Strange effects with blade springs

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Two puzzles

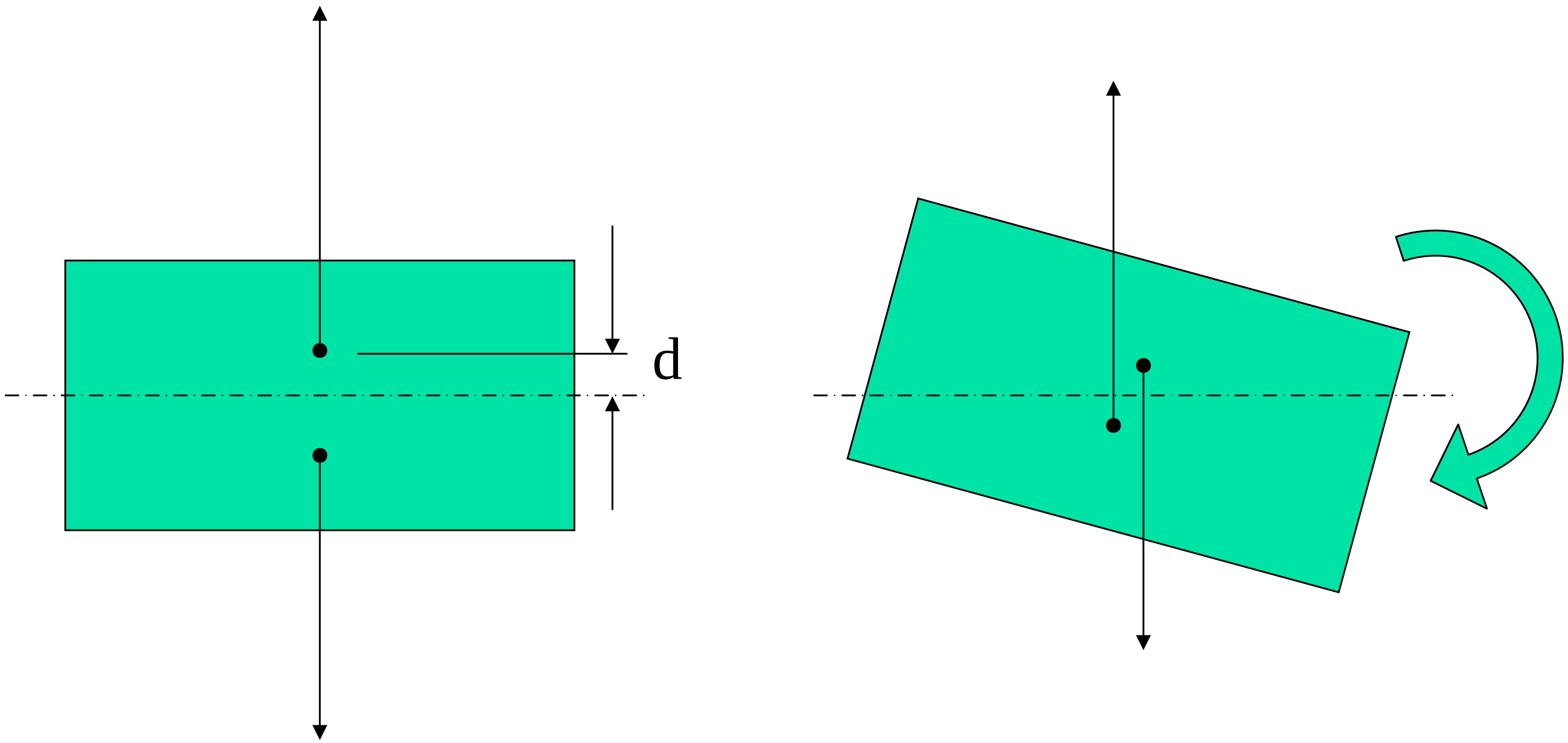
- On the controls prototype we found:

