Optimal Control of Robots and Kites

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Optimal Control

Idea: use *computer model*

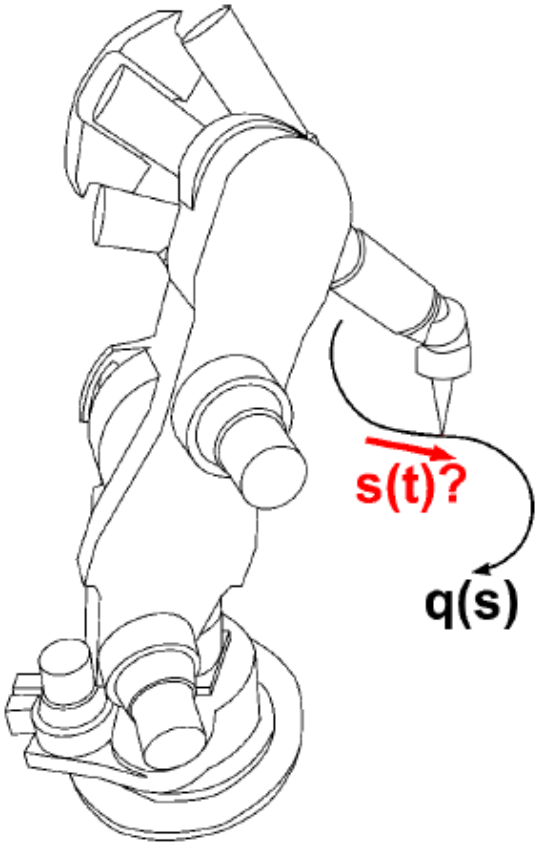
to ***control***

a ***dynamic system*** (aircraft, economy, robot, ...)

in an ***optimal*** way (highest efficiency, minimal time, ...)

Example: Time Optimal Robot Motion (with D. Verscheure, KUL)

Robot's Task: write a word as fast as possible



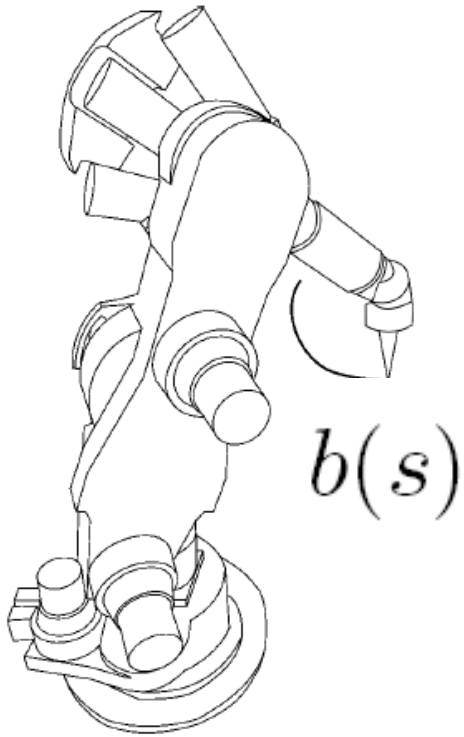
- geometric path prescribed
- velocity can be chosen
- allowable forces are limited
- detailed computer model exists

Desired: time optimal motion ("write as fast as possible")

New mathematical formulation (inspired by Y. Nesterov, UCL)

