Applications of State-Space Wake Models to Full and Partial Ground Effect

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Abstract

Previous research shows that finite-state modeling of ground effect by a ground rotor gives a more physical description of system behavior in a dynamic environment than do existing Hayden models. However, in cases for which such details are not significantly important, the widely-used Hayden approach has the advantage of less computational effort and becomes more attractive in applications. Considering that rotorcraft usually does operate in conditions that can be treated as quasi-steady, the calculation of the ground rotor flow field is often not necessary, making Hayden's method preferred. However, with partial ground effect, one has no option not to use a ground rotor.

A great advantage of simulating ground effect by a ground rotor is that this methodology can analyze ground effect in real time without any restriction in ground shapes or inclining angles. The traditional Hayden approach cannot treat either partial ground effect or inclined surface ground effect. This paper discusses dynamic full ground effect (FGE) and partial ground effect (PGE) simulations done by application of the ground rotor.

Introduction

State-space modeling is highly recognized in rotorcraft research and has been continuously developed through the years. The method has the advantages of small computation effort and ease of implementation in stability analysis. Despite success in many fields of rotor flow-field applications, state-space models have been limited in some applications, such as ground effect.

When a rotor is flying close to a non-penetrable surface, a boundary condition exists in the flow field: no flux through this surface. Flow is forced to turn away, and by momentum theory, the thrust generated by the rotor increases as the airflow is slowed. This is a common phenomenon while helicopters are taking off, landing, or operating close to ground, ship decks or building roofs. These are common tasks and central to the advantages of helicopters in operation. To make a modeling method complete and practical, capability of analyzing ground effect is required.

Methodologies of studying ground effect by state-space models have been developed in the past. Among which, use of an image rotor and addition of a pressure potential in the flow field are the most popular methods, Refs. [1–4]. With an image rotor, the boundary condition is satisfied automatically. However, this method places both rotors in the wake of the other. Since none of the existing state-space models is able to treat and investigate flow field in the wake, it is practically difficult to implement this method. Furthermore, the image rotor method fails for conditions of inclined ground, moving ground, or partial ground effect. The addition of a pressure potential loses its capability immediately if any slight changes at the rotor occur. Nevertheless, these approaches do give good simulation results in steady, or quasi-steady, conditions. On the other hand, helicopter operation often times cannot be simplified as quasi-steady state. Without the ability to predict the flow field in dynamic condition, these methods are greatly limited in practical applications.

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