GROUND TEST FACILITY FOR A TURBOSHAFT-TYPE APU TG-16M FOR PASSENGER AIRCRAFT

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Abstract: *This paper describes a ground facility for an APU, TG-16M-type.This kind of APU assisted some Russian (soviet) passenger aircraft during their ground engines' startup and also when the deicing electrical system was switched on. TG-16M turboshaft and generator embedded system together with its control panel and electrical sources are parts of the Aerospace Engineering Laboratories in University of Craiova facilities. One has realized a fuel supplying installation, an electrical supplying and control system, as well as an engine operating parameters' board apparatus panel. Tests results were used for some scientific contributions and papers, but the embedded system is also useful for aerospace students education (both for license and master studies); some specific results may be useful also for PhD studies.*

Keywords: *APU, turboshaft, engine, control, test, fuel, electrical generator.*

1. INTRODUCTION

An APU (which means Auxiliary Power Unit) allows an aircraft to operate autonomously, without reliance on ground support equipment, such as a ground electrical power unit, an engine start cart, or an external air-conditioning unit.

Some APUs are certified for use in flight, so those APUs can be used, as required, to provide an additional electrical power (in the event of the loss of an engine electrical generator); APUs can also be used as sources of electrical power for starter assist for an inflight engine relight, or to power the aircraft deicing (or anti-icing) system.

The auxiliary power unit TG-16M is a turboshaft-type turbo-engine, which spins up a 28 Volts DC electrical generator GSR-2000; this APU was used on soviet passengers airplanes Il-18 and An-24 type, as well as on some of their versions.

Il-18 airplane was a successful long range airliner, as well as a civil or military cargo plane, for several decades (starting with 1957 when it first flew), powered by four Ivchenko AI-20 turboprops engines, 3170 kW each. Airplane's main engines were started using a TG-16M APU, which was fitted in the rear part of the airplane's fuselage, in the tail-cone section, below the tail rudder.

An-24 (built in Soviet Union, then in Ukraine) was also a successful passenger airplane, but a short-medium range one. Its power installation consists of two Ivchenko AI-24 turboprop engines (driving four-bladed constant-speed reversible propellers, developing 1900 kW each), mounted in two nacelles under the wing; the TG-16M auxiliary power unit (APU) turboshaft engine was fitted in the left engine nacelle. Its destination was to assure electrical power during main engine start, as well as in flight deicing system electrical supplying, for some versions (such as An-24T).

The An-24T proved satisfactory in service, but its takeoff performance under "hot & high" (hot weather / high altitude) conditions left something to be desired. In cold weather conditions, the flight surfaces deicing system, driving by engine bleed air, drew off too much excess power, with the result that it couldn't be used on takeoffs. In addition, the TG-16M APU didn't always provide as much power as needed. However, avoiding these extreme conditions, the above mentioned APU was a successful and safe assistant of the airplane's power system.

A straightforward solution of this issue was a new kind of extra power engine, such as the compact RU-19A-300 turbojet (designed by Tumansky-office). This engine was a combination between a classic APU and a booster engine, with a thrust of 2.16 kN. In spite of a higher overall (which required a redesign of the left engine nacelle, in order to accommodate the new RU-19A-300), this new engine proved all that was hoped for, providing adequate boost power under difficult take-off conditions, plenty of airflow for the deicing system, and plenty of electrical power for ground operation. The new obtained version of An-24 was called An-24RV.

The studied TG-16M-type APU was in service on an An-24T passenger airplane (former in use at Romanian Airliner Company *Romavia*), which belongs now to Aerospace Engineering Laboratories in the University of Craiova.

2. SYSTEM'S PRESENTATION

Ground test lab facility for the above-mentioned APU consists of: a) starting and test control panel; b) electric power lab sources; c) electrical consumers group; d) TG-16M APU (consisting of a turboshaft engine and a 28 V d.c. electric generator).

