

# **Aerodynamics & Flight Mechanics Research Group**

## **Modelling Ground Effect (Cheesman & Bennett + Leishman)**

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Technical Report AFM-11/17

January 2011

UNIVERSITY OF SOUTHAMPTON

SCHOOL OF ENGINEERING SCIENCES

AERODYNAMICS AND FLIGHT MECHANICS RESEARCH GROUP

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# Introduction

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The following analysis is referenced in Cheeseman & Bennet together with Leishman.

## Analysis

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### Hover

Cheeseman & Bennet model the rotor in ground effect by using a source term as the image. This gives the following formula:

$$\begin{aligned} \frac{T_{IGE}}{T_{OGE}} &= \frac{1}{1 - \left(\frac{R}{4Z}\right)^2} \\ &= \frac{1}{1 - \left(\frac{1}{4\bar{Z}}\right)^2} \end{aligned} \quad (1.)$$

$$\bar{Z} = \frac{Z}{R}$$

This has a limitation on the minimum value of height ratio:

$$\bar{Z} > 0.25 \quad (2.)$$

### Forward Flight

This formula has been extended into forward flight by Leishman thus:



$$\frac{T_{IGE}}{T_{OGE}} = \frac{1}{1 - \frac{\left(\frac{R}{4Z}\right)^2}{1 + \left(\frac{\mu}{\lambda_i}\right)^2}} \quad (3.)$$

$$= \frac{1}{1 - \left(\frac{\cos \chi}{4Z}\right)^2}$$

$$\tan \chi = \frac{\mu}{\lambda_i}$$

Here the wake angle ( $\chi$ ) has been introduced.

If the rotor disc is assumed to be parallel to the forward flight direction, we have the following result from momentum theory:

$$\lambda_i = \frac{C_T}{4} \cdot \frac{1}{\sqrt{\mu^2 + \lambda_i^2}} \quad (4.)$$

Equation 4 can be recast by clearing the fractions, thus:

$$\lambda_i^2 (\mu^2 + \lambda_i^2) = \left(\frac{C_T}{4}\right)^2 \quad (5.)$$

$$(\lambda_i^2)^2 + \mu^2 (\lambda_i^2) - \left(\frac{C_T}{4}\right)^2 = 0$$



On substituting the expression for the wake angle this becomes:

$$\left(\mu^2 \cot^2 \chi\right)^2 + \mu^2 \left(\mu^2 \cot^2 \chi\right) - \left(\frac{C_T}{4}\right)^2 = 0 \quad (6.)$$

Which, after manipulation gives:

$$\cos \chi = \frac{2}{C_T} \cdot \left\{ \sqrt{\mu^4 + \frac{C_T^2}{4}} - \mu^2 \right\} \quad (7.)$$

