Wind Farm Layout Optimization: Horns Rev I

Marion Hall-Zazueta[1], Michael F. Howland[1], Sanjiva K. Lele[1,2]

[1]Department of Mechanical Engineering, [2]Department of Astronautics and Aeronautics

Motivation

Wakes in wind farms account for losses of up to 40% in power production [2]. Wake losses in wind farms account for significant losses in energy production. The wake is an area of lower wind velocity and greater turbulence behind the turbine, created as the upstream turbine extracts energy from the wind to produce power. The wake produced by one turbine in a wind farm impacts the turbines behind it, reducing the power production of those turbines. One approach to reducing these losses before wind farm construction is layout optimization of wind farms based on models of wake dynamics. In this project an optimized layout for Horns Rev I is created and examined.

Jensen Model

The Jensen Wake Model's simplicity, makes it useful for qualitative approximations of wake losses in wind farms. It assumes a linearly expanding wake based on the wake spreading coefficient selected as shown below [3].

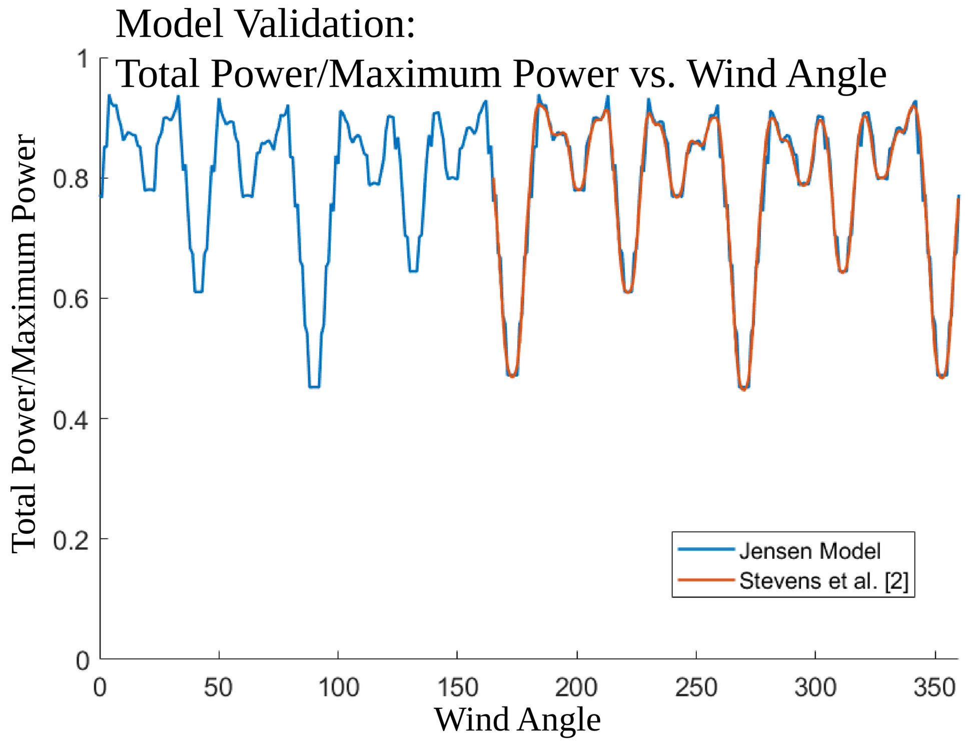
$$\delta u(x;j) = u_0 - u(x;j) = u_0\left(1 - \frac{1-\sqrt{1-C_t}}{{R_w}^2}\right) \qquad R_w = 1 + \frac{k_w(x-x_j)}{R}$$

$$u(x) = u_0 - \sqrt{\sum_j [u(x;j)]^2}$$

$$\frac{P_T}{P_1} = \left(\frac{1}{n}\sum_{k=1}^{n} \frac{u(x_{T,k})}{u_0}\right)^3$$