The studied TG-16M APU is mounted on an iron frame support (cart), as Fig.1 shows and consists of the main engine (turbo-shaft, with centrifugal compressor, inverted combus-tor, axial turbine, exhaust nozzle, fuel supply system, electrical system), the reduction gear and the electric power 28 Volts d.c. generator (with cool bleed air pipe).

Engine's fuel supply system is feeded from an external fuel tank (15 liter capacity), which is mounted on a flat sheet fixed on the upper engine crankcase and is connected to the engine through the lower fuel pipes common connection, before the isolating valve (see Fig. 1 and schematics in Fig. 4).

APU's cart has a pair of fixed wheels and a pair of adjustable wheels (directed by a beam), in order to facilitate the displacement in the laboratory. During the tests APU's cart is

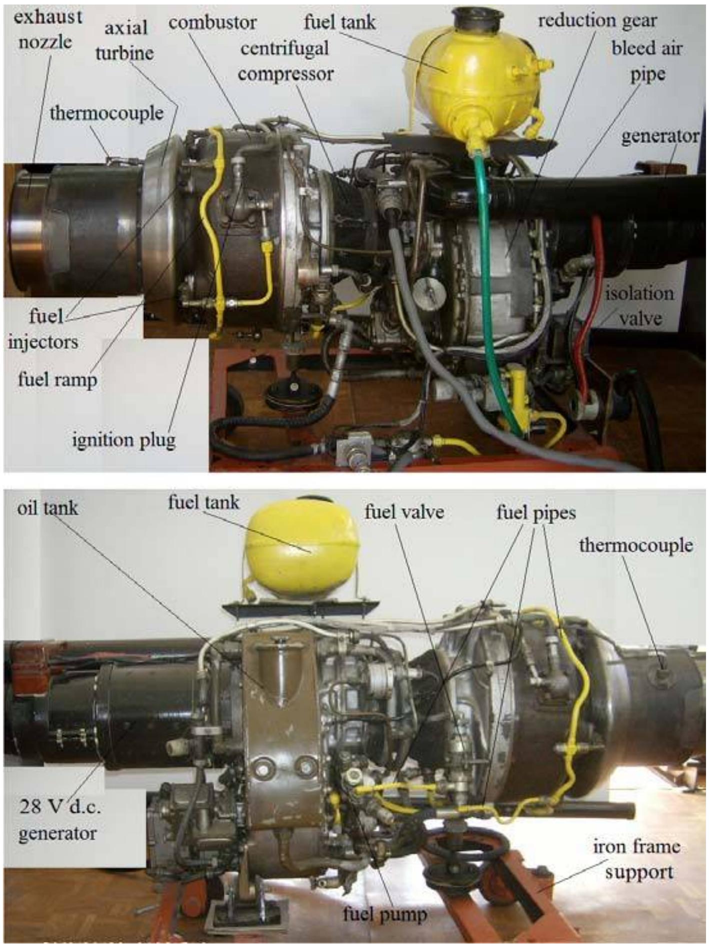

FIG. 1. APU TG-16M type on its ground cart (view from right side and from left side)

