flight refueling civil aircraft. Such technologies provide in particular for regional aircraft of Ukrainian production their main advantages at long flights. The variants of automation of this phase of the flight are proposed.*

Index Terms—Refueling; probe of refueling; drogue; refueled aircraft; tanker aircraft; control laws; remote-controlled drogue.

I. INTRODUCTION

To optimize the delivery of passengers is requiring for a particular flight not only choose the type of vehicle, but also ensure the effectiveness of its use by applying the modern transport technologies. Improving economic efficiency of air transport services can be accomplished through the use for regional aircraft technology of air-to-air refueling (AAR), which can provide the exploitation of these aircraft on long-haul non-stop flights instead of expensive long-haul aircraft [1].

A striking example of regional jets, for which can be applied, these technologies are modern jets: An-158 (passenger variant) and An-178 (transport aircraft) of the company Antonov. Comparative analysis of the technical characteristics of the aircraft An-158, characteristics of the aircraft of medium-range Boeing 737-900 and the long-range aircraft A330-300 of the company Airbus shows that short-haul (SHA) and medium-haul aircraft (MHA) can well solve the problem of transportation of passengers on long international lines. In this case the characteristics of navigation equipment of the aircrafts approximately the same and a flight comfort on SHA and on MHA is not worse than on the elite long-haul mainline jets (LHA). In addition, service for a smaller number of passengers could be better and it will cost less resource for the airline. The problem of LHA is also the fullness of load flights, which is low for the long international lines.

The AAR technology can significantly reduce the fuel consumption, will allow several times to increase the commercial aircraft load and reduce the emissions of CO_2, as well as reduce the cost of the flight fleet.

In addition, the implementation of direct long-haul flights using regional jets proportion of flights with a stopover in the airline hub is reduced, because passengers can be delivered directly to the destination without change of flights in international airports.

All this emphasizes the urgency of developing AAR technologies for civil aircraft. The development of this idea is currently engaged in leading aviation research organizations in Europe in the framework of "Recreate" project [2], as well as scientific institutions of Russia and Israel problem.

II. PROBLEM STATEMENT

Analysis of existing refueling systems shows that the most common and relatively simple system is the "probe-and-drogue system". Therefore this method is taken as the basis for the development of the automated system of AAR for civil aircraft.

But in order to reduce the requirements for pilots of civil airliners in the article is proposed for the "probe-and-drogue" system use the method of "inverse" AAR (Fig. 1). This method requires no special training pilots of the aircraft, which should be re-filled.

Fig. 1. The method of "inverse" air-to-air refueling

Special modifications of civil aircraft, as an aircraft that refuel in the air, is not required, if using a unified outboard unit of refueling (Fig. 2) that is suspended under the fuselage of the refueled aircraft.

The crew of this aircraft, equipped with the unit of refueling, by command of the tanker only let out a flexible hose with the drogue, which trails from the

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aircraft. The entire alignment process of rapprochement and contact performs a trained crew of the tanker aircraft, which is approaching to the commercial aircraft behind and performing the maneuvers, connects its own fueling system with the extended drogue. Alterations in accordance with the «inverse» AAR exposed only the outboard unit of refueling.
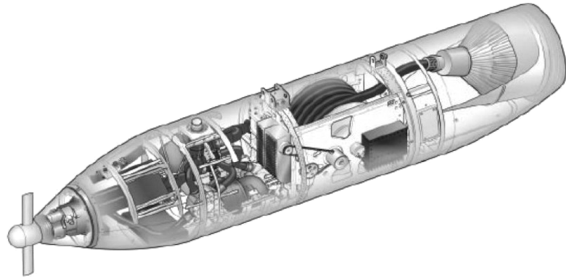

Fig. 2. The unified unit of refueling

Additionally refueling process can be automated to reduce the load on the tanker aircraft crew. At the same time it's necessary to automate not only the control of the aircraft, as well as the control of a drogue of AAR, equipping the drogue aerodynamic control surfaces and thereby turning it into the remote-controlled UAV, which the crew of tanker will be able to direct on its probe of a refueling system.

The control system of a drogue using their own control arrangements can carry out the stabilization of a drogue in the air, fending turbulent perturbation, and as well as to direct the drogue on the probe of a tanker aircraft in an automatic or automated regime of control.

The statement of the problem can be formulated as follows: for the parry of turbulent perturbations acting on the drogue and impeding the contact process, on the basis of one embodiment of an aerodynamic control of the drogue design the system of its stabilization (SSD), and then based on SSD build the system guidance of the drogue (SGD) at the probe of refueling.