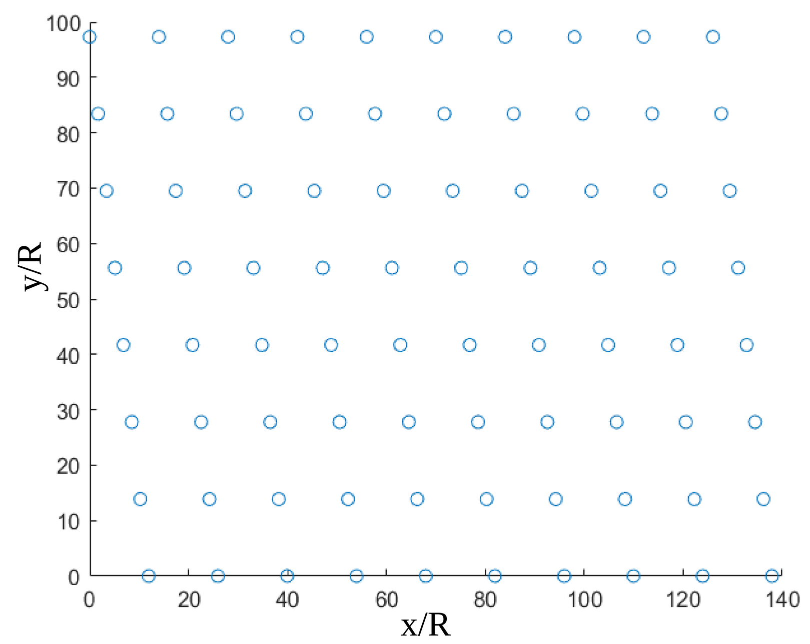
δu - wake deficit u_0 - incoming freestream wind velocity
u - wind velocity C_t - wind velocity R_w - wake radius
k_w - wake spreading coefficient x - downstream distance
R - rotor radius P_T - predicted power of turbine T
P_1 - power of freestanding turbine
n – number of points in turbine

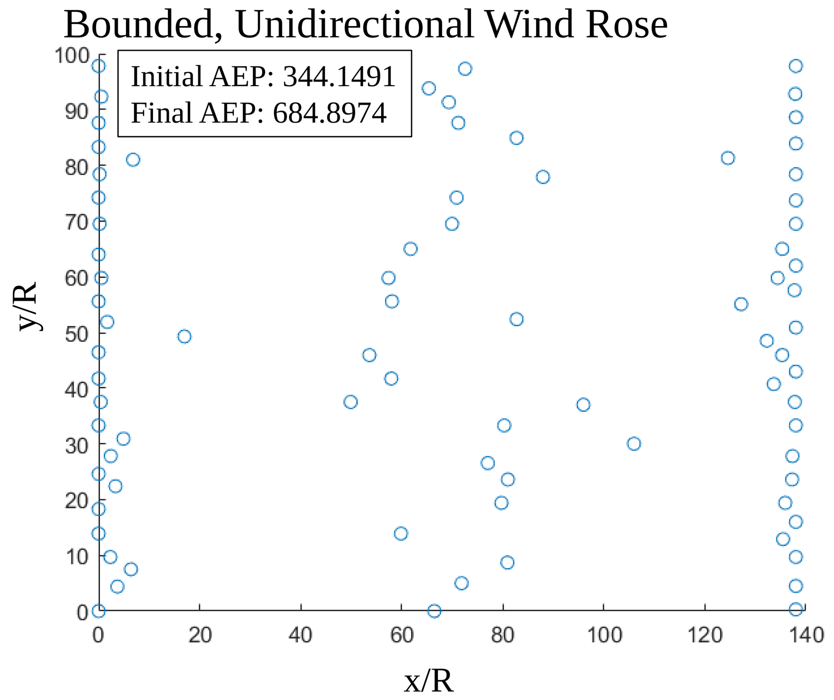
The Jensen Model created in MATLAB for this project was validated against the model used in Stevens *et al.* [3].

