RESTARTING OF A JET ENGINE DURING FLYING AND FLIGHT SAFETY

Miroslaw KOWALSKI*, Antoni JANKOWSKI*, Jan RAJCHEL**
* Air Force Institute of Technology, Ks. Boleslawa street 6, 01-494 Warsaw, Poland,
**Polish Air Force Academy, Dywizjonu Street 303/35, 08-521 Deblin, Poland

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Abstract

The paper presents the analysis of the drive unit start-up process of training aircrafts during flight, which are equipped by the Dęblin's "School of Eaglets" and intended for a flight training of officer cadets. The analysis of the start-up process was conducted using data from on-board flight recorders recorded during a flight training, whose aim was an emergency launch of particular drive units, and with the help of the so-called phase diagrams of the selected operating parameters of the particular flight drive systems. The construction principle of typical start-up systems was presented schematically presenting their base subassemblies. The importance of proper selection of the start-up system for the particular aircraft was emphasized and the basic indicators, which must be taken into account in the process, were cited. The basic mathematical dependences necessary in designing and determining the basic characteristics of the engine start-up process were explained. At the end, the obtained results and the main problems that need intervention as well as the proposal of preventive activities were shortly commented.

1 Introduction

The start-up process of drive units during the flight of training aircrafts, which are equipped by the Dęblin's "School of Eaglets" and intended for flight training of future pilots is a very important element in terms of flight safety. During use of the engine in the air, there is a possibility of its spontaneous turn-off. The causes of the turn-off, assuming that the fuel system operates correctly, are numerous, e.g.: execution of rapid maneuvers at an earlier reduction in engine speed, which can cause an asymmetric airflow around the engine intake, incorrect regulation of inlet diffusers, flow disturbances caused by e.g. firing of rockets, icing of the inlet, etc.

The construction of the aircraft engine start-up system is often an indicator of ranges of the aircraft's possible applications. The start-up system – regardless of the type – consists of three main systems: start-up automatics (exercising also a control function), a basic generator, and a power supply (Fig. 1). The power source can be an integral part of the aircraft or engine (a dual generator).

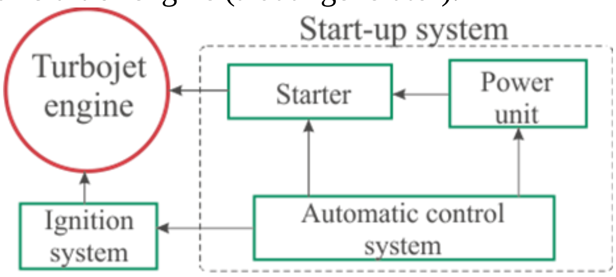

Fig. 1. Diagram of the start-up system [3]

In modern turbine jet engines, start-up is automatic in accordance with the specially tailored program of the generator turn-on/turn-off, ignition and start fuel. The type of start-up system determines also its weight and dimensions, which is especially important for small aeroplanes, as well as the necessary actions to be performed by the pilot during its launch. This is especially important during the flight training in the air, of the future pilots and it is directly related to flights' safety.

The task of the start-up system of the aero engine is to give the necessary rotational speed of the engine power transmission (an air compressor and turbine unit), at which the power developed by the turbine N_t is greater than the sum of the power pulled by the air compressor N_s and other engine subassemblies – in accordance with the balance of the power of the turbine specified by the dependency:

$$N_t > N_s + N_{agr} \qquad (1)$$

where: N_{agr} - the power needed for the units' drive and overcoming the frictional resistances.

The engine start-up is an unsteady process lasting from the standstill to the achievement of the necessary, minimum rotational speed in ground conditions, and during the flight, also from the minimum speed of "autorotation" to the minimum rotational speed (often referred to as minimum flying speed). The engine start-up in the range to the minimum rotational speed must be carried out continuously, with the specified acceleration.

The research and analysis of the start-up processes were conducted on, among other, the PT6A-25C engine by the Pratt & Whitney Company constituting a drive unit of the PZL-130TC-II „Olik" aircraft, the PZL-10WM engine constituting the drive unit of the W-3 "Sokół" helicopter, as well as the SO-3 turbojet engine of the TS-11 "Iskra" aircraft. These are the basic aircrafts equipped by the Dęblin's School of Eaglets, whose task is to secure the practical flight training in the air. The Air Force Institute of Technology derived the data for the analysis from on-board flight data recorders type S2-3a, which are built in the above-mentioned aircrafts. The analysis was conducted mainly using the so-called phase diagrams of the selected engine operation parameters, described with the general dependency:

$$\frac{dX}{dt} = f(X) \qquad (2)$$

where: X - tested parameter,
t - time [s].

