Conceptual design of an unmanned aerial vehicle for fast container transport

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Abstract. The rapid development of technologies in the area of unmanned aircraft systems (UAS) combined with its wide spread in the civil market, indicates the possibility of creating a relatively large unmanned aerial vehicle (UAV) for cargo transportation (maximum take-off weight more than 18 tons). The concept of unmanned flight will improve the efficiency of an airplane with conventional layout. The removal of the crew compartment and associated systems makes it possible to apply advanced layout solutions that refine aerodynamics, reduce the airframe weight, direct operating costs, etc. This paper presents the conceptual design of a Civil Transport UAS (CITRUS). The CITRUS is intended for fast transportation of commercial containerized loads up to 7 tons with speed 830-850 km/h. The article provides the basic premises and principles of the new concept. The features of the aerodynamic layout of the CITRUS are described. Estimates of the aerodynamic and performance characteristics are given.

1. Introduction

The rapid development of technologies in the area of unmanned aircraft systems (UAS) combined with its wide spread in the civil market [1, 2, 3], indicates the possibility of creating a relatively large unmanned aerial vehicle (UAV) for cargo transportation (payload up to 7 tons) on regional routes. The removal of the crew compartment and associated systems makes it possible to apply advanced layout solutions that refine aerodynamics, reduce the airframe weight and operating empty weight (OEW), direct operating costs, etc. The absence of a crew allows transportation around the clock (there is no requirement to change the crew) in almost any weather conditions.

The Arctic regions could become starting area for operation of cargo UAV. Operating over almost deserted areas of the Arctic will significantly reduce the likelihood of damage on the ground in the case of an accident that will only lead to the loss of the aircraft and cargo, which would be an insured case.

One of the most important principles formulated by ICAO for integrating UAVs into airspace [4] is UAVs should not have a significant impact on current airspace users, must comply with existing and future standards and procedures established for manned aviation.
This paper represents preliminary results of conceptual design of the UAS for fast container transportation. The Civil Transport UAS (CITRUS) is intended for fast transportation of commercial containerized loads up to 7 tons with speed 830-850 km/h on regional routes.

The following concept basic principles for the CITRUS were defined:

- Commercial containerized cargo transportation on existing air routes;
- Certification under CS-25;
- Simple flight avionics on board (measuring devices, control surface actuators, telemetry and remote control), major flight control system on ground in special datacenters (GCS [5]);
- Advanced aircraft health management system;
- Cruise speed 830-850 km/h (Mach number = 0.78–0.8);
- Flight altitude – 11-13 km;
- Maximal payload – 7 t;
- Runway length – 1300 m;
- Pressurized fuselage;
- Automated cargo loading/unloading process.

The integration of the CITRUS into the existing route network is shown in the figure 1. The scheme is based on the SF Express (China) project "36-hour delivery" [6]. It can be seen that the aircraft occupies a niche of cargo transportation that is not available for medium-and long-haul aircraft with higher runway airfields requirements.

![Figure 1. The integration of the CITRUS into the existing route network.](image)

2. Basic layout

At the initial stage of design, the critical point is the choice of an aerodynamic configuration that meets the specified conceptual requirements. In modern research in relation to transport aviation, quite a lot of attention is paid to unconventional aerodynamic configurations such as "Blended Wing Body" (BWB) and "Hybrid Wing Body" (HWB). However, the conventional aerodynamic configuration used on the vast majority of modern civil aircraft is well established in operation and its use on an unmanned transport aircraft will reduce technical risks. The conventional aerodynamic configuration was accepted for the CITRUS – a high-placed swept wing scheme with horizontal and vertical stabilizers located on the fuselage (Figure 2).
The basic layout of the CITRUS was formed using the well-known engineering methods [7]. It is worth noting that a conservative approach intended for estimate weight of manned passenger airplanes was used to estimate the OEW. The weight of windshields, windows, doors, equipment and systems disappear on the unmanned cargo aircraft, so it was subtracted from the estimated OEW. But this approach does not take into account the reduced weight of the structure, so the new unmanned aircraft is not a modification of the existing one.