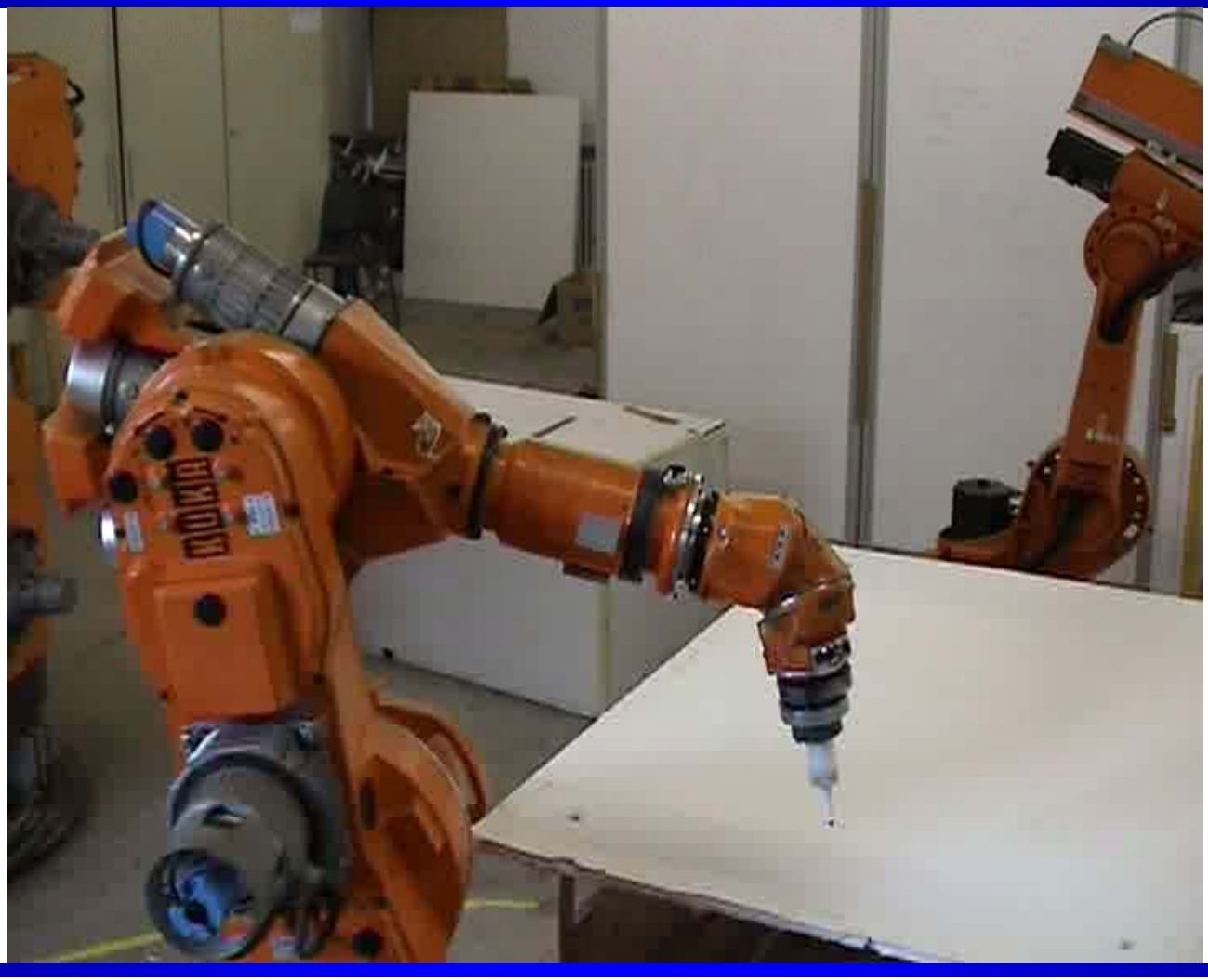
Problem can be shown to be equivalent to a **"convex problem":**
global optimum can be computed easily

$$
\begin{aligned}
&\min_{a(\cdot),b(\cdot),\boldsymbol{\tau}(\cdot)} \int_0^1 \frac{1}{\sqrt{b(s)}} ds, \\
&\text{subject to } \boldsymbol{\tau}(s) = \mathbf{m}(s)a(s) + \mathbf{c}(s)b(s) + \mathbf{g}(s), \\
&\qquad b(0) = \dot{s}_0^2, \\
&\qquad b(1) = \dot{s}_T^2, \\
&\qquad b'(s) = 2a(s), \\
&\qquad b(s) \geq 0, \\
&\qquad \underline{\boldsymbol{\tau}}(s) \leq \boldsymbol{\tau}(s) \leq \overline{\boldsymbol{\tau}}(s), \\
&\qquad \text{for } s \in [0,1].
\end{aligned}
$$



→ In fraction of a second, computer can find optimal solution!