- Odd things about the "d" parameter
- Linear springs that don't deflect by F/k

The “d” parameter

- To keep the suspension stable, each mass should be suspended just above its centre of mass and the supports for masses below should be from a point just below the centre of mass. These offset are known as the “d” distances (d_1, d_2, etc)

Stability



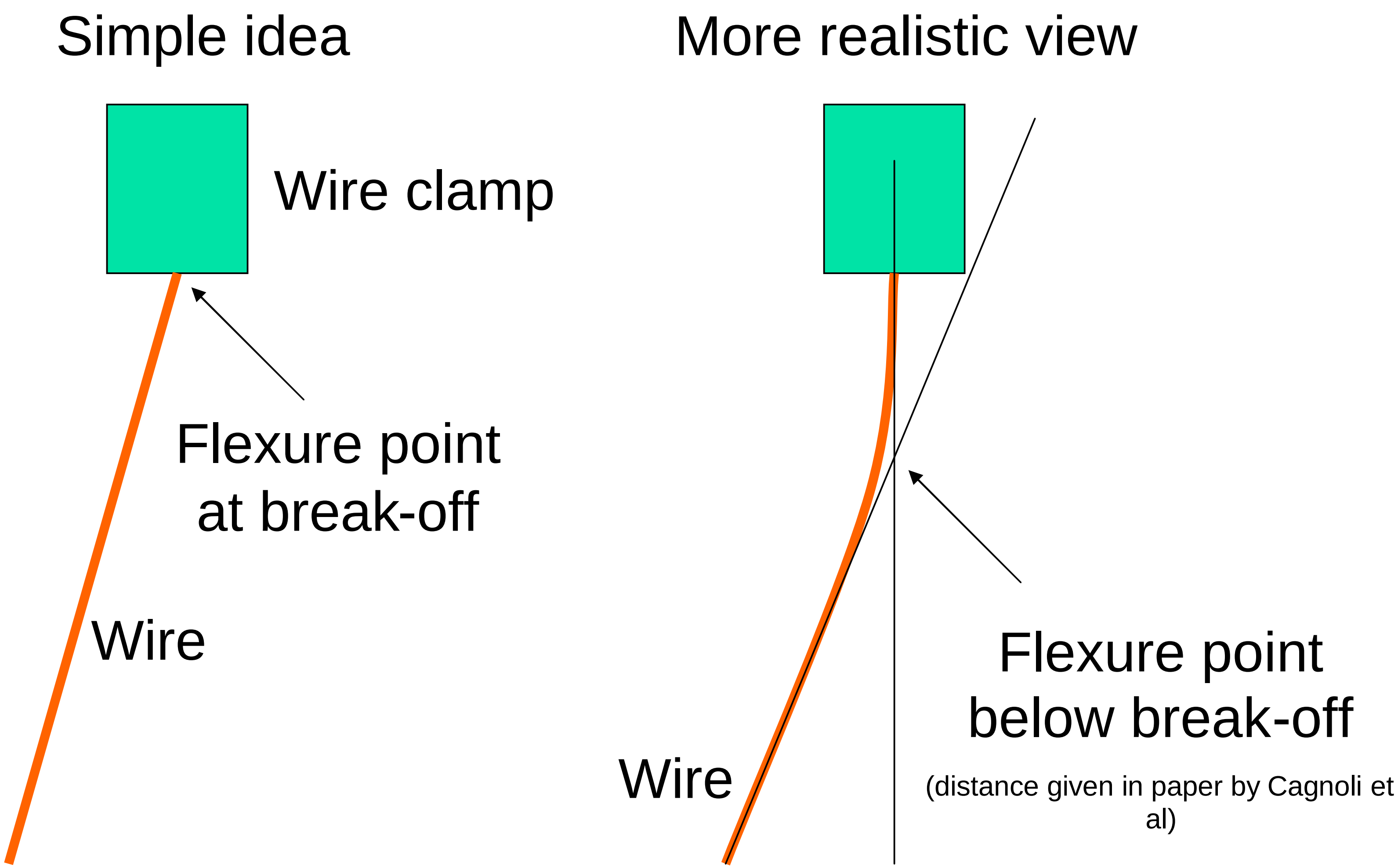
Stable

Unstable

The “d” parameter

- To keep the suspension stable, each mass should be suspended just above its centre of mass and the supports for masses below should be from a point just below the centre of mass. These offset are known as the “d” distances (d_1, d_2, etc)
- The stability of the different masses interacts
  - one very unstable mass can destabilise the whole chain
  - Conversely making one mass very stable can compensate errors elsewhere
- The “d” distances are influenced by the wire flexure.

Wire flexure



Damping dilution factor for a pendulum in an interferometric gravitational waves detector, Cagnoli et al, Physics Letters A 272 2000 39–45

“d” parameter