III. PROBLEM SOLUTION

In this paper, on an analysis of possible options for constructing of an aerodynamic control surfaces of a drogue was selected the jet system of a control type FLAVIIR (Fig. 3) which is based on slit channels as the least energy intensive, reliable and easy to maintain.

The jet control system of a drogue used as controls a slotted channel 2 on the casing filling drogue 1, which ends on the window 3. Slotted windows 3 are closing dampers 4, which connected with actuators 5. Using the technology changes a flow of air

jets along an aerodynamic profile of the drogue allows you to change a speed and a pressure flowing stream and thereby change the distribution of aerodynamic forces acting on the drogue, that is, to control a movement of the drogue in an air stream. As the power amplifier of actuators 5 are used the linearized relay amplifier.
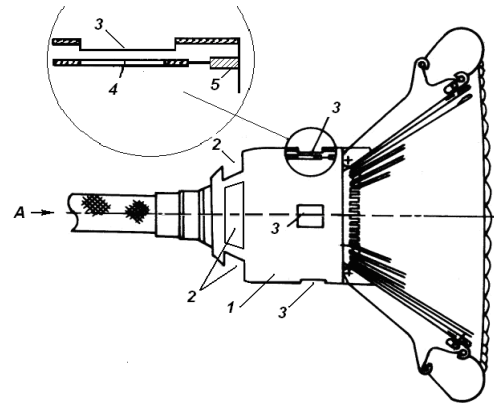

Fig. 3. Aerodynamic control units of a drogue

Alternatively, can be used the fowler flaps as the controlling aerodynamic surfaces drogue. These controls act as spoilers. When advancing flap in air flow occurs inhibition of flux as a result of the pressure in front of the flap will increase and will decrease the aerodynamic force in this part of the drogue. Thus, the flaps act as executive units of direct controls aerodynamic force.

To parry disturbances acting on the drogue while refueling in the air, it is proposed the system SSD, a sensor of which is a small, ultralow power, 3-axis digital MEMS accelerometer, installed under the hood of a drogue. The measuring axis accelerometer coincides with an axis of symmetry of the drogue. Outputs of the accelerometer are connected to two inputs of actuators, which connected with the damper control system, located on a body of the drogue. Each control channel consists of a power amplifier and a calculator forming control laws actuators. The algorithm of the SSD is a classic damper.

Control laws of actuators dampers for vertical and horizontal channels are identical.

$$\delta_h = \left(K_{n_y} + K_{\dot{n}_y} \big/ p \right) \Delta n_y;$$
$$\delta_z = \left(K_{n_z} + K_{\dot{n}_z} \big/ p \right) \Delta n_z,$$

here δ_h, δ_z are displacements of dampers in vertical and horizontal channels respectively; Δn_y, Δn_z are values of surplus vertical and horizontal accelerations, which are measures ADXL345.

A basis for the system SGD is the technology RTK [4], which provides a measure of relative provisions of objects with an accuracy of about 10 mm at baseline distances of ~ 20 m.

On the drogue of the refueling outboard unit are located (Fig. 4): the receiver GPS, the command radio line transceiver, the linear notifier of an entrance of the probe in a basket of the drogue and SSD.
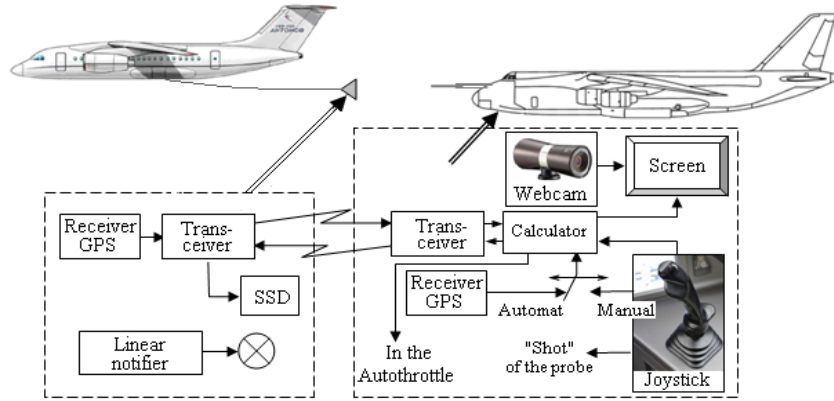

Fig. 4. The system guidance a drogue at the probe refueling

The equipment of a tanker aircraft includes a telescopic probe with the GPS receiver and the webcam, the command radio line transceiver, the joystick remote control of a drogue of co-pilot, the indicator screen and the calculator of SGD. Information from the calculator SGD also direct in the autothrottle of a tanker aircraft. The autothrottle working at the control law (1) implements the exponential trajectory change a speed of docking approach ΔV_{des}, which is proportional to the relative distance of the drogue Δd, which is calculated on the technology RTK, using information two receivers GPS.

$$p\delta_{\text{throt}} = K_{\dot{V}} pV + K_V \left[(V_{\text{des}} + \Delta V_{\text{des}}) - V \right], \quad (1)$$

here δ_{throt} is the displacement of throttle lever; V_{des} is the desired speed of flight at the phase of refueling; $\Delta V_{\text{des}} = -\Delta d / T$ is the change desired speed of approach; T is the time constant of exponent.