Based on the transport tasks, a variant of a pressurized fuselage with a circular cross-section (as compromise between aerodynamics and cross-section size) was selected (Figure 3). Cargo hold provides transportation of the most common types of standard containers and pallets on local and regional lines. When choosing the length of the cargo hold, the possibility of accommodation a container for the helicopter rotor blades was taken into account. The CITRUS has a hinged nose for frontal cargo loading (Figure 4). The CITRUS can be equipped with additional fuel tanks in fuselage (Figure 5).
3. Aerodynamics
Aerodynamic layout of the CITRUS is based on classic high-wing scheme with wing aspect ratio AR=10, fuselage with a circular cross-section and classic empennage with one vertical tail and fuselage-placed horizontal tail. Engine nacelles are placed under the wing. Main landing gear fairings are placed on the fuselage. Main geometric parameters of the CITRUS layout are presented in table 1.

| Parameter                        | CITRUS       |
|----------------------------------|--------------|
| Wingspan w/o wingtips, m         | 22.59        |
| Wing area, m²                    | 48.4         |
| Wing aspect ratio                | 10           |
| Wing sweep at ¼-chord, °         | 25           |
| Fuselage length, m               | 22.7         |
| Fuselage cross-section area, m²  | 5.31         |

The aerodynamic design of the CITRUS was performed in the BLWF program.
Analysis of aerodynamics was performed in two ways – constant Mach number characteristics at different angle of attack (Figure 6) and constant lift coefficient characteristics at different Mach number (Figure 7). Results show a satisfactory behavior of aerodynamic characteristics, which is expressed in Lift-to-Drag ratio dependence on Mach number and lift coefficient. Maximum L/D ratio is \(\approx 15.5\) at \(M=0.78\), and maximum of \(L/D\times M\) is lie at \(M=0.78\) for basic layout. Visualization of surface Mach numbers shows that the CITRUS layout has a normal flow around without critical problems.

At the next stage, the wing will be optimized to ensure cruise speed 850 km/h (\(M=0.8\)).

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**Figure 6.** Curves for Lift-to-Drag ratio (L/D) versus lift coefficient of the CITRUS layout.

**Figure 7.** Curves of L/D ratio and L/D\(\times\)M versus Mach number.

**Figure 8.** Visualization of surface Mach numbers.

### 4. Performance

The CITRUS can transport 7 t payloads at 1700 km range with cruise speed 830 km/h and required runway length 1300 m. Note that the CITRUS with fuselage removable tanks can transport 2 t payloads at 6500 km. The CITRUS could transport 5 standard containers of LD-3, 3 pallets of P9 or 6 P8 pallets (Figure 9).

It is interesting to compare the characteristics of the CITRUS with rival of close capacity (Figure 10, Table 2). The closest analogues of the CITRUS are regional freighter turboprops – IL-114T and ATR 72F.

The CITRUS has 60-70% higher cruise speed; therefore its transport output per hour will be higher.
Figure 9. Cargo capabilities of the CITRUS.

Table 2. Comparison of the main parameters of the CITRUS, IL-114T and ATR 72F.

| Parameter                  | CITRUS | IL-114T [8] | ATR 72F [9] |
|----------------------------|--------|-------------|-------------|
| MTOW, t                    | 20     | 23.5        | 22          |
| OEW, t                     | 10.73  | 15.2        | 11.9        |
| Max payload, t             | 7      | 7           | 8.625       |
| Range with max payload, km | 1700   | 1000        | 963         |
| Cruise Mach number         | 0.78   | 0.45        | 0.45        |
| Cruise altitude, km        | 13     | up to 7.6   | up to 7.6   |

Figure 10. Payload-range diagram.
5. Conclusion
This paper reviews the results of conceptual studies of the unmanned aerial vehicle for the fast container transportation.

In the process of conceptual design, the geometrical and weight parameters of the aircraft were determined, ensuring the transportation of 7 t payload at 1700 km range with cruise speed 830 km/h.

The chosen parameters of the cargo hold provide transportation of the most widespread on local and regional lines of types of standard containers and pallets. The CITRUS could transport 5 standard containers of LD-3 or 3 pallets of P9.

The results of the flight performance calculations show that the CITRUS with conventional configuration and given geometric, aerodynamic and weight parameters ensure the transportation of goods with comparable fuel efficiency and higher transport output per hour, than the regional turboprop.

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