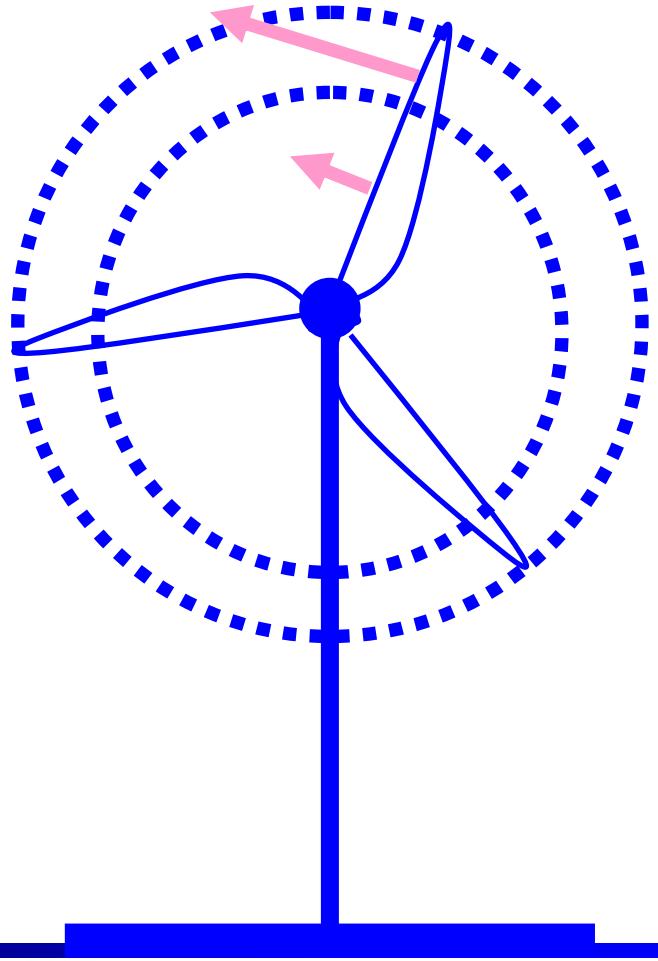
Result: Ultra Fast Optimization of Robot Path



Optimal Control of Kites

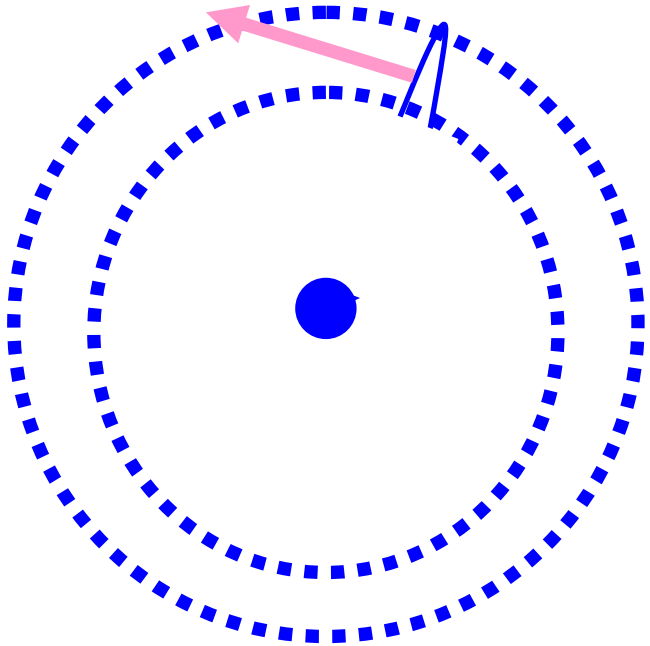
(with Boris Houska, J. Swevers, D. Vandepitte,, ...