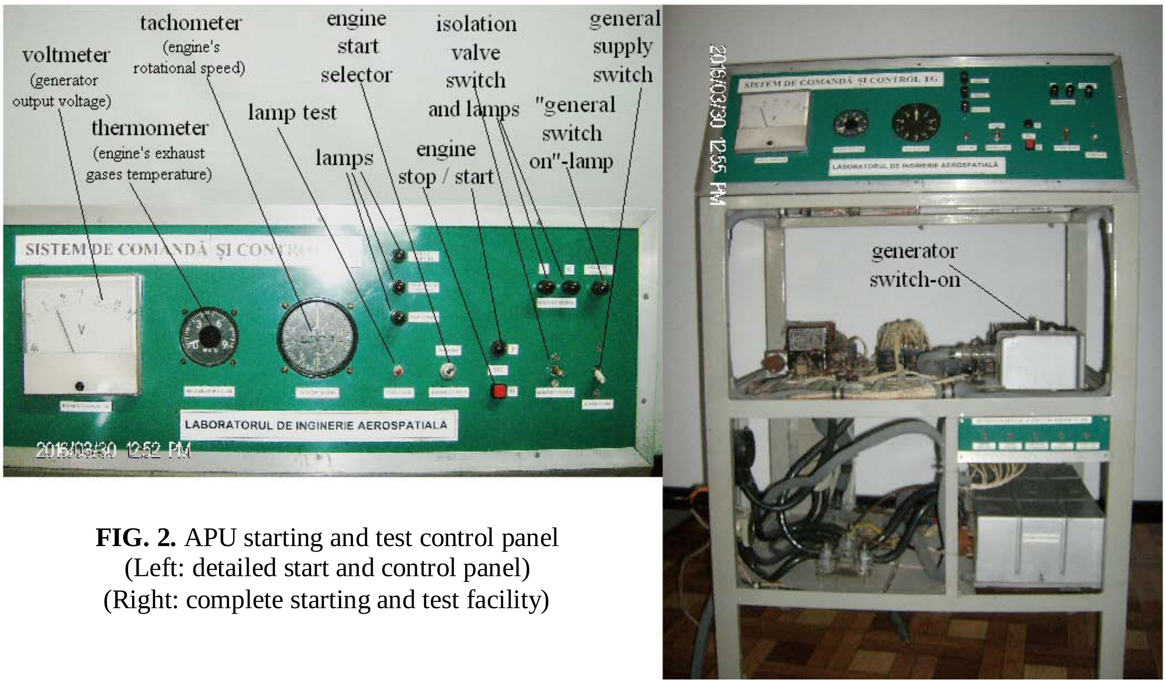

FIG. 2. APU starting and test control panel
(Left: detailed start and control panel)
(Right: complete starting and test facility)

secured by linking it to two short pillars stuck in the ground floor of the test facility.

The group of starting and test facilities is presented in Fig. 2 (detail in the right photo). Starting and test control panel is positioned on top of the facility (Fig. 2, left photo) and consists of three groups of elements: indicators (generator's output voltage, exhaust gases temperature, engine's shaft rotational speed), lamps (pilot lamps, for presence of electrical supply, for switch on/off, for complete start cycle) and buttons/switches (lamp test button, engine start and stop buttons, engine start mode selector). The mode selector for the engine start is a switch, which upper position commands a "hot start" (meaning an effective engine start), while lower position commands a "cold start" (meaning an engine start without flame/ignition, only with engine shaft spinning).

Electrical consumers group is not a specific facility, but it may be formatted occasionally, when the APU test with effective load is necessary. This group may contain resistors, converters or other electrical machines and drives, equipment which could absorb electricity (electrical power) supplied by APU's generator (see Fig. 3.a).

Power sources are standard equipment of the laboratory (see Fig. 3.b); for the APU test there are necessary: a high power 30 V d.c. source (for engine's start), as well as a common lab source (28 V d.c.).