- When the controls prototype suspension was built, it was not stable (or only marginally so).
- An extra ~10mm of d distance was needed to stabilise the suspension.
- This was the first suspension to which this had occurred.
- There seemed to be something wrong with the “d” distances.

Candidate solutions

- Candidate solutions:
  - (a) Something wrong with the wire flexure calculation?
  - (b) Something misaligned (only one mass needs to be badly out to pull the rest of the marionette)?
  - (c) Something about the way the blades and clamps interact?
  - (d) Something weird we have not thought of?

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  - (c) Something about the way the blades and clamps interact?
  - (d) Something weird we have not thought of?
- It turns out that the correct suggestion was (c)

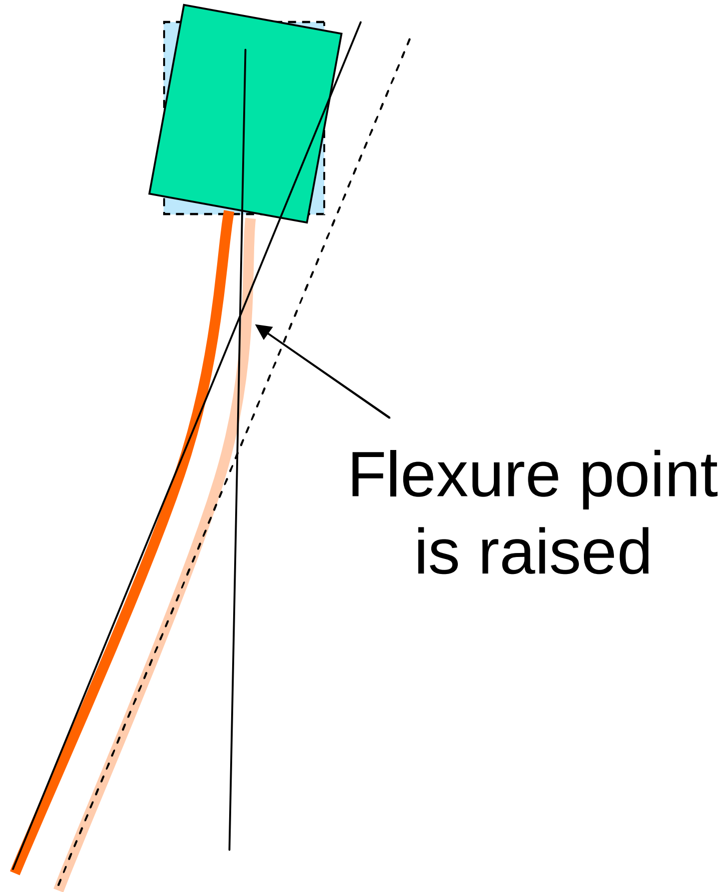
Theories for blade/wire interaction

- As the suspension swings back and forth, the end of the blade twists slightly.
  - Caused by the extra bending resistance imparted to the wire by the tension from the masses below