Conventional Wind Turbines



- Due to high speed, wing tips are ***most efficient*** part of wing

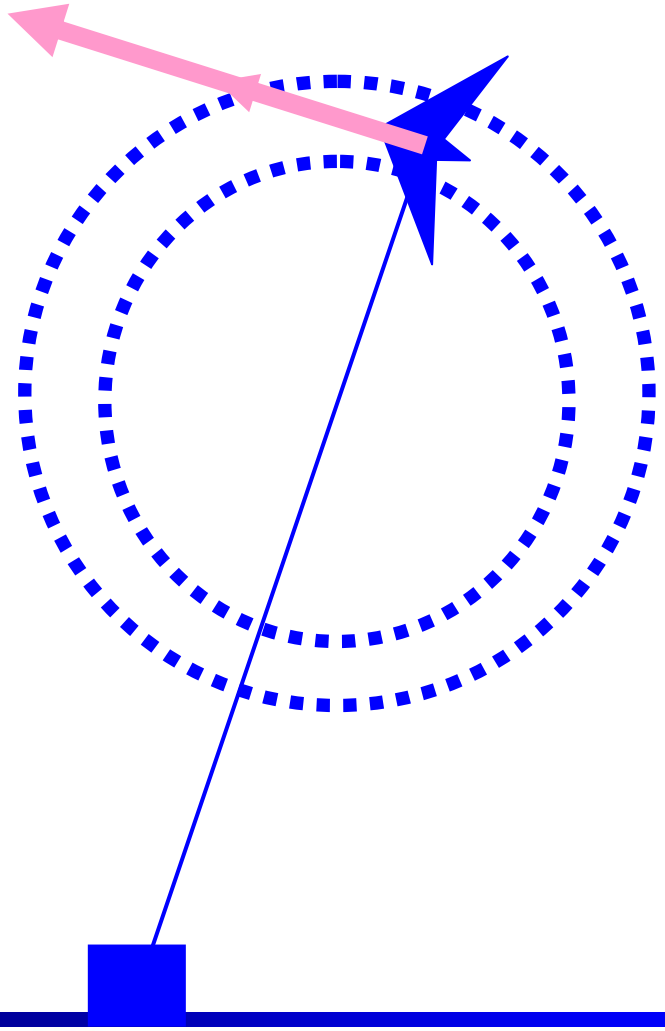
Conventional Wind Turbines



- Due to high speed, wing tips are ***most efficient*** part of wing

Could we construct a wind turbine with only wing tips and generator?

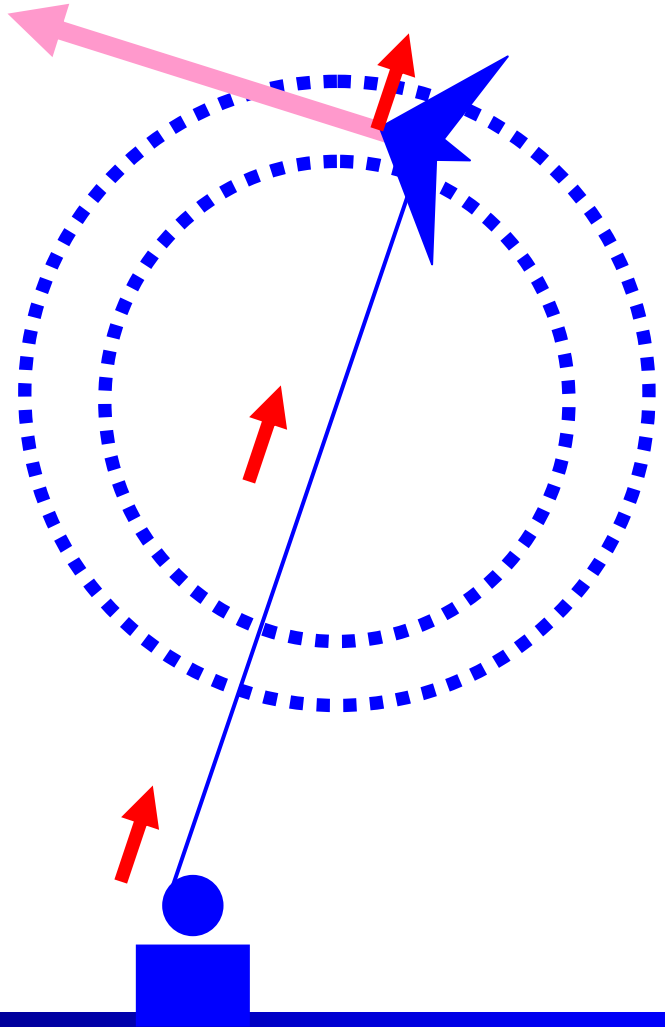
Crosswind Kite Power



- Fly kite fast in crosswind direction
- Very strong force

But where could a generator be driven?