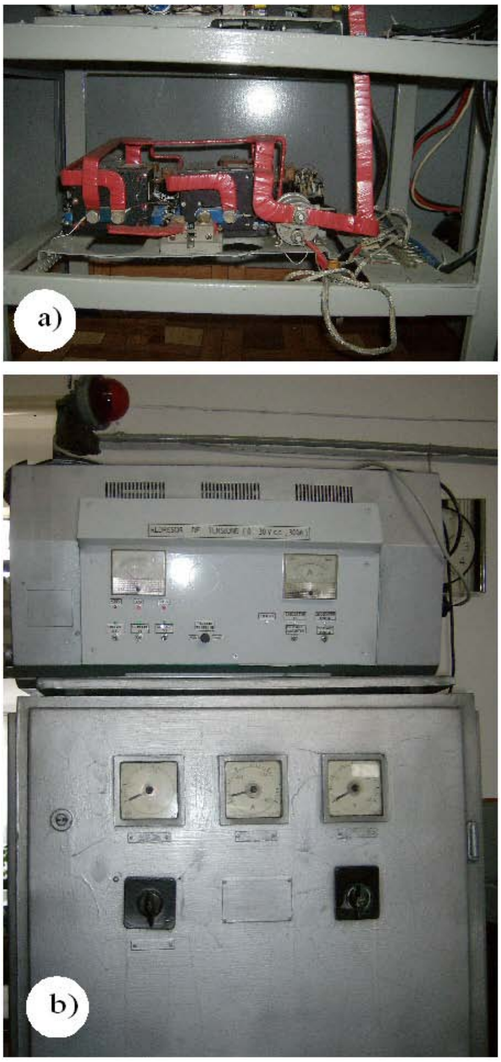

FIG. 3. Lab facilities: a) electric consumers group (resistors, electrical drives and machines); b) electric power sources.

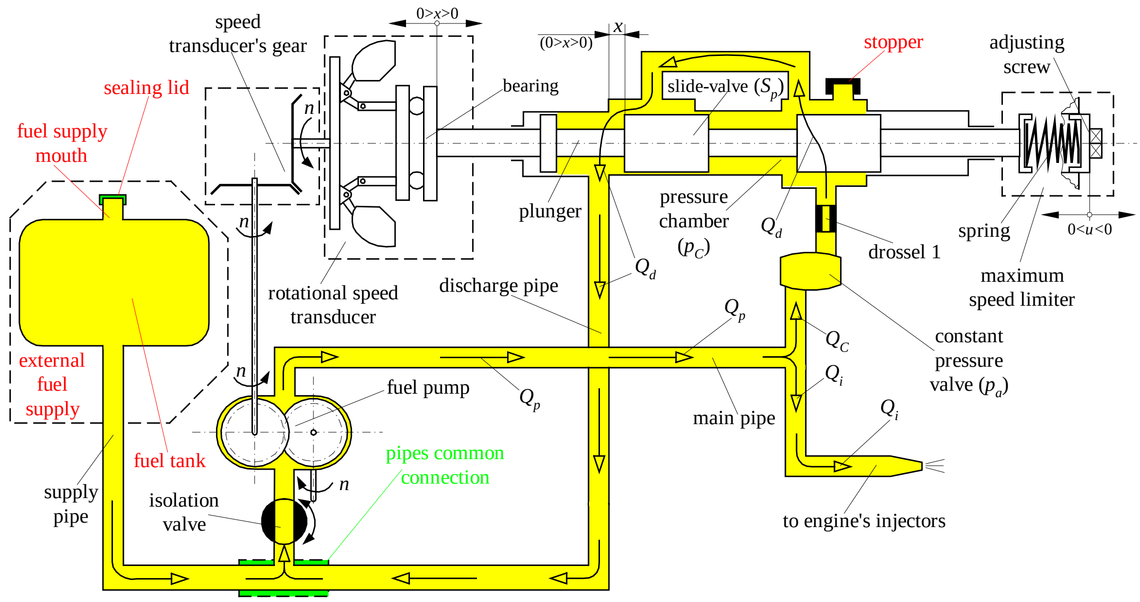

FIG. 4. APU fuel system with external supply

3. APU'S CONTROL SYSTEM WITH EXTERNAL FUEL SUPPLY

Unlike the way the APU is mounted on the airplane, on the ground test facility, because of some constraints, APU's fuel system had to undergo few structural changes.

The external fuel tank of the facility is smaller than any fuel tank of an airplane, it has no air pressuring system and it is refilled through an upper supply mouth, which is sealed with a lid after complete refueling.