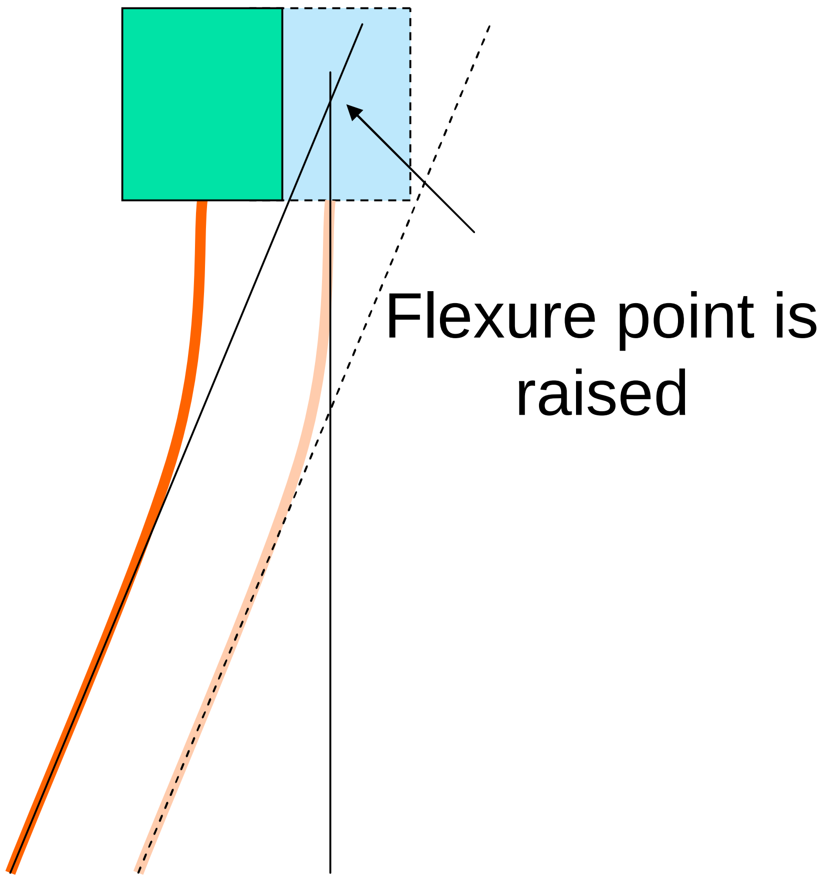
- As the suspension swings back and forth, the end of the blade moves laterally