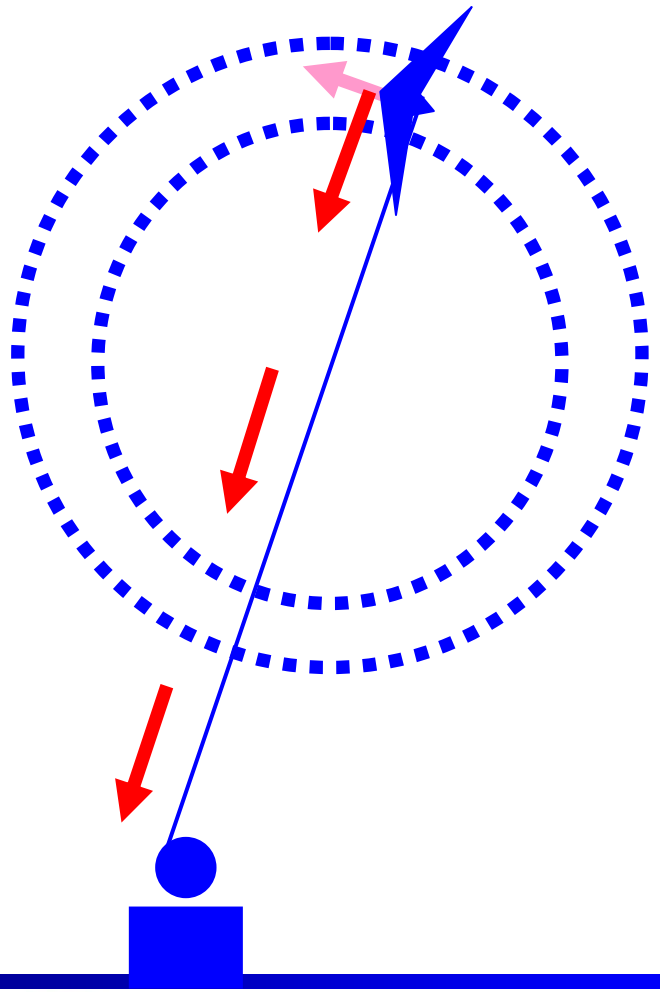
New Pumping Cycle



New cycle consists of two phases:

- ***Power generation phase:***
  - ***unwind cable***
  - generate power

New Pumping Cycle



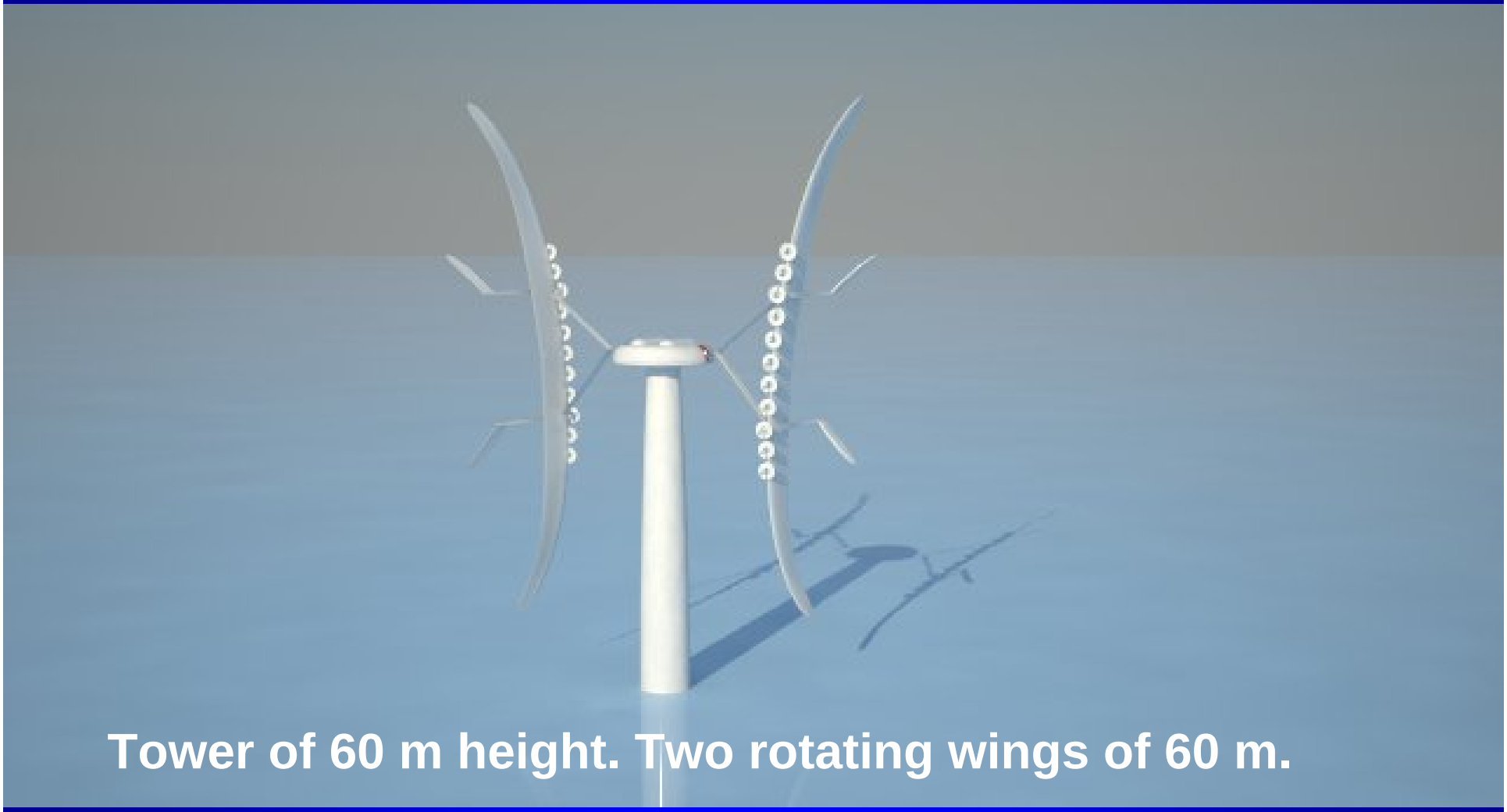
New cycle consists of two phases:

- ***Power generation phase:***
  - ***unwind cable***
  - generate power
- ***Retraction phase:***
  - Reduce tension
  - pull back line

Optimal control allows to find best flight paths...

Potential enormous: 5 MW for 60 m wing!

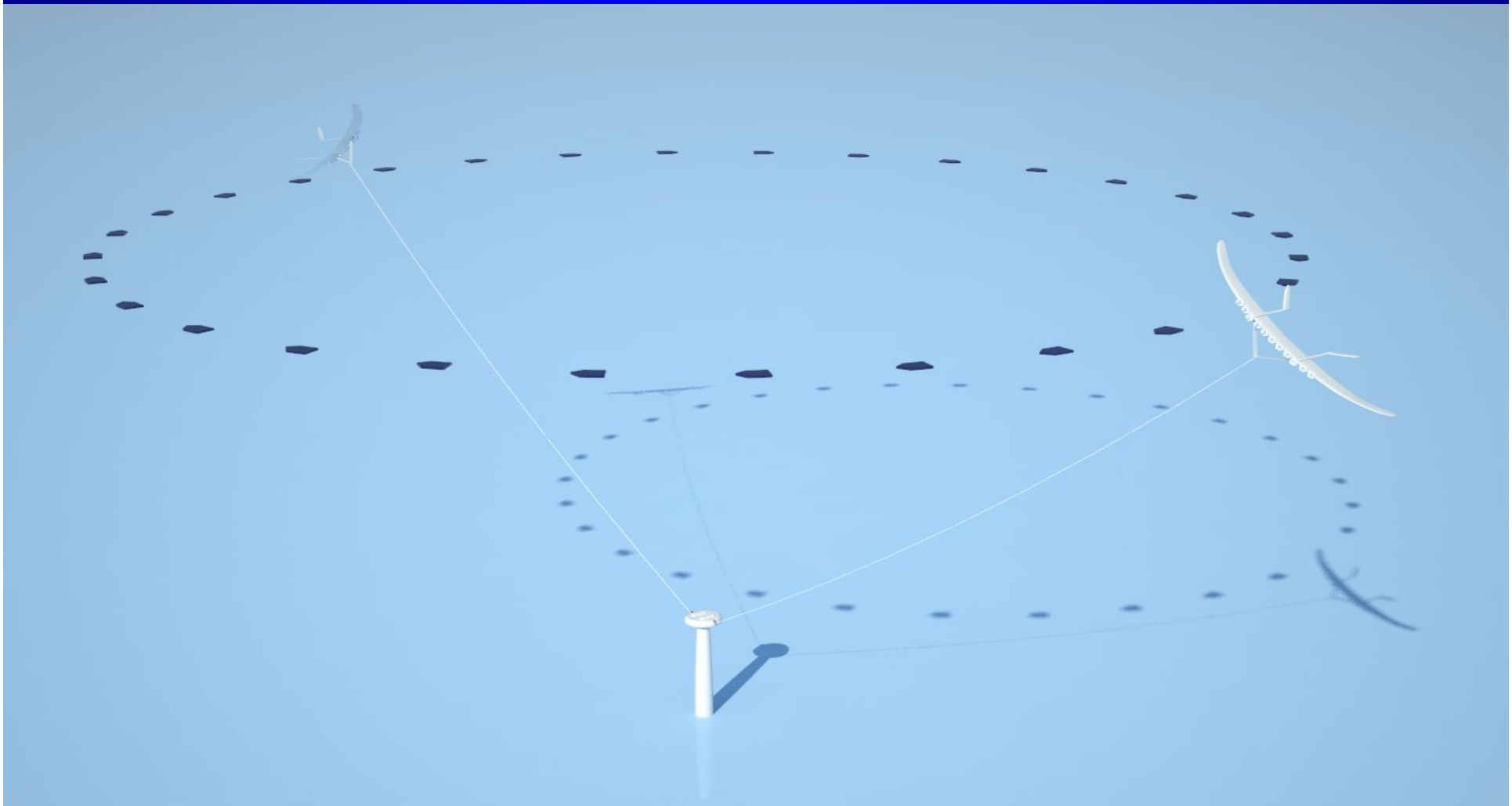
New rotation start (Visualization: Reinhart Paelinck)



