Dymore User's Manual
Aerodynamic Model

1 Aerodynamic model

When dealing with aeroelastic problems, aerodynamic forces are applied to a flexible structural system. In turn, the aerodynamic forces deform the elastic system, modifying its positions and velocities. This new configuration of the system changes the aerodynamic problem, and hence, the aerodynamic loads. Clearly, aeroelastic problems are inherently coupled problems, and the interaction between the structural and aerodynamics models is represented in a schematic manner in fig. 1.

To treat aeroelastic problems it is necessary to define an **aerodynamic model**. The aerodynamic and structural dynamics models are defined independently and should remain as independent as possible. For instance, it must be possible to change the mesh of the structural model without affecting the aerodynamic model; vice versa, changes in the aerodynamic model should not affect the structural model.

The definition of the aerodynamic model fulfills two tasks. First, it evaluates aerodynamic loads and second, it applies these loads on the structural model. **Airstations** control the interplay between the structural and aerodynamic models and are the only element shared by the two models. As indicated in fig. 1, the structural model will compute the positions and velocities of all airstations, whereas the aerodynamic model computes the aerodynamic forces and moments at those same airstations.

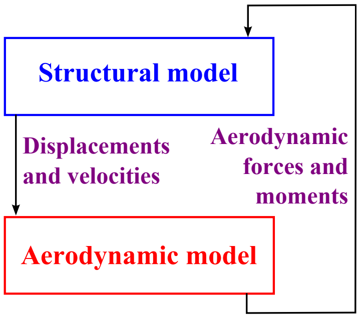

Figure 1: Interplay between the structural and aerodynamic models.

Airstations are rigidly attached to the structure and hence, their motion is completely defined by the dynamic response of the structural model. Consequently, at any time, the position, velocity, and acceleration of each airstation can be computed from the dynamic response of the structural model. These quantities are an input to the aerodynamic model, which at any time, can compute the aerodynamic forces and moments acting at airstations. In turn, this aerodynamic loading becomes an input to the structural dynamics model, as indicated schematically in fig. 1. Clearly, the airstations play a crucial role in interfacing the aerodynamic and structural models.

For some problems, it is common to model wings or rotor blades structures with one-dimensional beam elements. In this case, the aerodynamic loading on the beam consists of a field of distributed forces and moments along the beam. If the aerodynamic loads are computed using approximate methods such as thin airfoil theory and tabulated wind tunnel measurements, the sectional lift, drag and moment can be readily computed. On the other hand, if the aerodynamic loads are computed with the help of a computational fluid dynamics code, pressures are evaluated throughout the flow field. Integration of this pressure distribution over an airfoil then yields sectional forces and moments. With both options, aerodynamic computations yield sectional forces and moments at the airstations, which form a discrete approximation to the distributed aerodynamic loading along the blade. If the wing or rotor blade is modeled with plate and shell elements, the computed aerodynamic pressure field could still be evaluated at the airstations and transferred to the structural model as airstation forces.

The aerodynamic model consists of a collection of *aerodynamic elements*.

1. **Lifting lines**. A lifting line is a collection of airstations that are rigidly connected to structural elements.

2. **Rotors**. A rotor is a collection of lifting lines that are connected to a rotating shaft. The aerodynamic loading on the rotor is the combined loading acting on the associated lifting lines. The aerodynamic elements forming a rotor are shown in fig. 2.

3. **Wings**. A wing is a collection of lifting lines that are connected to a fuselage. The aerodynamic loading on the wing is the combined loading acting on the associated lifting lines. The aerodynamic elements forming a wing are shown in fig. 3.

4. **Inflows**. An inflow is an aerodynamic element that computes an induced flow at the airstations. The inflow field is caused by the circulation generated at each airstation.

5. **Aerodynamic interfaces**. An aerodynamic interface specifies how the aerodynamic loads at the airstations will be computed.

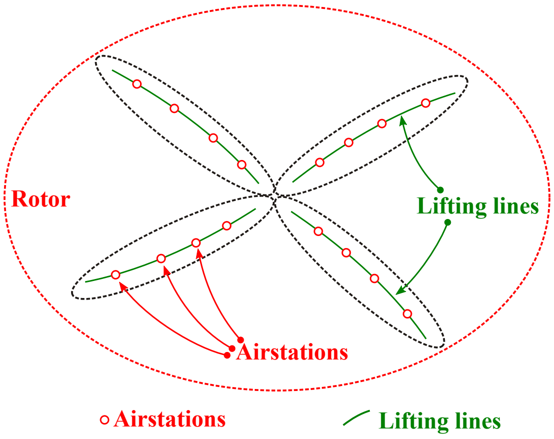

Figure 2: Schematic of the aerodynamic elements forming a rotor.

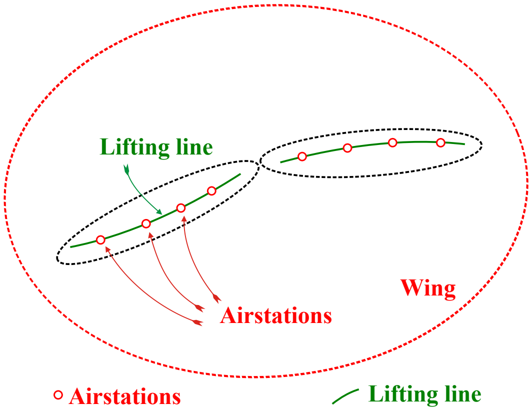

Figure 3: Schematic of the aerodynamic elements forming a wing.

The coupling between structural and fluid dynamics within the context of aeroelastic analysis involves the following components.

1. A *computational structural dynamics* (CSD) code. This code requires the knowledge of distributed aerodynamic forces and moments and predicts the resulting displacements and velocities of the structure.
2. A *computational fluid dynamics* (CFD) or a *simplified airloads computation* code. Both codes requires the knowledge of positions and velocities of the blade surface and predict the resulting aerodynamic forces and moments.
3. An optional *wake model*. This code requires the knowledge of airstation circulations and predicts the resulting inflow at all airstations. When using a CFD code that models the entire flow field around the wing or rotor, the wake model is not required.

These three modules interact by exchanging data at a set of air points and/or airstations defining lifting lines. The interactions between these three modules is schematically described in fig. 4. Two main interfaces are clearly needed: a **kinematics interface** that transfers the displacements and velocities computed by the CSD code to the CFD code and a **loads interface** that transfers the aerodynamic forces and moments computed by the CFD code to the CSD code. The data to be exchanged through both interfaces is clearly associated with airstations.

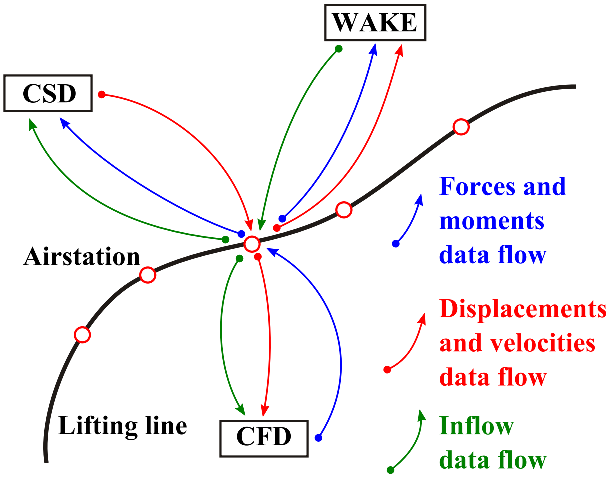

Figure 4: Schematics of the aerodynamics interface.