Meanwhile, facility's external fuel tank has no booster-pump assistance for the APU's fuel supply, therefore it had to be mounted at a height of at least half meter from fuel pipes common connection level; consequently, fuel supply pressure at the APU's pump inlet is at most (0.04÷0.05) bar, which is too low and it could be lower than that in the secondary discharge pipe (from the second drossel of the transducer's pressure chamber), which would create a counterpressure in the common connection and would induce disturbances into fuel pump's input (supplying) circuit. In order to avoid this situation, the secondary discharge pipe had to be cancelled, so its drossel was sealed by a stopper (see Fig. 1 and Fig. 4, where the new fuel supply schematics is presented).

In fact, secondary discharge pipe and its drossel's role is to assure a small but permanent fluid (fuel) circulation through slide-valve's slots, even when main discharge circuit is closed (when slide-valve closes the main discharge slot); this fuel circulation transforms the basic distributor into a circulation distributor and prevents hydraulic shocks to occure when the slide-valve is repositioned during engine's transient (dynamical) regime.

Consequently, APU's fuel system operates a little different when mounted on the ground test facility, which, obviously, may be reflected by the mathematical model form, as well as by time step response curve(s).

4. APU'S BEHAVIOR ON GROUND TEST FACILITY

4.1. Mathematical model. For the TG-16M APU the mathematical model was determined and studied in [14], based on ground tests, developped on the above-described test facility. Most important consequence of the secondary discharge pipe cancellation is that the fuel flow rate Q_R (given by eq. (4) in [14]) becomes null, so equation (6) modifies, as follows:

$$Q_C - Q_d = S_p \frac{\mathrm{d}x}{\mathrm{d}t} + \beta_f V_C \frac{\mathrm{d}p_C}{\mathrm{d}t}. \tag{1}$$

Furthermore, k_{RC} – co-efficient becomes also null, which modifies values of k_{xC} and a co-efficients, as follows

$$k'_{xC} = \frac{x_0}{(k_{CC} - k_{dC})p_{C0}}; \tag{2}$$

$$a' = k_{QC} k'_{xC} k_{es}. \tag{3}$$

Obviously, because of the reduced right member expression in Eq. (2) denominator, above described quantities become bigger, so embedded system's time constant $(\tau_m - a'\tau_x)$ is also affected, becoming smaller; meanwhile, the term $1 - k_f k_{pn} + a'$ becomes bigger, but system transfer function keeps its same form in [14]

$$H_n(s) = -\frac{k_{cg}}{(\tau_m - a'\tau_x)s + 1 - k_f k_{pn} + a'}. \tag{4}$$

4.2. Stability and quality. Stability conditions remain the same described in [14]; determined transfer function's co-efficients for the discussed embedded system are both positive, so this system is a stable one.

In terms of system's quality, it remains asimptotic stable (studied system being a first order one). Transfer function's co-efficient values changes induce time behavior changes. Because of time constant decreasing, the embedded system becomes faster and its stabilisation time becomes smaller; meanwhile, because of the second term increasing, system static error grows (in absolute value), as curves in Fig. 5 show.

Studies were performed based on embedded system block diagram with transfer functions (Fig. 4 in [14]), where appropriate modifications were realized, using Matlab-Simulink. One has studied system's step input time response for both cases: APU on the ground test facility, respectively APU on the airplane.

Co-efficients were determined for the first case (when the fuel system is connected as shown in Fig. 5) during the ground tests, by measurements and analitical estimations, studying both idle regime and several regimes with different electrical generator's loads (power consumption inputs).

System's behavior as presented in [14] was obtained based on the above determined co-efficients, completed with the estimated k_{RC} – co-efficient; this estimation was based on author's observations