However, the use of such a law greatly increases time of approach, because direct contact a probe with the drogue theoretically will be realized only in infinity. To avoid this, the asymptote of the exponential must be located behind a drogue at a distance Δd_{as}. In this case, the trajectory of an approach is realized in the form of:

$$\Delta V_{\text{d}} = -\left(\Delta d + \Delta d_{\text{as}} \right) / T .$$

Control laws of actuators of the drogue at the stage of automatic guidance on the refueling probe are of the form:

$$\delta_h = \left(K_{n_y} + K_{\tilde{n}_y} / p \right) \Delta n_y + K_h \Delta h;$$
$$\delta_z = \left(K_{n_z} + K_{\tilde{n}_z} / p \right) \Delta n_z + K_z \Delta z,$$

here Δh, Δz is the vertical and lateral deviation of the drogue from the axis of the refueling probe, which are calculated similarly to the calculation of the distance Δd.

In automatic mode, the control signals Δh, Δz in control laws are replaced with the signals from the joystick remote control co-pilot, which are received by the command radio line with tanker aircraft.

The research of the proposed loop stabilization drogue conducted by mathematical simulation using the program Simulink, which is part of the mathematical package Matlab programming.

In researches the model of the dynamic of drogue was introduced as a system of linear differential equations,

$$a_{\ddot{h}}\Delta\ddot{h} + a_{\dot{h}}\Delta\dot{h} + a_h \Delta h + a_{\delta_h}\Delta\delta_h + h_{\text{tur}}(t);$$
$$a_{\ddot{z}}\Delta\ddot{z} + a_{\dot{z}}\Delta\dot{z} + a_z \Delta z + a_{\delta_z}\Delta\delta_z + z_{\text{tur}}(t).$$

The mathematical model of the drogue motion dynamics was obtained by simplification the known model motion of hose points [3]:

$$\rho \frac{\partial^2 u}{\partial t^2} = F \frac{\partial^2 u}{\partial x^2} - \rho g - D \frac{\partial u}{\partial t} - A \frac{\partial u}{\partial x} + A\alpha_{\text{tur}}(x,t),$$

and given boundary conditions on the right and left ends of the hose respectively [3]:

$$M_{\text{dr}} \frac{\partial^2 u}{\partial t^2} = -M_{\text{dr}} g - D_{\text{dr}} \frac{\partial u}{\partial t} - (C_y + F)\frac{\partial u}{\partial x}$$
$$+ C_y \alpha_{\text{tur}}(x,t)|_{x=L};$$

$$u(0,t)|_{x=0},$$

where u, (Δh, Δz) are functions of coordinate deviation of hose points (drogue); $\Delta\delta_h, \Delta\delta_z$ are impacts of the drogue control system; M_{dr} is the mass drogue; ρ is the linear density of the hose; t is the time; g is the acceleration of gravity; D is the damping coefficient of antihunting; D_{dr} is the damping coefficient the drogue; A is the coefficient of the linear aerodynamic force; F is the force of a hose tension; $\alpha_{tur}(x,t)$, $h_{tur}(t)$, $z_{tur}(t)$ are components of gusts turbulent atmosphere; L is the hose length; C_y is the aerodynamic coefficient of the drogue; x is the coordinate along the hose; $a_{\ddot{h}}, a_{\dot{h}}, a_h, a_{\delta_h}, a_{\ddot{z}}, a_{\dot{z}}, a_z, a_{\delta_z}$ are coefficients of the simplified model of a spatial movement of the drogue.

Comparing the simulation results of a simplified model when subjected at the drogue the gusts turbulent atmosphere of medium intensity with the results of the simulation the full model "probe-and-drogue system", which were received in MFTI [5], showed an acceptable adequacy of the simplified model.

The difference of the simplified model is that it does not describe the drogue altitude separation along the length of the hose, which for a standard length of the hose (26 m) is approximately 5 m.

And at the simulation of a turbulent atmosphere was used the generally recognized Dryden model.

$$S_w(\omega) = \sigma_u^2 \frac{L}{2\pi V}\left[1 + 3\left(\frac{L}{V}\right)^2 \omega^2\right] \cdot \left[1 + \left(\frac{L}{V}\right)^2 \omega^2\right]^{-2},$$

where σ_u is the mean-square value of the speed of a random eddy wind; L is the linear scale of an atmospheric turbulence; V is the flight speed.

