Vortex Lattice Methods - Applications

Examples of the use of VLM method
Outline

• **Basic Concepts**
  – Boundary conditions on the mean surface
  – Vortex Theorems, Biot-Savart Law
  – The Horseshoe Vortex
  – Selection of Control Point and Vortex Location

• The Classical Vortex Lattice Method

• Software
  – VLM (Fortran program)
  – TORNADO (in MATLAB)
  – AVL (Fortran/C program)

• **Applications**
  – Examples of the use of VLM method
  – Insights into wing and wing-canard aerodynamics
Using VLM in Aircraft Design and Analysis

- For conceptual and preliminary design predictions
- Insight into the aerodynamics of wings, including interactions between lifting surfaces
Typical Analysis Uses in a design environment

• Predicting the configuration neutral point during initial configuration layout, and studying the effects of wing placement and canard and/or tail size and location.

• Finding the induced drag from the spanload in conjunction with farfield methods.

• With care, estimating control and device deflection effectiveness

• Investigating the aerodynamics of interacting surfaces.

• Finding the lift curve slope
Typical design applications

\[ \sum_{n=1}^{2N} C_{m,nK} \left( \frac{\Gamma_n}{V_\infty} \right) = \left( \frac{df_c}{dx} - \alpha \right)_m \quad m = 1, \ldots, 2N \]

- Initial estimates of twist to obtain a desired spanload, or root bending moment.
- Starting point for finding a camber distribution in purely subsonic cases.
Use of the VLM

- Geometric model
  - For wing-body cases simply specify the projected planform of the entire configuration as a flat lifting surface made up of a number of straight line segments.
The common rules in selecting the planform break points

• The number of line segments should be minimized,
• Streamwise tips should be used
• Small spanwise distances should be avoided by making edges streamwise if they are actually very highly swept
• Trailing vortices from forward surfaces cannot hit the control point of an aft surface.
Example 1: F-15 case

• Background
  – F-15 STOL/Maneuver demonstrator
Example 1: F-15 case

- Panel models used for the three-surface F-15

Vortex Lattice
233 panels

Woodward
208 panels

Pan Air
162 panels
Example 1: F-15 case

- Comparison with wind tunnel data

The vortex lattice method produces excellent agreement with the data for the neutral point location, and lift and moment curve slopes at Mach 0.2.

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Neutral Point (% mac)</th>
<th>$C_{m\alpha}$ (1/deg)</th>
<th>$C_{L\alpha}$ (1/deg)</th>
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from reference 15, Appendix by John Koegler
Example 1: F-15 case

- Studying the effects of moving the canard using VLM

**Effect of canard height variation on three-surface F-15 characteristics**

- When the canard is above the wing the neutral point is essentially independent of the canard height.
- When the canard is below the wing the neutral point varies rapidly with canard height.
Example 1: F-15 case

- Horizontal tail effectiveness

VLM estimate is within 10% accuracy at both Mach .2 and .8.
Example 1: F-15 case

- aileron effectiveness

- The device deflection is subject to significant viscous effects
- The actual results are found to be about 60% of the inviscid prediction at low speed.
Example 2: F/A-18 case

• Objectives
  – Investigating the contributions to the longitudinal derivatives by the wing-tip missiles and the vertical tails canted outward.
Example 2: F/A-18 case

- Results
  - Over-predicts the effect of the wing-tip missiles
  - Under-predicts the effects of the contribution of the vertical tail

<table>
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<tr>
<th>Wing Tip Missiles and Launchers</th>
<th>Mach Number</th>
<th>$\Delta$ Neutral Point (% mae)</th>
<th>$\Delta C_{M\alpha}$ (1/deg)</th>
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Example 2: F/A-18 case

- The effects of the number of panels and the way distributed
  - About 120 to 240 panels are required to obtain converged results.
  - The vortex lattice methods obtains the best results when many spanwise stations are used, together with a relatively small number of chordwise panels.
Example 3: Slender lifting body

- **Objectives**
  - To illustrate the capability of the vortex lattice method for bodies that are more fuselage-like than wing-like

- **VLM code**
  - For highly swept wings, leading edge vortex flow effects are included
  - The program \texttt{VLMpc} contains the option of using the leading edge suction analogy to model these effects.
Example 3: Slender lifting body

- Highly swept lifting body type hypersonic concept
Example 3: Slender lifting body

- Results
  - Remarkably good agreement with the force and moment data is demonstrated
Example 4: Non-planar

- Wing with a fence
  - The agreement is very good on the inboard side
  - The comparison is not so good on the outboard side of the fence
Example 4: Non-planar

- A ring wing
  - The estimates are compared with other theories, and seen to be very good.
地效飞行器
New Concept: Ultra Large Transport Aircraft

The concept aeroplane, called the Pelican Ultra Large Transport Aircraft (ULTRA), would exploit an aerodynamic phenomenon known as the "wing-in-ground effect" to glide just six metres above the waves.
Example 5: The ground effects

- Effects on lift slopes
  - The agreement between the data and calculations is excellent
  - As the AR increases, the magnitude of the ground effects increases.
  - The lift curve slope starts to increase rapidly as the ground is approached.
Example 5: The Ground Effects

- Effects on pitching moment slopes

![Graph showing effects on pitching moment slopes with different AR values. Solid lines represent computed values using JKayVLM (Ref. 12), while dashed lines are from Kalman, Rodden, and Giesing (Ref. 17).]
- Ground effects for a wing with dihedral
Project

- Pick the aircraft you have studied, and then draw the drag polar of this aircraft at M=0.3 by using the program FRICTION and a VLM (or AVL, or TORNADO) code.
  - Use FRICTION to predict its zero lift drag
  - Use VLM to predict the slope of the lift curve and induced drag
  - Use the following equation to calculate the total drag.

\[ C_D = C_{D_0} + C_{Di} \]