# An evaluation of methods and assumptions used in potential flow modelling of swirl recovery vanes

Honours Programme Delft

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## Shortened Abstract

Various potential flow methods with different assumptions are available to quantify the efficiency increase and thrust provided by a swirl recovery vane (SRV). In this research, thrust coefficients and efficiency results obtained by different potential flow methods for the same SRV geometry at different advance ratios are presented. The methods include two VLM and four lifting line (LL) models with different assumptions. The models are compared in terms of accuracy with respect to RANS results and computational cost. This makes it possible to evaluate the benefits and drawbacks of neglecting or accounting for the presence of certain effects and modelling choices. The effects taken into account or deliberately neglected in different models include; finite propeller-SRV distance, nacelle presence, wake and free stream nonalignment, flow interaction between vane blades, the Kutta condition and SRV sweep.

## Introduction

### What is a swirl recovery vane (SRV)?

SRV is a simple device that can increase the propulsive efficiency of an aircraft. SRVs are stators that convert rotational energy in the propeller slipstream into additional thrust. SRVs can already be seen in the next generation CFM RISE open fan engine concepts.

### Where is the knowledge gap regarding SRVs?

Commonly, lifting line (LL) modelling is used to model SRVs. But LL used by Li [1] showed a 30% discrepancy compared to wind tunnel results. This error is significant given that the efficiency gain from the SRV is only of order 2% [2]. This raises the question: "Which assumptions in SRV potential flow modelling lead to the most error and which of these assumptions can be eliminated without significantly increasing the computational effort?"

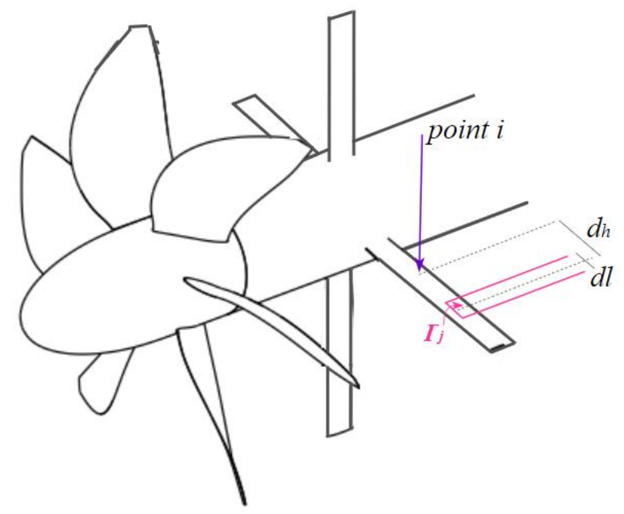


Figure 1. SRV Geometry (adapted from [3])

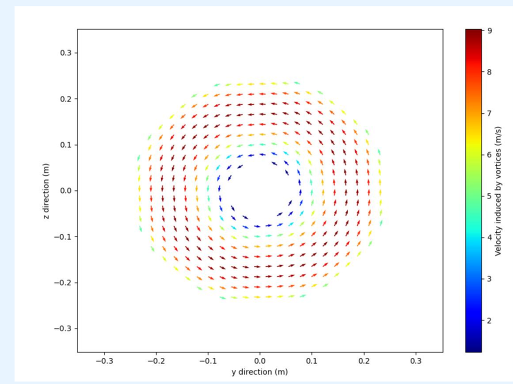
## Modelling & Assumptions

Models with different assumptions and modelled phenomena are compared in terms of the SRV thrust coefficient with respect to RANS results. The effects or phenomena that are investigated include:

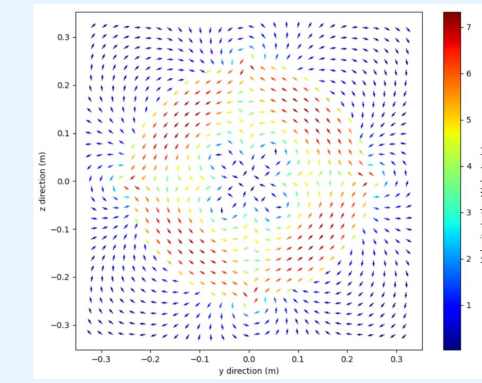
- Finite propeller-SRV distance: Assuming that the SRV does not change the flow profile directly after the propeller, the finite distance between propeller and SRV leads to a change in the angle of attack at the location of the SRV. This can be investigated by contrasting the SRV thrust coefficient from the model 'LL Base Model' and 'LL w. Finite Slipstream'.
- Nacelle presence: The presence of a nacelle can be modelled by replacing it with a number of Horseshoe vortices such that the nacelle wall is represented as a free slip wall. This alters the flow field at the SRV blade. This can be investigated by contrasting the SRV thrust coefficient from the model 'LL Base Model' and 'LL w. Nacelle Correction'.
- Non-alignment of SRV wake with free-stream direction: The swirl direction of the wake downstream of the SRV is unknown when running a potential flow simulation. Thus, by prescribing the wake swirl at different feasible angles and comparing the SRV thrust for these different cases reveals the maximum error that can be made by picking an arbitrary swirl angle for the wake. This can be investigated by varying the wake angle in the model 'LL w. Local Flow Oriented Trailing Vortices'.
- Flow interaction between vane blades: Modelling all SRV blades together and using the induced velocity of one blade to impose flow tangency at another blade rather than modelling the flow around an isolated vane blade makes it possible to compute the effect of assuming infinite unperturbed flow in the tangential (azimuthal) direction. This can be investigated by contrasting the SRV thrust coefficient from the model 'VLM Base Model' and 'VLM w. Vane Interaction'.
- The Kutta condition: Since VLM modelling explicitly enforces the flow tangency unlike LL, the difference in thrust coefficients can be used to evaluate this effect. This can be investigated by contrasting the SRV thrust coefficient from the model 'LL Base Model' and 'VLM Base Model'.
- SRV Blade sweep: Using the VLM model to compute the effect on thrust of an SRV geometry when its sweep is increased highlights the severity of the error that would be made by neglecting the sweep. The sweep has to be neglected automatically if an LL model is used.

## Results

By comparing Figures 2a and 2b, a reduction in swirl velocity after SRV installation can be seen.



(a) Propeller Slipstream velocities without SRVs



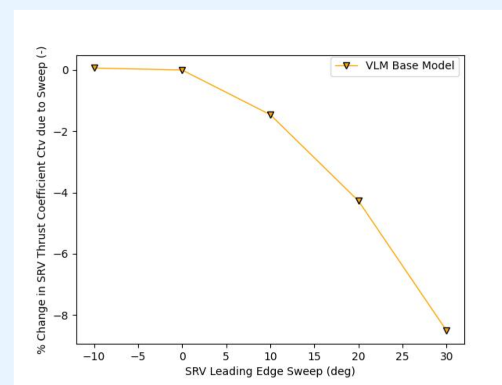
(b) Wake after Installing SRV

Figure 2. Wake Modelling Based on the VLM w. Vane Interaction Model

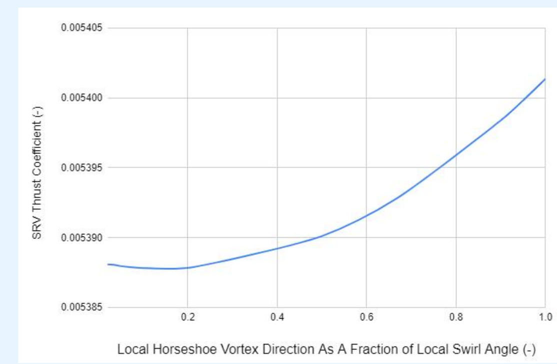
By analyzing Figure 3 the vane thrust coefficients ($C_{T_V}$) predicted by different models can be seen.

Figure 3. SRV Thrust Coefficients Predicted by Different Models

Figure 4a presents the SRV thrust coefficient as a function of sweep. Figure 4b presents the effect of the different alignments of trailing horseshoe vortices on the SRV thrust coefficient prediction.



(a) $C_{T_V}$ as a function of sweep



(b) $C_{T_V}$ as a function of trailing horseshoe vortex alignment

## References

[1] Li, Q., "Towards optimum swirl recovery for propeller propulsion systems," Ph.D. Thesis, Delft University of Technology, 2019.

[2] G. Eitelberg, T. S. T. S., L. Veldhuis, "ANALYSIS OF SWIRL RECOVERY VANES FOR INCREASED PROPULSIVE EFFICIENCY IN TRACTOR PROPELLER AIRCRAFT," 30th Congress of the International Congress of Aeronautical Sciences,, 2016

[3] T. Stokkermans, L. V., N. v. Arnhem, "Mitigation of propeller kinetic energy losses with boundary layer ingestion and swirl recovery vanes," Royal Aeronautical Society Applied Aerodynamics Conference, 2016