In researches of dynamics of movement in an air the components of a spectral density of an atmospheric turbulence can be extracted from a random noise by means of the shaping filter

$$\Phi_w(p) = 1/(T_f p + 1).$$

This transfer function corresponds to the differential equation of unit realization of the random stationary process, which describes the transverse component of atmospheric turbulence in the time domain

$$\frac{dh_{tur}}{dt} = \frac{dz_{tur}}{dt} = \frac{dw_{tur}}{dt} = \frac{S_0\xi(t) - w_{tur}}{T_f},$$

here $\xi(t)$ is the unitary realization of a discrete white noise with unit intensity; $S_0 = \dfrac{\sigma_u^2 L}{V}$ – the intensity of white noise; $T_f = \dfrac{L}{V}$ is the time constant of the shaping filter.

Simulation results (Figs 5 and 6) showed the efficiency of developed algorithms SSD and SGD, even when refueling in a turbulent atmosphere. In particular, the amplitude of bumpiness of the drogue in a turbulent flow is reduced by almost four times. Significantly reduces the docking time and simplifies the process of piloting a tanker aircraft. The pilot for 5–7 s eliminates the error of guidance and to further easily holds a drogue in the region of the contact zone.
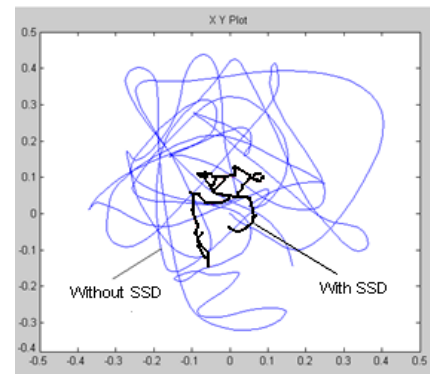
Fig. 5. Simulation results of the drogue motion at refueling in the turbulent atmosphere
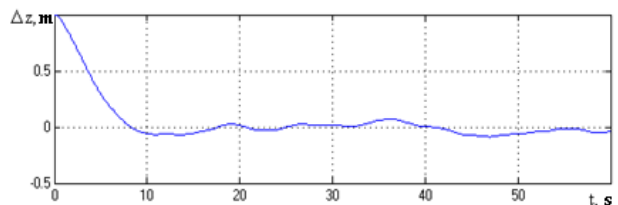
Fig. 6. Simulation results of the guidance a drogue at the probe refueling

Implementation of the proposed AAR system will improve safety at the stage of contacting and significantly reduce the time of refueling.

IV. CONCLUSIONS

The technology in-flight refueling of regional jets will allow: to increase their commercial payload; significantly save fuel and reduce CO_2 emissions into an atmosphere.

The technology of an inverse refueling will reduce the load on pilots airliners that are refuels.

The proposed system of the drogue stabilization and the system guidance of the drogue at the probe of refueling greatly facilitate the piloting technique at the contacting stage, even when refueling in a turbu-

lent atmosphere, and substantially reduce psycho-physical loads of tanker aircraft pilots.

Regional aircraft of type An-158, An-170, equipped with the proposed air refueling system on routes Europe − South-East Asia may be out of competition.

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М. К. Філяшкін. Автоматизація технології дозаправлення у повітрі регіональних літаків
Розглянуто переваги повітряних перевезень з використанням у польоті етапу дозаправлення цивільних літаків. Такі технології забезпечують, зокрема, для регіональних літаків українського виробництва значні переваги під час їх експлуатації на дальніх магістральних рейсах. Запропоновано варіанти автоматизації цього етапу польоту.
Ключові слова: штанга системи дозаправлення; конус системи дозаправлення; заправний літак; літак-заправник; закони керування; дистанційно-керований конус.

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Напрям наукової діяльності: комплексна обробка інформації в пілотажно-навігаційних комплексах, автоматизація та оптимізація керування повітряними суднами на різних етапах польоту.
Кількість публікацій: більше 150 наукових робіт.
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Н. К. Филяшкин. Автоматизация технологии дозаправки в воздухе региональных самолетов
Рассмотрены преимущества воздушных перевозок с использованием в полете этапа дозаправки гражданских самолетов. Такие технологии обеспечивают, в частности, для региональных самолетов украинского производства значительные преимущества при их эксплуатации на дальних магистральных рейсах. Предложены варианты автоматизации этого этапа полета.
Ключевые слова: штанга системы дозаправки; конус системы дозаправки; заправляемый самолет; самолет-заправщик; законы управления; дистанционно-управляемый конус.

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