Wire flexure/blade interaction

Twist theory



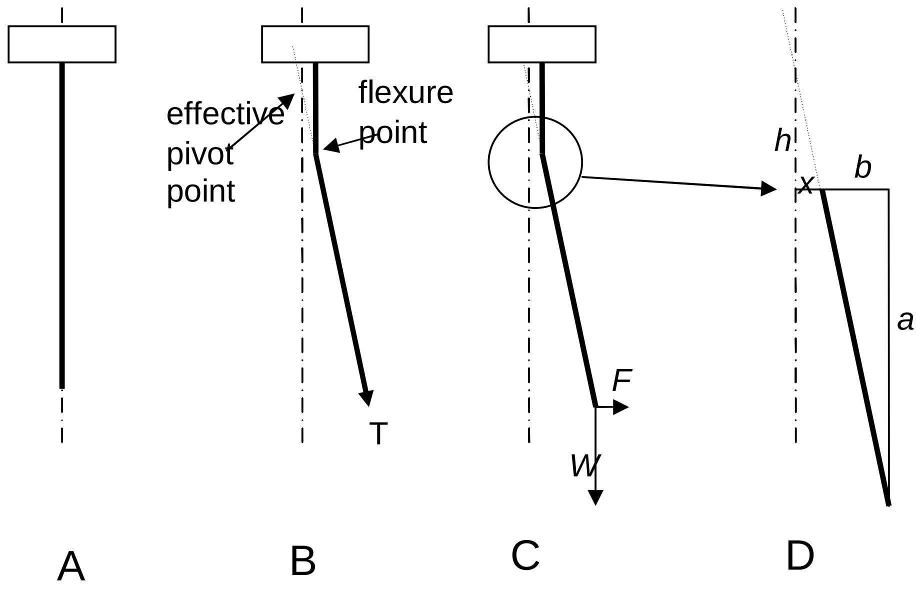
Lateral compliance theory



Theories for blade/wire interaction

- As the suspension swings back and forth, the end of the blade twists slightly.
  - Caused by the extra bending resistance imparted to the wire by the tension from the masses below
  - FE and theoretical work saw only small effects
- As the suspension swings back and forth, the end of the blade moves laterally
  - Theoretical and FE work showed that this effect would be just big enough to explain the effect seen.

Theory – 1 (T050255)