Moreover, it was noted that the rate of acceleration of the engine has a decisive influence on the obtained start-up time, which is one of the main parameters of all start-up systems. It was indicated that securing the so-call surplus power, which requires a continuous supply of fuel and air into the combustion chamber of the engine, is necessary to maintain acceleration at the required level. Selected characteristics obtained during the start-up processes analysis of particular drive units during flight.

2 Examples of procedures of start-ups in the air of the flight drive units

The start-up of the turbo-prop engine is slightly different from the one of the jet engine. This is due to the fact that the specified rotational speed of the air compressor turbine is called mainly by the autorotation of a propeller set at appropriate angles of attack. Depending on the angle of the propeller blades setting, there are several opportunities of cooperation of the propeller with the engine. The most favorable setting is the one, in which the blades are set in the so-called "pennant" (the angle of attack of the propeller in relation to the plane of rotation is near to 90^o), which gives a minimum drag. The surplus power of the turbine from the dynamic pressure is consumed on the internal air stream choking in the engine.

For the drive unit of the PZL-130TC-II "Orlik" training aircraft (the PT-6A engine), there is no automatic ability to set the propeller in the "pennant" setting. The pilot is required to switch the power lever manually (fig. 2) to the engine speeds range of the idle run in order to attack the safety switch responsible for moving the propeller blades in the "pennant" position. This solution is not so fortunate from the point of view of the need for the proper response of the crew in a very stressful situation, which often takes place during the spontaneous turn-off of the engine, especially in the young pilots.

Fig. 2. View of the power lever (a green arrow – direction of lever movement)

During the qualification tests, three subsequent start-ups were conducted in the air at an altitude of about 3,000 m and velocity in the range of 230 to 260 km/h. The first one was executed after 30 seconds after turning off the engine; the second one, when the engine speed dropped below 50%, and the third one – also after 30 seconds after the emergency turn-off. The visualization of particular start-ups of this engine is shown in fig. 3, which presents the course of engine rotational speed in function of the flight duration.

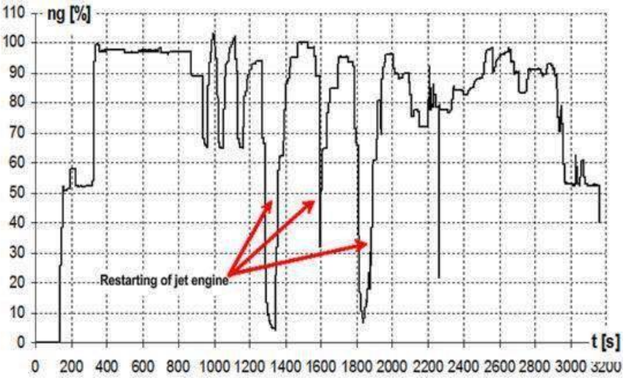

Fig. 3. Course of change in engine rotational speed during the flight to check the possibility of starting up the engine in the air

During start-up of the engine in the air, the propeller – in a certain range of angles of attack – is an additional source of significant torque, exceeding manifold the maximum torque of the generator. Thus, the time required to achieve the idle run engine speeds (released gas) by the engine is slightly shorter than for the start-ups on the ground. The time histories of the change in engine rotational speed during execution of the analyzed starts-up show their slight reduction, apart from emergency launch.

The conducted analysis of change in the drive unit basic operation parameters during subsequent start-ups allows determining which start-up method is the most effective and proceeds the most gently.

The applied on the Polish helicopter W-3A "Sokół" is another example indicating a minor inconvenience in the start-up procedure of the aircraft drive unit. The PZL-10WM type turbine engine is built in this helicopter. It is equipped with a full authority digital engine control (FADEC).

Within the in-flight tests, so-called cold and hot start-ups were conducted at altitudes up to 4,000 m. In one case, at altitudes above 3,000 meters (i.e. 3,500 and 4,000 m), attempts to perform start-ups failed. The reason for this state of affairs was not launching an additional bleed air (e.g. for the needs of an airframe – prescribed in the User Manual of this engine).

The fig. 4 presents the one of the unsuccessful attempts to start-up the left engine in flight at an altitude H≈3,500 m, at flight velocity V_p≈115 km/h. The visible phase mapping is typical for the very generator's operation, which suggests that the increase in the rotational speed N1 to almost 30% were just the consequence of the generator operation.