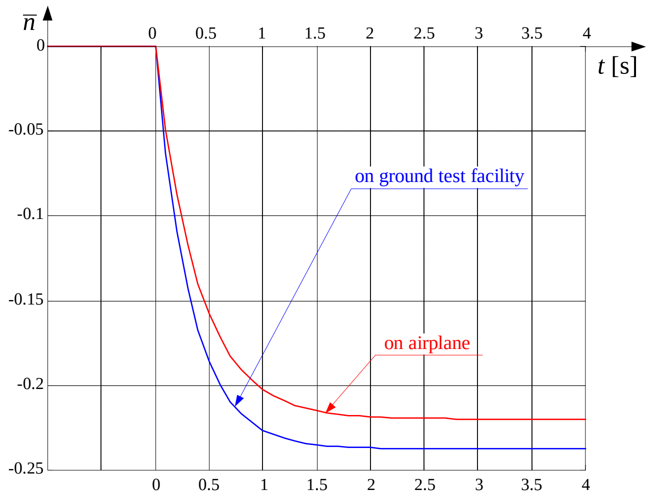

FIG. 5. System's quality: engine's speed step responses for APU's ground test configuration comparing to APU's airplane configuration

and on literature specifications [2, 8, 11, 12], so Eq. (6) in [14] was formally completed and used for system mathematical model, as well as for the described studies.

CONCLUSIONS

The paper has presented a laboratory ground test facility for an APU, TG-16M-type, which has equipped an An-24T passenger airplane. Above mentioned lab test facility consists of : a) APU's frame support; b) starting and test control panel; c) electrical consumers group; d) electric power lab sources.

The involved APU's fuel system has undergone few changes on ground facility comparing to the aircraft fuel supply system, in order to avoid malfunctions due to the lack of an external fuel supply pump to assist the fuel tank.

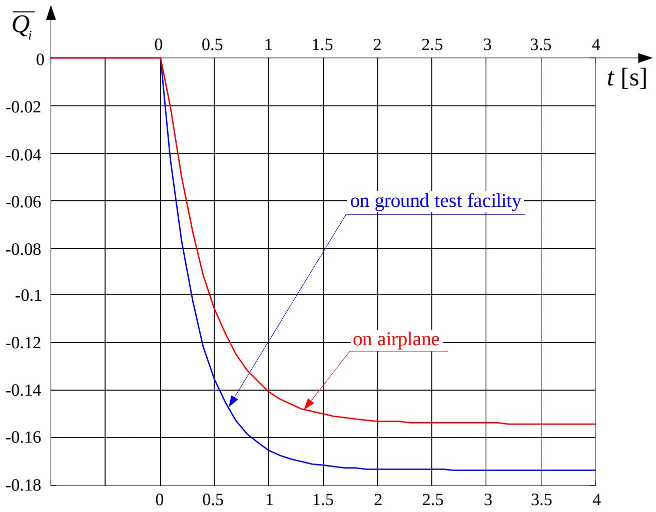

FIG. 6. System's quality: injection fuel flow rate parameter's step response for APU's ground test configuration comparing to APU's airplane configuration

Embedded system (turbo-shaft engine and electric generator) as controlled object was studied in [14], mathematical model's co-efficients being experimentally determined just with the described facility and/or analytically estimated. Embedded system has resulted as a first order system, just as its transfer function proves; consequently, system's stability is asymptotic-type (as shown in figures 5 and 6).

Comparing both embedded system time behaviors from the engine's speed, as well as from the injection fuel flow rate points of view, one has observed some differences. On ground test facility the embedded system is more rapid, its time response being around (1.8÷2.3) s, comparing to (2.2÷2.8) s onboard of the airplane. Meanwhile, static error has grown on ground test facility: as Fig. 4 shows, speed non-dimensional parameter has a higher static error by 10%, while injection fuel flow rate parameter (see Fig. 6) has a higher static error by 12%.

However, APU behavioral differences are small and doesn't matter in terms of teaching (from didactical point of view), nor in the experimental studies of engine's equipment and its electrical system.

Although the ground test facility was designed specifically for a TG-16M-type APU, some parts of starting and test control panel, as well as electric power lab sources and electrical consumers group can be used for other APUs or turbo-engines tests.

Lab test ground facility, as well as the embedded system engine+generator is useful for didactical demonstrations and training, as well as for scientific researches of master and PhD students.

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