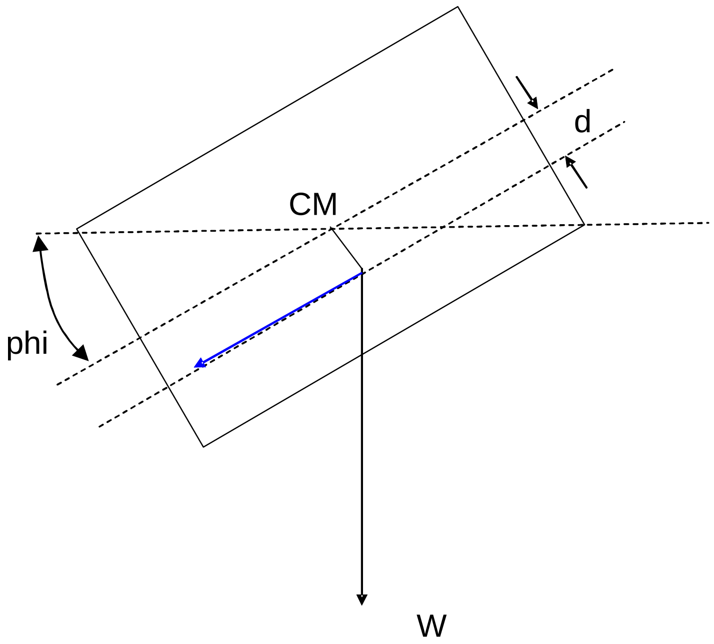
$$\frac{h}{x} = \frac{a}{b}$$

$$h = x\frac{W}{F} = \frac{F}{k_l} \bullet \frac{W}{F} = \frac{W}{k_l}$$

Stable when

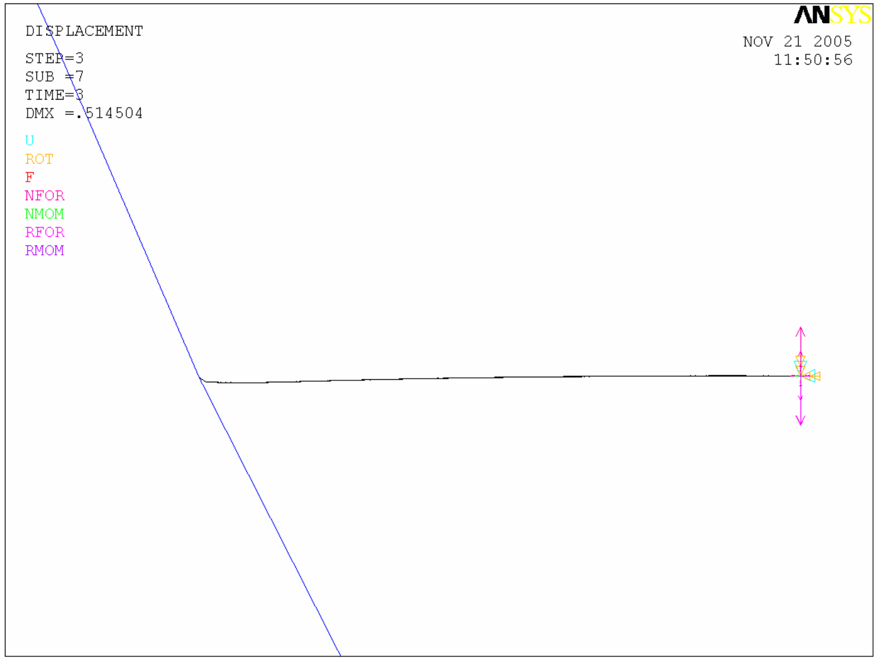
W/k<d

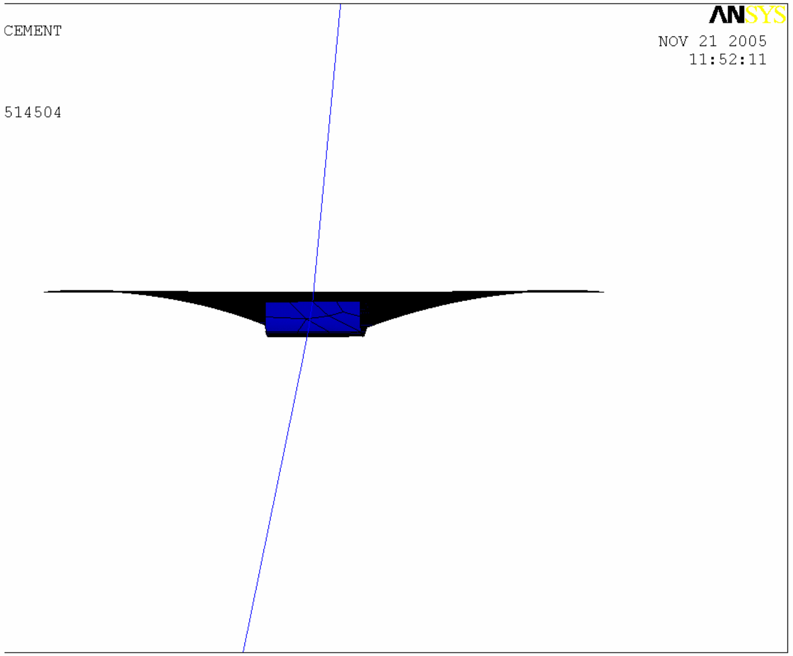
Theory - 2



- Load is W
- Blade stiffness is k_t, k_v
- Deflection under load mg is D
- Small perturbation of mass, phi
- Restoring torque is W*d*phi
- If blade tip moves sideways (blue arrow), restoring torque is reduced
  - restoring torque is removed if movement > d*phi
- Movement is W*phi*k_t
- Unstable if k_t<W/d
  - Equivalent to previous slide
- Can also show condition is k_t/k_v<D/d, approx 200 to 1
- Noise prototype blades have smaller width to thickness ratio than used in previous blades.

And FEA agrees





Stiffness of blades

- We know the stiffness of the blades
  - Analytical, FEA, measurement
  - Put on the correct mass, blades deflect the right amount within 1%
- So can predict the frequency

$$f = \frac{1}{2\pi}\sqrt{k/m}$$

  - But when we measure it we get the wrong number: the measured frequency is too low