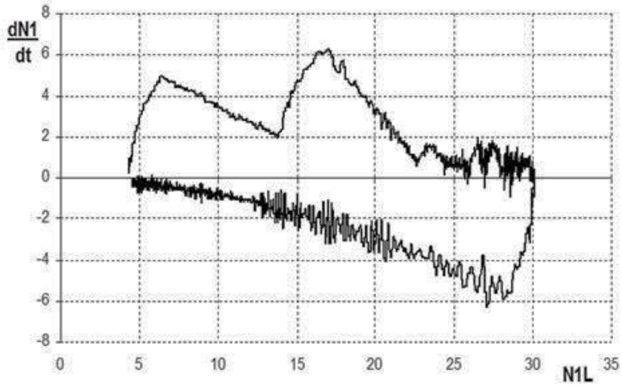

Fig. 4. Phase mapping of growth of the rotational speed N1 during the failed start-up in flight

Looking at fig. 5 depicting the flow rate of fuel supplied to the combustion chamber in function of the rotational speed N1 of a turbocharger, one can state that at proper air pressure p_2 behind the engine compressor, the start-up would have ended with a positive result.

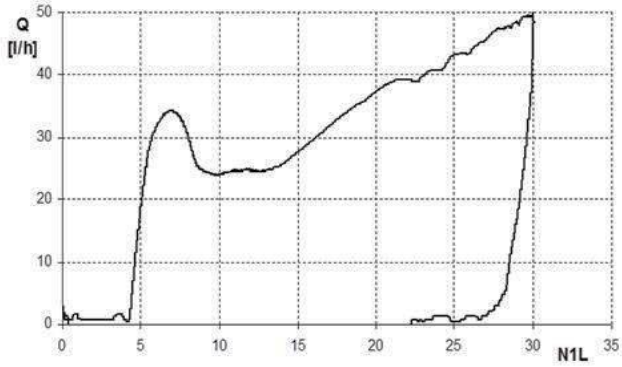

Fig. 5. Fuel flow rate Q in function of the turbocharger rotational speed N1 during the failed attempt of the left engine start-up in flight

In subsequent checks, after taking into account the need of the additional bleed air from the compressor, the attempts were positive then, and their parameters were consistent with the technical conditions (TC). It should be noted, however, that the ensuing instance of failed start-up of the engine at high altitudes, in the presence of subzero ambient temperatures, without the use of the additional bleed air is a big problem worth of deeper analysis. Because it requires the crew is remembering about additional activities in a very stressful situation (an emergency situation) and at very often deficit of time. For this reason, the application for consideration of possibility of the program consideration of such a situation directly in an electronic box – of course, in the phase of further development and modernization of the full authority digital engine control – was sent to the Producer of the helicopter.

The next example of strongly complicated procedure of start-up (during the flight) concerns a single flow turbine jet engine SO-3 built in the aeroplane TS-11 "Iskra." This aeroplane is quite simple to use – it is designed for an advanced training of young pilots at the School of the Polish Air Force Academy in Dęblin – Poland. In the ordered procedure of the engine start-up during the flight, there are many activities to accomplish, which, in addition, must be carried out in the correct order. Moreover, there is a need for continuous monitoring the temperature growth of the exhaust gas in order not to exceed the maximum permissible value, i.e. 800^{o}C. This is very important because its excess forces the pilot to stop the engine start-up. The re-attempt to launch the engine, after such an interruption, requires the so-called engine purging for 20 seconds in order to remove surplus amount of fuel, which – in extreme cases – may lead to a fire. This is very dangerous because of the fairly frequent lack of time for the execution of all these activities and it requires the implementation of automated start-up systems.
However, it must be noted that very often, after the unsuccessful attempts to launch the engine, it is necessary to analyze the causes of this incident. This will allow for the development of appropriate prevention and avoiding such events in the next training flights. For this type of analysis, among others, the already mentioned method of phase mapping of rotational speed growth can be applied. It allows, among others, to recognize irregularities in the engines control through a comprehensive analysis of the operation (or the technical state) of all elements of the engine start-up system. The increase in engine rotational speed during start-up in function of time provides (sometimes) pretty poorly noticeable symptoms its disturbance (a red line in fig. 6).

Fig. 6. Change in the engine rotational speed during start-up of the SO-3 engine during flight

As late as presenting the so-called phase diagram of rotational speed growth, it can be quite clearly seen that a small disturbance of the rotational speed growth is the result of, for example, growth of an exhaust gas limiter system, which slows its growth with pretty rapid reduction in the amount of fuel supplied to the combustion chamber. Such a phenomenon can be seen in fig. 7, where as a result of a relatively rapid gradient of the increase in rotational speed (as a result of supplying excessive amounts of fuel into the combustion chamber) at a relative rotational speed of about 45%, a significant reduction of supplied fuel amount occurred, which caused a slowdown in the rotational speed, and, thus, the decrease in the gradient of the exhaust gas temperature. This state of affairs greatly strains – especially rotating engine components (such as e.g. compressor and turbine blades) – due to excessive thermal loads occurring simultaneously.