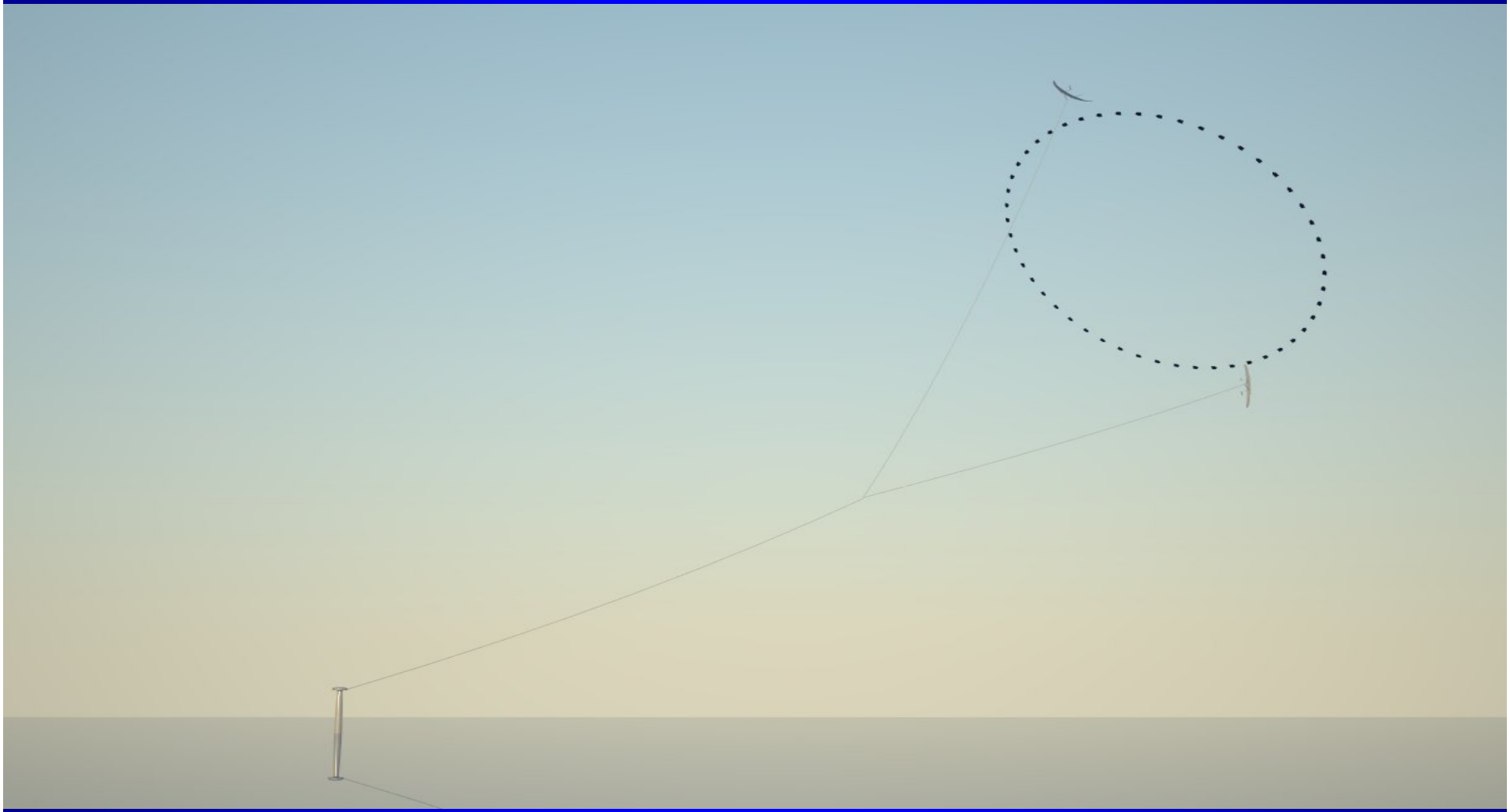
Tower of 60 m height. Two rotating wings of 60 m.