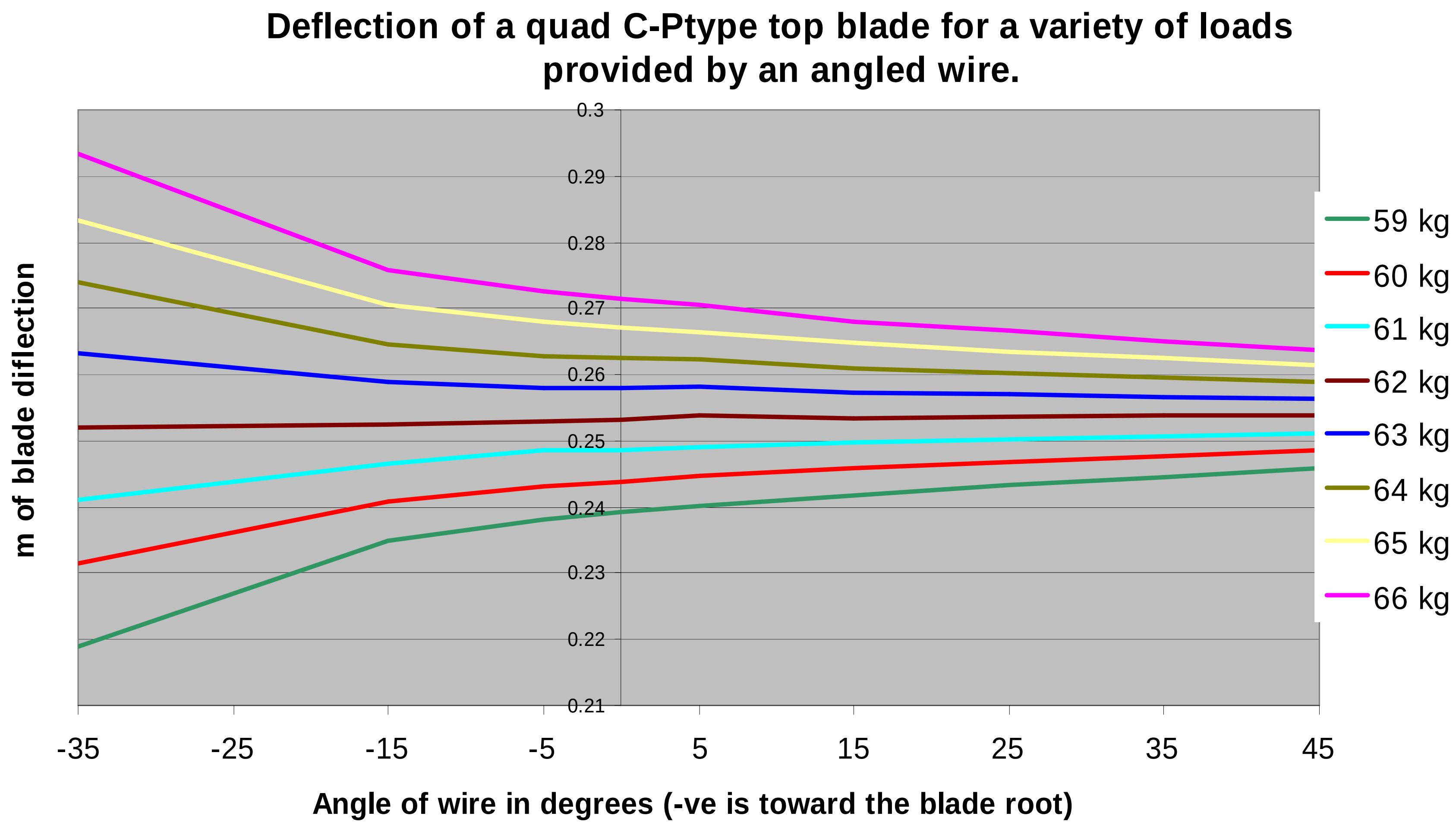
Theories

- Something strange about the overall dynamics
  - We only noticed the effect with whole suspension assembled
  - But what?
- Something about the maraging steel material?
  - But all the static deflections were OK
- Maybe if we measured more carefully the effect would go away?
  - Pretty unlikely – it was too big
  - We were also distracted with the “d” distance problem and many others

Explanation

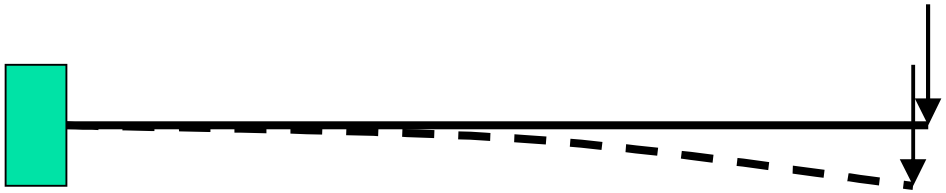
- It turns out that the effect is caused by the end loads on the blades induced by the wire angles.
- This was found from some FEA work, but once seen the effect is simply explained by analytical means.

