DEPARTMENT OF AUTOMOTIVE AND AERONAUTICAL ENGINEERING

Identifying Wave Drag for the Generic Drag Polar Equation – Unveiling Polars of 16 Passenger Aircraft

Task for a Project

Background

The drag polar of an aircraft shows its aerodynamic behavior. Drag consists of zero lift drag, wave drag (due to shock waves), and induced drag (due to lift). The drag coefficient is expressed primarily as a function of the lift coefficient. The result is plotted or expressed in the well-known equation, $C_D = C_{D,0} + C_{D,W} + C_L^2/(\pi A e)$. The next important parameter is the Mach number. All three drag components depend on Mach number. The drag coefficient is plotted versus lift coefficient with Mach number as a parameter. Alternatively, drag coefficient is plotted versus Mach number with lift coefficient as a parameter. For the drag polar equation, the graphical representation does not matter. Mach number influences induced drag when compressibility becomes noticeable (beyond compressibility Mach number, typically beyond 0.3). Wave drag starts beyond the critical Mach number, M_{crit} (where shock waves start to form). Per definition, the wave drag coefficient is 0,0020 (20 drag counts) at drag divergence Mach number, M_{DD}. Desired is a difference $\Delta M = M_{DD} - M_{crit}$ as large as possible. Passenger jet aircraft are usually designed such that they cruise at M_{DD} and hence with 20 drag counts of wave drag. This gives a good design compromise. The generic drag polar equation must have a convenient structure (made up of different terms, functions, and parameters) to describe all this and more. The history of aerodynamics shows many pragmatic approaches to such an equation. Also, the Aircraft Design and Systems Group (AERO) has contributed to the discussion, but work has not come to an end so far. Aerodynamic data of (passenger jet) aircraft is needed to determine a practical generic drag polar equation. First, an optimum form of the equation must be determined together with the numerical values of the parameters that achieve a representation of available real-world aircraft data with sufficient accuracy. The next task is to answer the question: How are the parameters in the generic drag polar equation related to the geometry of the aircraft? With these relationships established, a generic drag polar equation can be written also for new aircraft in preliminary design based on their geometry.

Task

Task of this project is to study the drag polar of 16 passenger jet aircraft presented in Obert (2009) in graphical form. Obert plots drag coefficient versus Mach number with lift coefficient as a parameter. Propose a suitable form for a generic drag polar equation. Find the numerical values of the parameters in the generic equation representing the 16 aircraft. Focus on wave drag but include older findings on induced drag in your equation. The subtasks are:

- Perform a literature review on the topic so that you can link your results to the history of aerodynamics in the field.
- Scan and digitize Obert's diagrams. This can be done e.g. with the WebPlotDigitizer used also in Chapter 2.5 of this project.
- Examine existing approaches (here and here) and new mathematical approaches for the wave drag term in the generic drag polar equation. Propose a function best suitable for the task.
- Based on the selected form of the generic drag polar equation, unveil the polars of the 16 passenger jet aircraft by providing parameters and plots for visualization.
- Propose how parameters in the generic equation can be linked to the geometry of the aircraft. In this way it should be possible to estimate the drag coefficient for new aircraft in preliminary design.

The report has to be written in English based on German or international standards on report writing.

Drag polars are given in Chapter 24 of:
OBERT, Ed, 2009. *Aerodynamic Design of Transport Aircraft*. Delft, The Netherlands: IOS Press.

- DC 10 / MD 11 (Fig. 24.26),
- B 707 (Fig. 24.49),
- B 727 (Fig. 24.53),
- B 737-200/-300/-800 (Fig. 24.72),
- B 747-100 (Fig. 24.78),
- B 757 (Fig. 24.90),
- B 767 (Fig. 24.96),
- B 777 (Fig. 24.99),
- A 300-B2 (Fig. 24.107),
- A 320 and B 737-800 (Fig. 24.123),
- A 340-200 (Fig. 24.131),
- Fokker 28 (Fig. 24.142),
- Fokker 100 (Fig. 24.143).