Development of LANE software for the modelling complex engineering systems in aerospace

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Abstract. The article deals with the modelling the complex engineering systems in Aerospace on pre-conceptual design stage. It has been established that the analytical dependence for the modelling do not fully satisfy the modern requirements for the accuracy of calculations and can lead to large errors. This suggests a lack of methodological security of modelling in the pre-conceptual design. The developed software LANE is a sequential process of iterative procedures of the modelling, decomposition, analysis and synthesis new complex engineering systems in Aerospace.

1. Introduction
"Green" air transport is a strategic issue for researcher in the world. Advancing scientific and technological capabilities, computational modeling to simulate a new flight systems (FS) is critical for competitiveness. Upon analysis, the following conclusions about prospective lines of investigation in these field:

- improving the aerodynamic performance (lift-to-drag ratio, lift-induced drag) of aircraft systems
- reduced fuel consumption,
- reduced noise
- reducing environmental impact
- increased strength characteristics
- weight reduction
- increasing the speed and accuracy of calculations

Within the three phases of FS design (conceptual, preliminary and detailed) the conceptual design phase is the most challenging one: a high number of complex decisions regarding configuration has to be taken with a long-term irreversible impact. As more than only one solution of a problem exists, improved designs can be identified within the defined design space if the set of potential flight systems solutions can be enlarged compared to present possibilities [1]. The accumulated project costs are minimal at the concept stage, but the impact of engineering solutions decided during this phase is maximal. Typically, the conceptual design phase absorbs only around 5% but determines around 70% of the total project cost. Therefore, the conceptual design is the basic phase of design process. Computer Aided Innovation, which can be considered as part of knowledge-based engineering [2], supports identification and evaluation of FS during conceptual design [3]. Automation and “intellectualization” of some aspects of conceptual design phase would be of immense practical benefit [4]. During the conceptual phase, the designer must devise an initial design which (a)
incorporates “working principles” or physical solutions for all required “essential” features of the problem and which (b) has been evaluated to be acceptable and feasible [5]. The developed modeling environment should be universal and provide calculation and analysis of various configurations [6,7].

2. Calculation errors of FSs when using simple analytical equations

Currently used analytical dependencies at the stage of conceptual design can give significant errors. So the use of Breguet range equation for determining the range of flight give a deviation. Calculated stage length is larger than actual stage length flown by about 10% for long range aircraft, and the deviation gradually increases to as large as 120% for short-range aircraft as shown in figure 1) [8]. This determines the use of numerical methods for calculating of FSs characteristics.

![Figure 1. Deviation of calculated stage length versus (Breguet) actual stage length flown [8].](image)

3. Computational modelling the complex flight systems

After the stage of structural synthesis and analysis, the modelling and parametric calculations of the selected FSs was carried out with use of the software LANE. The software enables aircraft specialists to work on a fast modeling and simulation solution. The research and modeling components are based on mathematical models and techniques for analysis, simulation, and evaluation of flying qualities. The fast modeling helps to reduce mistakes and the need for rework and significantly reduces the time required for pre-design phase [9, 10]. Program LANE calculates the complete range of performance parameters over a user-specified range of ballistic and aerodynamic variables and provides the user with useful quick-look (evaluate) functions for the examination of a wide variety of data (e.g. thrust, fuel flow, lift, drag, etc.) [11]. LANE provides a powerful framework to support the iterative process of unconventional aircraft pre-design (electrical airplanes, hybrids etc.) The software includes a variety variants of planes, engines, aerodynamic and flight paths. The development of flight dynamics models is a key aspect of the FS design process. The developed algorithms are based on modeling the equations of FS movement, taking into account the initial conditions and restrictions imposed on them. The flight dynamics was calculated by integrating the Euler equations of motion. For example for re-entry vehicles the equations of motion are as follows:

\[
\frac{dV}{dt} = -\sigma \rho V^2 \frac{g_0}{2} - g \sin \Theta,
\]

(1)

Where V - flight speed; t - time; \(\sigma\) - ballistic coefficient; \(\rho\) - air density; \(g_0\) - free-fall acceleration; \(\Theta\) - trajectory angle.
\[
\frac{d\Theta}{dt} = \frac{1}{V} \left( \sigma K \frac{pV^2}{2} - g_0 + \frac{V^2}{R_p + H} - g \right),
\]  
(2)

Where \( R_p \) - radius of the Earth; \( K \) - Lift-to-drag ratio; \( K \)-aerodynamic quality, \( H \) – flight height.

\[
\frac{dH}{dt} = V \sin \Theta,
\]  
(3)

\[
\frac{dx}{dt} = V \cos \Theta,
\]  
(4)

\[
K = \frac{c_l}{c_d}
\]  
(5)

Where \( c_l \) - lift coefficient; \( c_d \) - drag coefficient.

\[
C_l, C_d = f (M, geometry)
\]  
(6)

Where \( M \) – Mach number.

\[
Re = \frac{PV L}{\mu}
\]  
(7)

Where \( Re \)-Reynolds number; \( L \)-characteristic size of FS; \( \mu \)-kinematic viscosity.

\[
Kn = \frac{\lambda}{L} = 1.26\sqrt{k} \frac{M}{Re}
\]  
(8)

Where \( Kn \) - Knudsen number; \( \lambda \) - molecular mean free path length.

![Figure 2. Types of possible FS design configurations.](image)
4. Modelling and calculation of e-aircraft with LANE

On the basis of the LANE will be applied for calculation the new configurations FS with reduced environmental impact – reduced fuel consumption, flight noise and better energy performance. The studied flight system shall have a performance potential to fulfil the following mission (Top Level Aircraft Requirements):

- FS with civil mission (e.g. observation, research, communication node, etc.)
- Max Thrust - 2850 N
- Flight Speed - 42 m/s
- Flight altitude - 3000 m
- Specific Energy - 220 W/kg
- Energy efficiency - 0.82
- MTOW - 900 kg
- Range - 500 km
- Lift-to-drag ratio – 34
- Area -14 m²
- Wing loading -63.8
- Aspect ratio – 21
- Angle of the trajectory during takeoff – 5
- Angle of the trajectory during descent – 3
- Take-off Field Length - 160 m
- Battery weight - 222 kg
- Flight time - 191 min

Figure 3 shows the screenshot of LANE with the flight profile. Figure 4 shows the change of flight system characteristics during launch.
Figure 4. Flight system characteristics during launch (screenshot).

The application of the developed program allowed increasing the accuracy and speed of calculations, as well as reducing errors in determining characteristics. For example, for aircraft, the error was reduced by 3-4 times compared to the range equation Breguet (figure 5).

Figure 5. Compare the correctness of calculations with LANE and equation Breguet.
5. Conclusion
The study of relationships between configuration of FS and their parameters is important task in the analysis of designing aspects for new innovation flight systems. The developed software LANE allows to quickly synthesize various configurations, make calculations, evaluate and select the best FS. Software development and synthesis of innovative FS to be studied will permit to have a synergistic effect. The results of the calculations performed with the use of physical-mathematical models analysed with regard to the known results and those obtained in the course of present calculations so as to establish the adequacy of their description.

The application of the developed software LANE allowed increasing the accuracy and speed of calculations.

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