FEA results

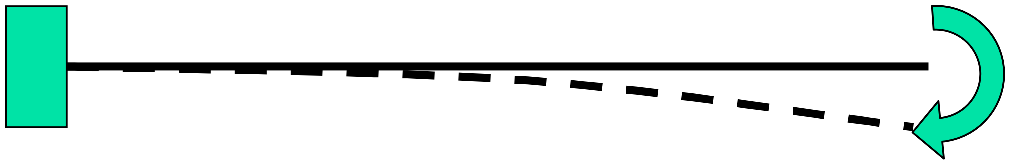


Deflection of a quad C-Ptype top blade for a variety of loads provided by an angled wire.
m of blade diflection
0.3
0.29
0.28
0.27
0.26
0.25
0.24
0.23
0.22
0.21
-35
-25
-15
-5
5
15
25
35
45
Angle of wire in degrees (-ve is toward the blade root)
59 kg
60 kg
61 kg
62 kg
63 kg
64 kg
65 kg
66 kg

Effect of moment loads on cantilever



Vertical load causes deflection



End moment causes deflection

Longitudinal load gives no deflection BUT

Effect of moment loads on cantilever

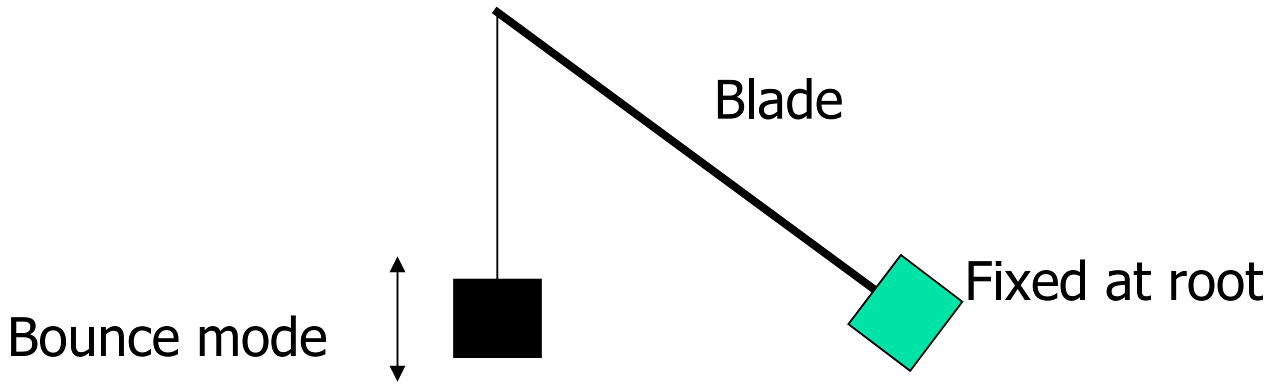
Longitudinal load gives moment IF THE BEAM IS BENT → moment causes deflection

And the bigger the amount by which the beam is bent by other loads, the bigger the effect.

Net result is to change the vertical stiffness of the beam (without changing the initial deflection)

Size of effect

- FEA results show effect that is just what we measured on the controls prototype
- Practical tests with a blade fixed at an angle showed the effect



- We hope to do further practical tests soon using some of the masses on the marionette (single chain suspension) at RAL.

Conclusions

- Two effects seen for the first time on the controls prototype
- Both explained with reasonably straightforward analysis
- Both allowed for in design of noise prototype
- Similarity between noise and controls prototypes leads us to hope we will find no such surprises on the noise prototype…