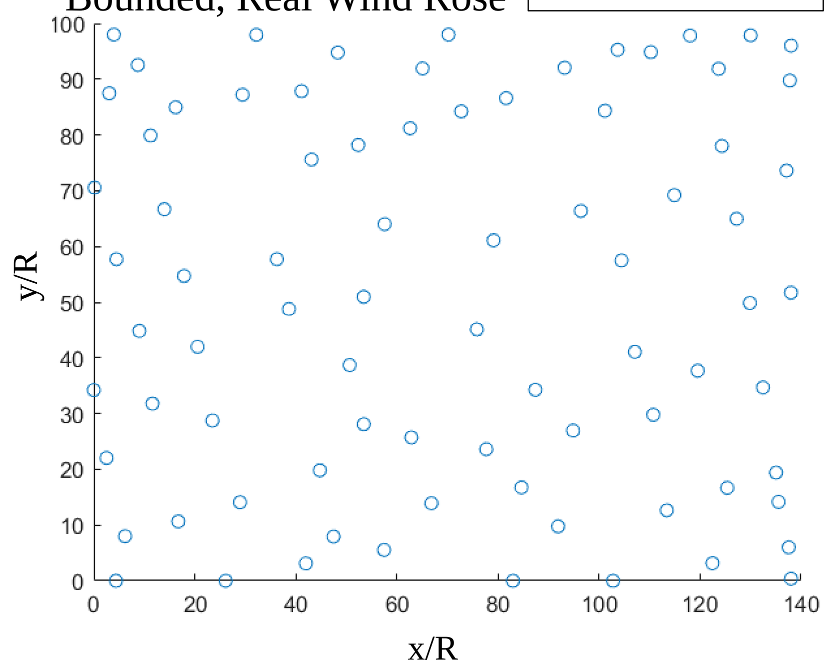


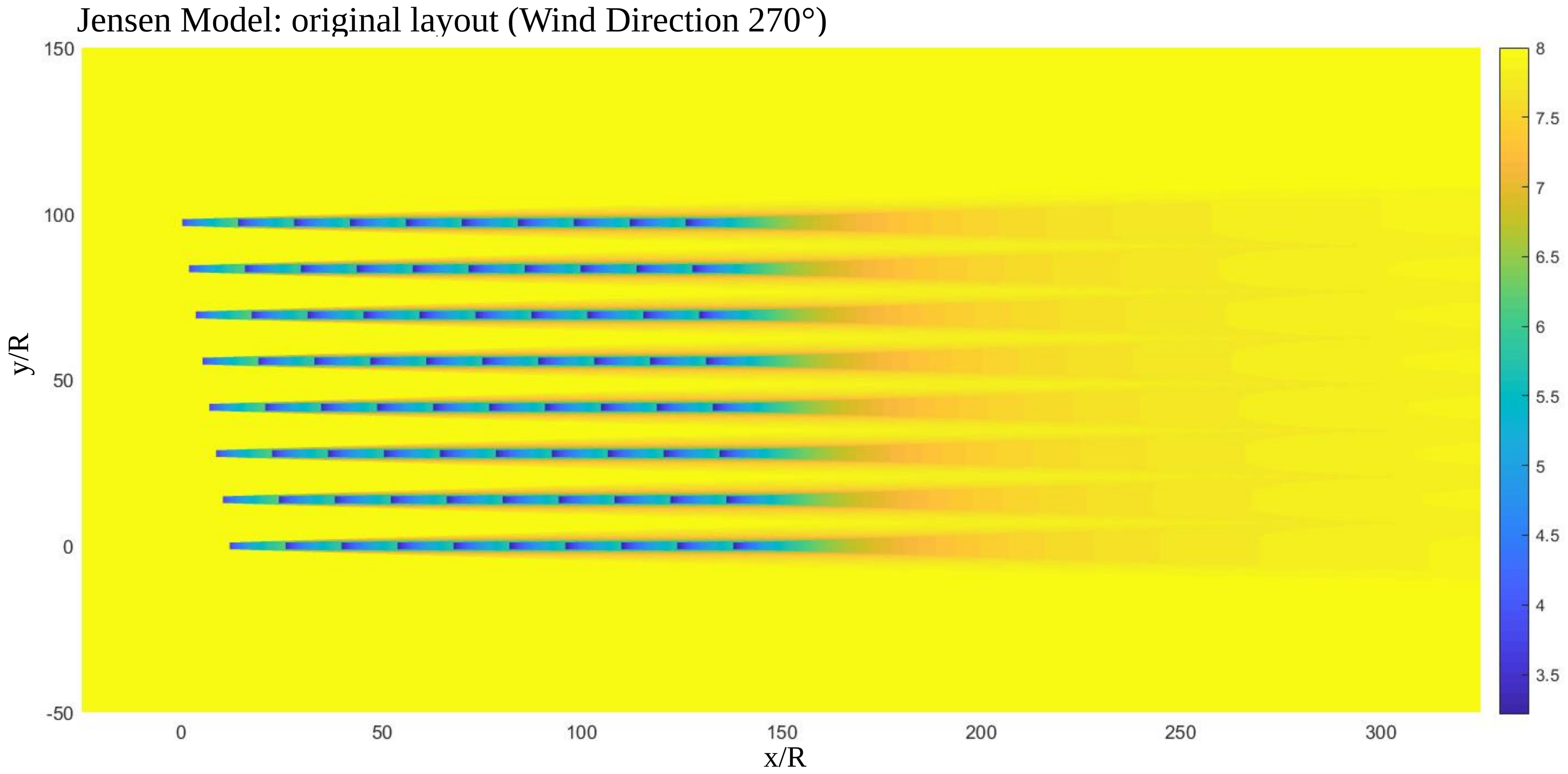
Optimization

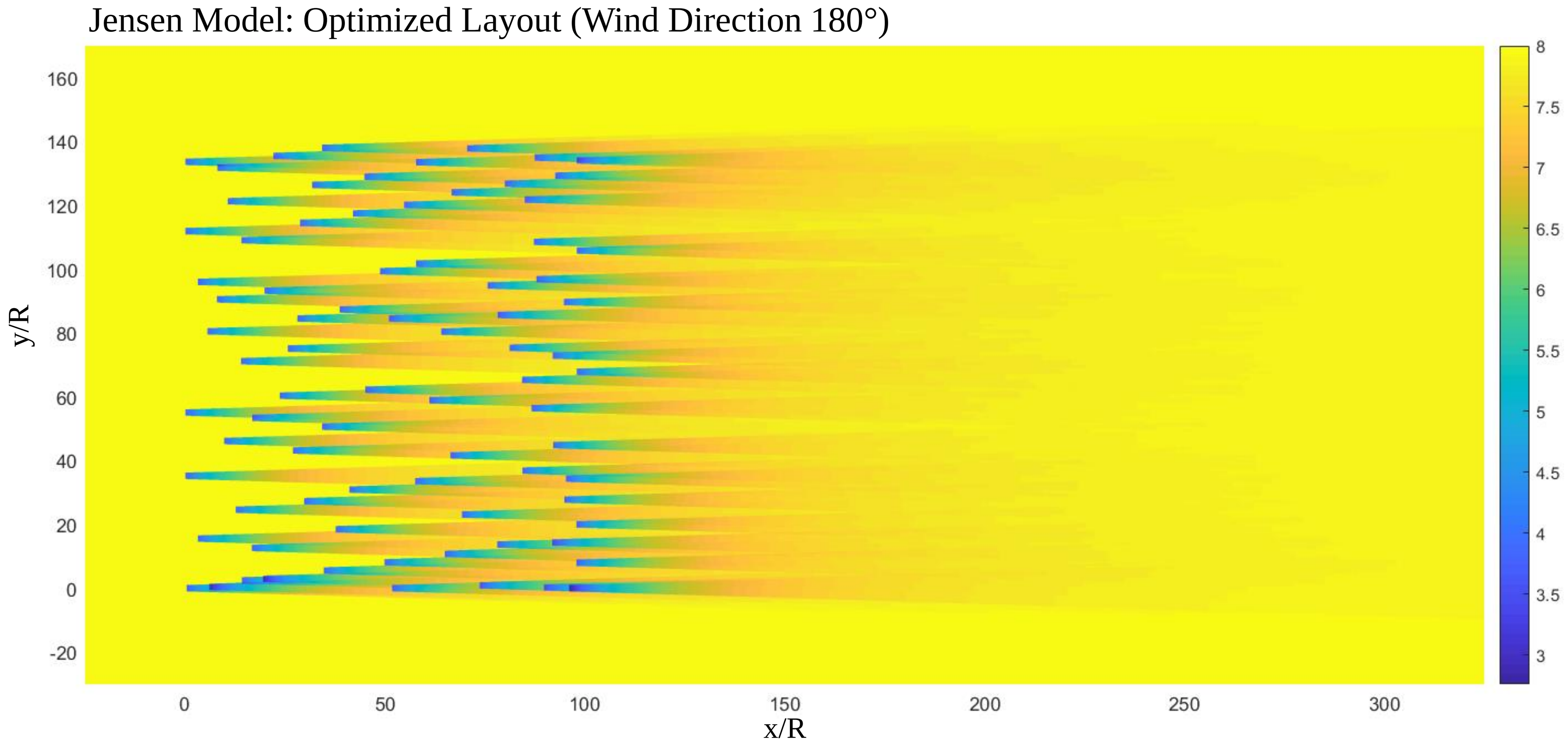
- Optimization carried out using MATLAB's built in pattern search
- Objective function based on annual energy production (AEP) of the wind farm calculated using the Jensen Model and wind data [3]
- Objective function penalizes layouts containing turbines within 2 rotor diameters of each other to yield a more realistic result
- To validate the optimization, it was run with a simple unidirectional wind rose
- For unbounded optimization: turbines should be spaced very far apart, AEP should reflect essentially zero wake losses
- For bounded optimization: layout should have greatest possible spacing
- Once validated, the optimization was run with the real wind data, bounding the wind farm to approximately its original area