Centrifugal and lifting forces keep kites in the air

Later, lift forces dominate



Lines are connected to reduce line drag



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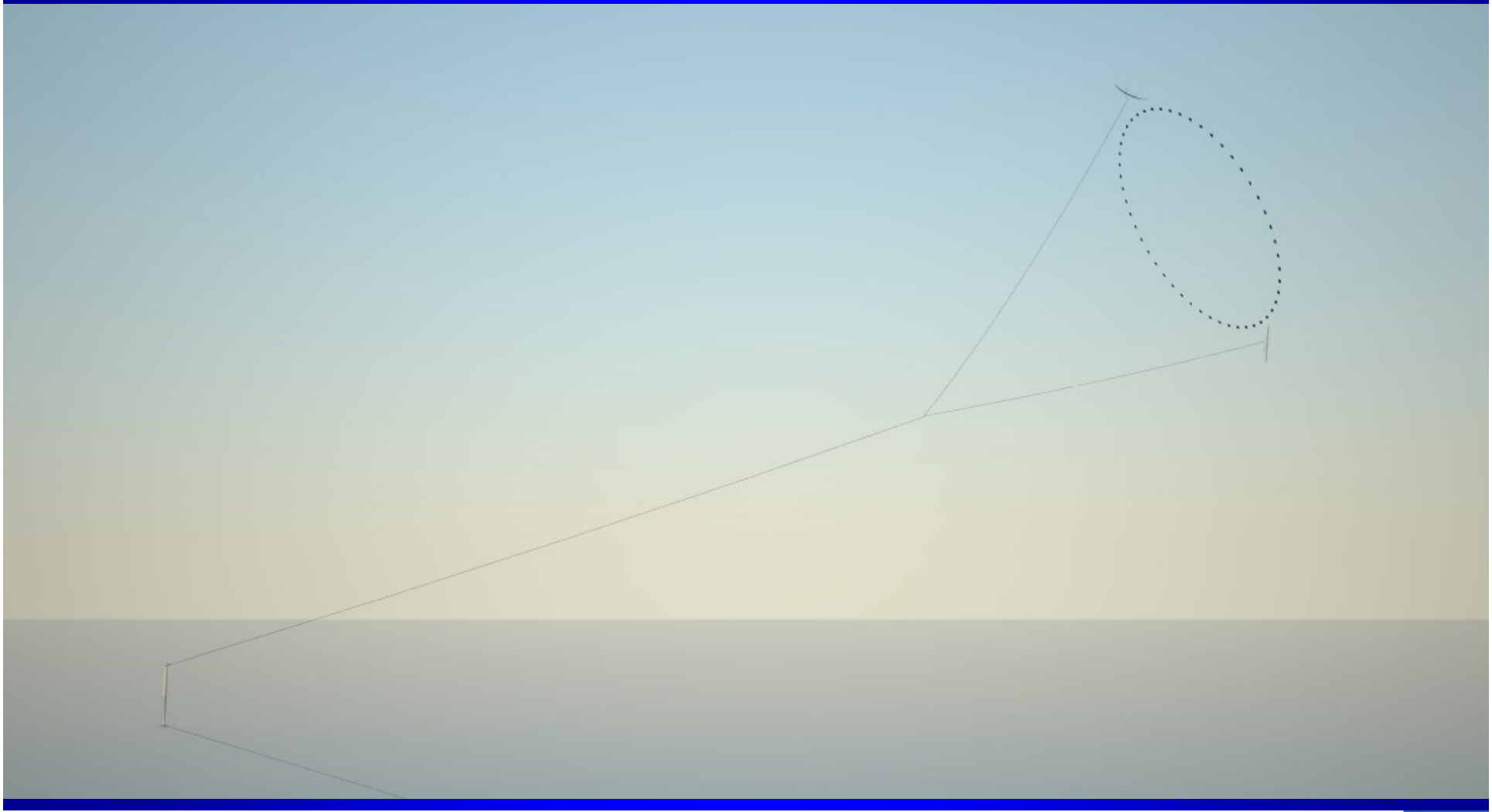
Final orbit – A virtual 18 MW windmill is erected!



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