Such an analysis allows for earlier response and readjustment of the engine start-up system, which may significantly reduce negative phenomena accelerating the destruction processes of sensitive parts of the aero engine.

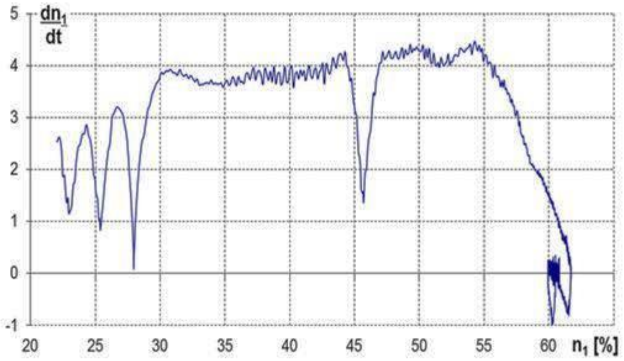

Fig. 7. Phase mapping of growth of the rotational speed during the start-up in flight

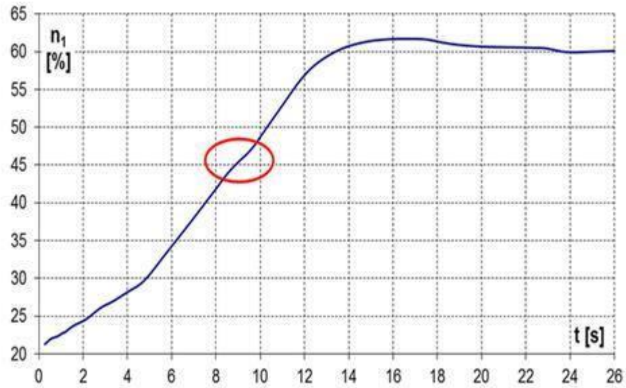

Fig. 8. Change in the rotational speed of the engine during start-up of the SO-3 type engine during the flight (much lower collapse of rotational speed growth visible)

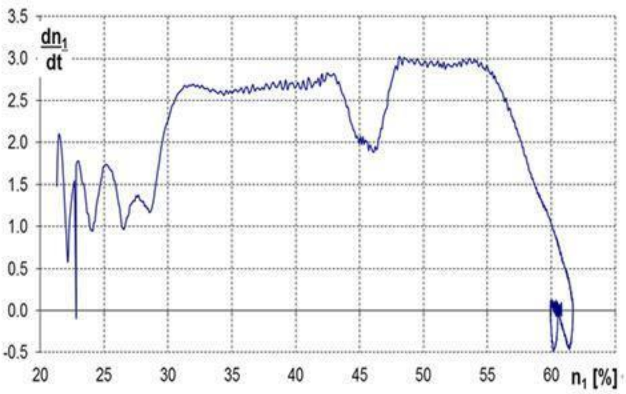

Fig. 9. Phase mapping of growth of the rotational speed during the start-up in flight (much lower slowing of the rotational speed visible)

Figs. 8 and 9 present similar characteristics, but after the executed engine control, which significantly reduced the growth dynamics in engine rotational speed n_1 during start-up, and, thus, the temperature gradient of exhaust gases – excessively burdening particularly rotating elements of the engine. This is mostly result of the fact that the very high temperature of exhaust gases work on too much cooled blades. This significantly weakens the fatigue strength of these elements and may lead to their coming off (damage).

Conclusion

The executed analyses of the drive units' start-up processes analysis show that the start-up systems of the drive units are effective and provide good operational (practically) in all conditions. However, they are not devoid of minor flaws, whose existence directly affects the safety of flights and requires taking preventive actions or even modernization of certain elements of the given start-up system.

Particular attention was paid to cases of failed engine start-ups during the flight, which were affected by mainly additional activities, without which it is impossible to launch the engine during the flight, imposed on the pilot. This is very important from the point of view of flight safety and poses a threat of a disaster.

In addition, forcing the pilot to perform additional activities during the flight and in a very stressful situation (turning off the engine during the flight) is not acceptable and needs to take concrete prevention activities or redesign the start-up system.

It is also important to keep the current verification of state of control of aircraft drive unit start-up processes, which allows avoiding unnecessary loads (e.g. thermal ones) of the engine drive units. The method of phase mapping of the rotational speed growth is a very good way of such monitoring of engine control state. It pretty accurately indicates the points of excessive loads of aircraft drive units' elements.

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8 Contact Author Email Address

miroslaw.kowalski@itwl.pl

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