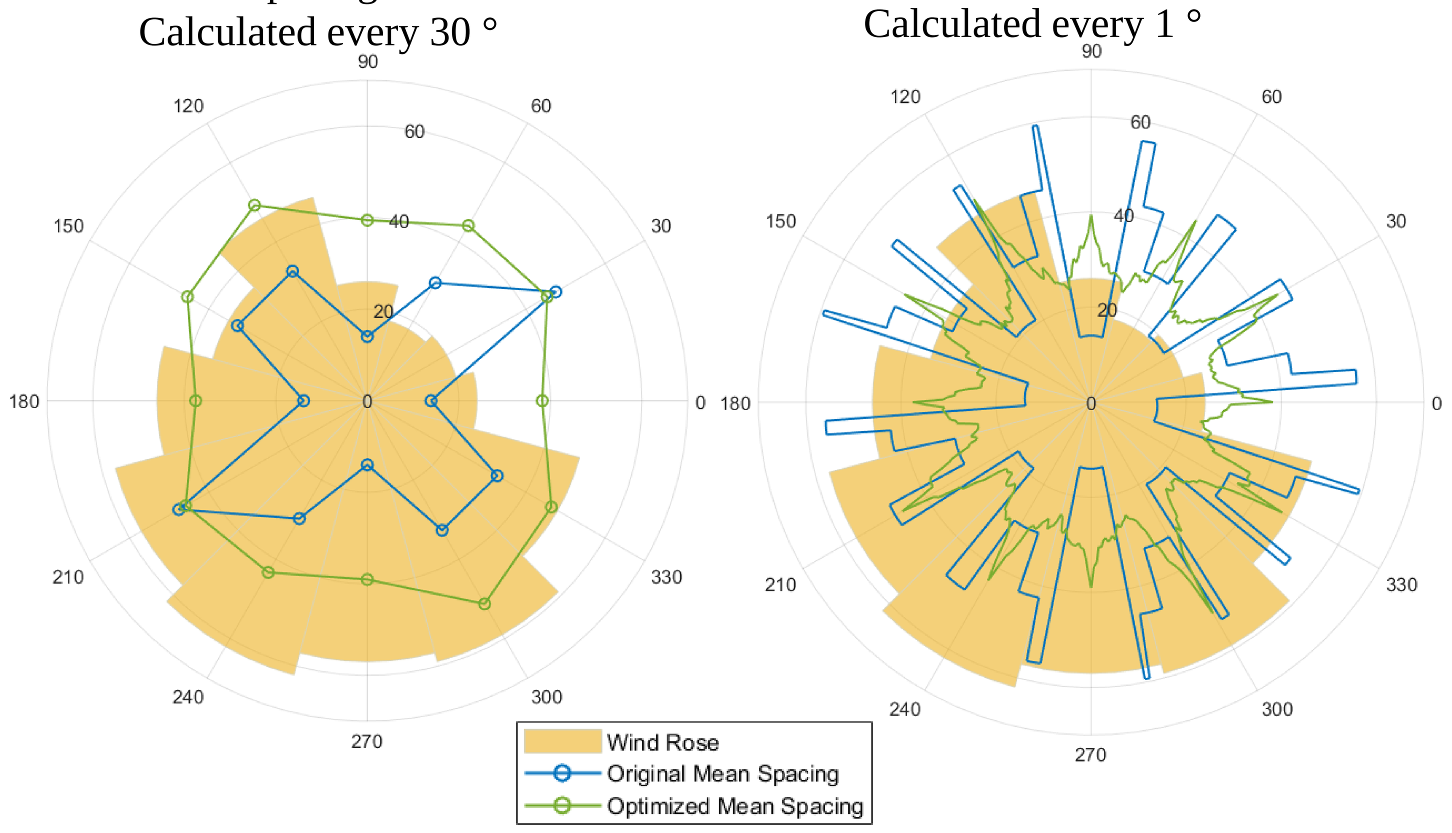


Conclusions

- Model predicts a 14.74% increase in AEP from the original layout to the optimized layout for the real wind rose
- Optimization tends to place wind turbines just outside the wake of other turbines
- To characterize layouts, mean spacing between turbines is calculated as the mean space between each turbine and its nearest neighbor in its wake
- As expected, the optimized layout has higher overall mean spacing between turbines; however, when the mean spacing is calculated at 1° increments it is shown to peak at each of the angles given in the wind rose and drop between them. This conveys the importance of the model's structure to the final result.

Future improvements to model:

- Average power calculations over smaller angle increments or interpolate wind frequency data to achieve smaller bin sizes
- Add the variation of thrust coefficient with wind speed
- Calculate optimal layouts for different values of the wake spreading coefficient



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References

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