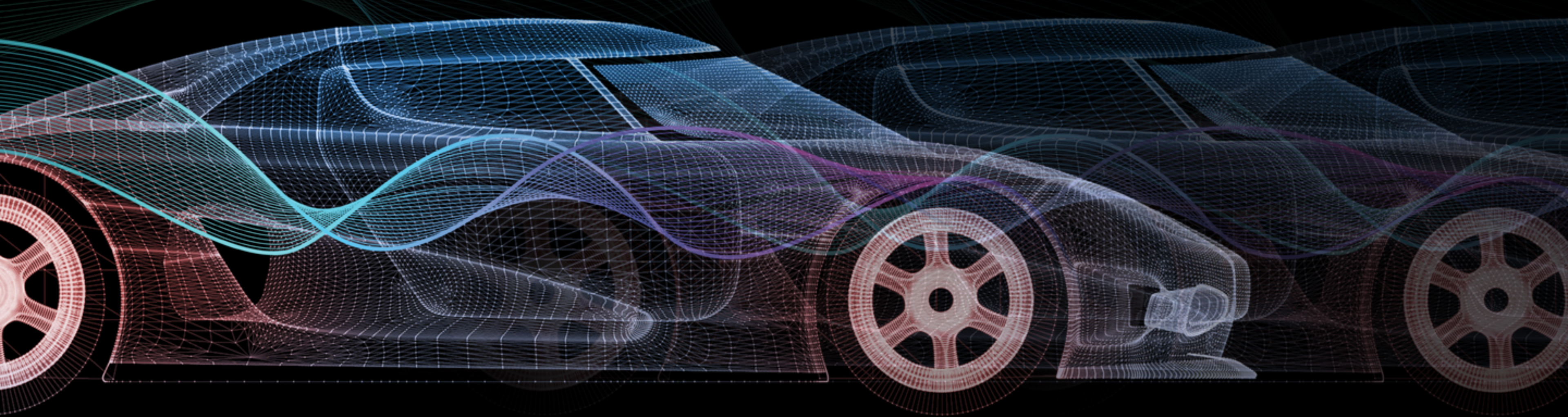
Visible Knowledge

Presented By Durward K. Soebek II



Designing the Future Summit 2018

lppd Lean Product & Process Development

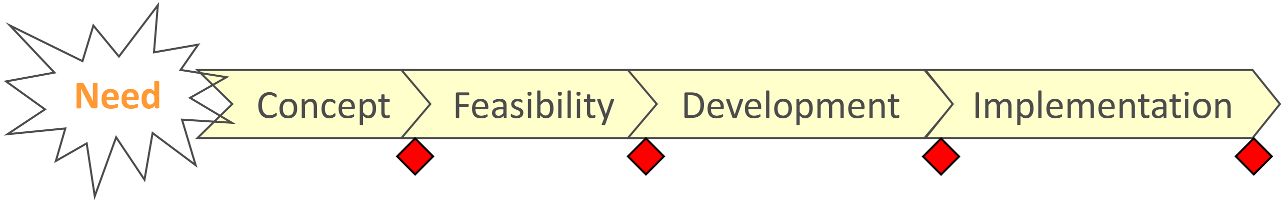
Introductions

Professor of Industrial & Management Systems Engineering, Montana State University

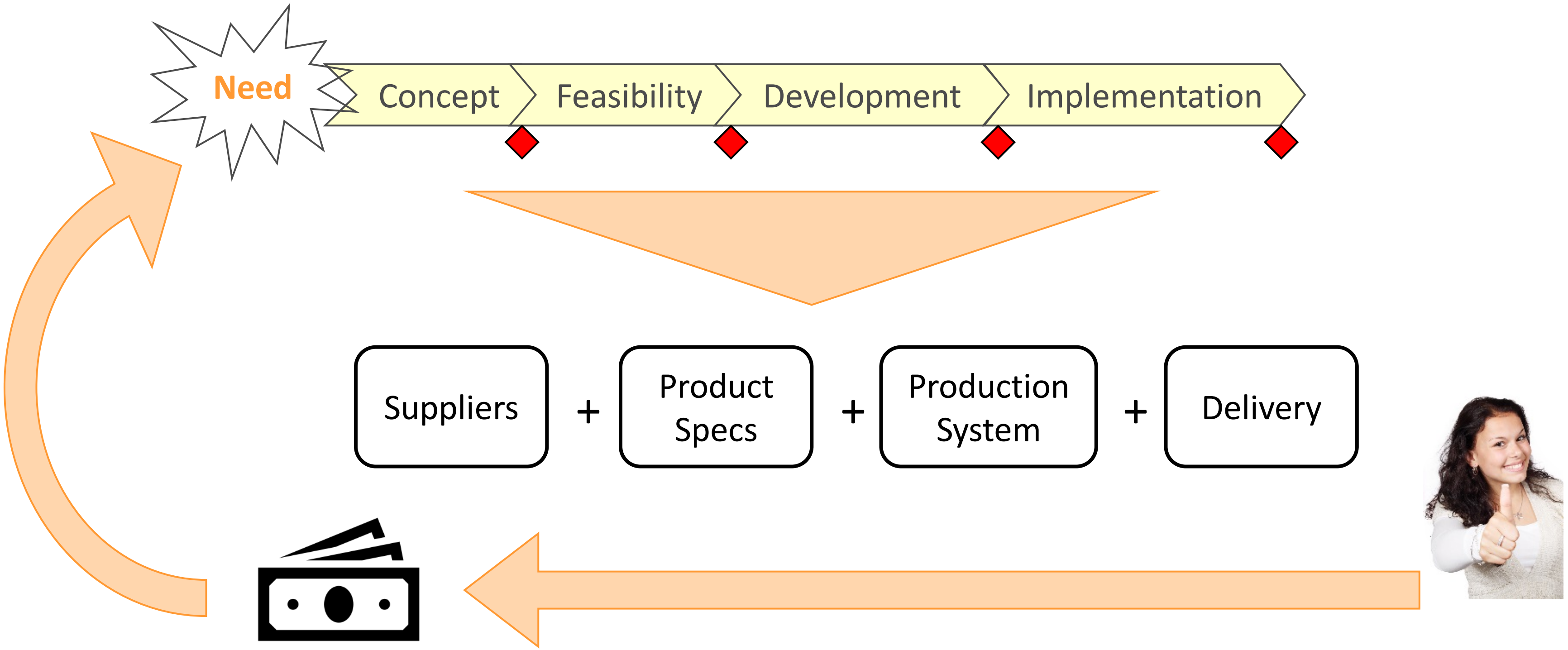
Ph.D. in Industrial and Operations Engineering from The University of Michigan

Researcher in Lean PD for two decades

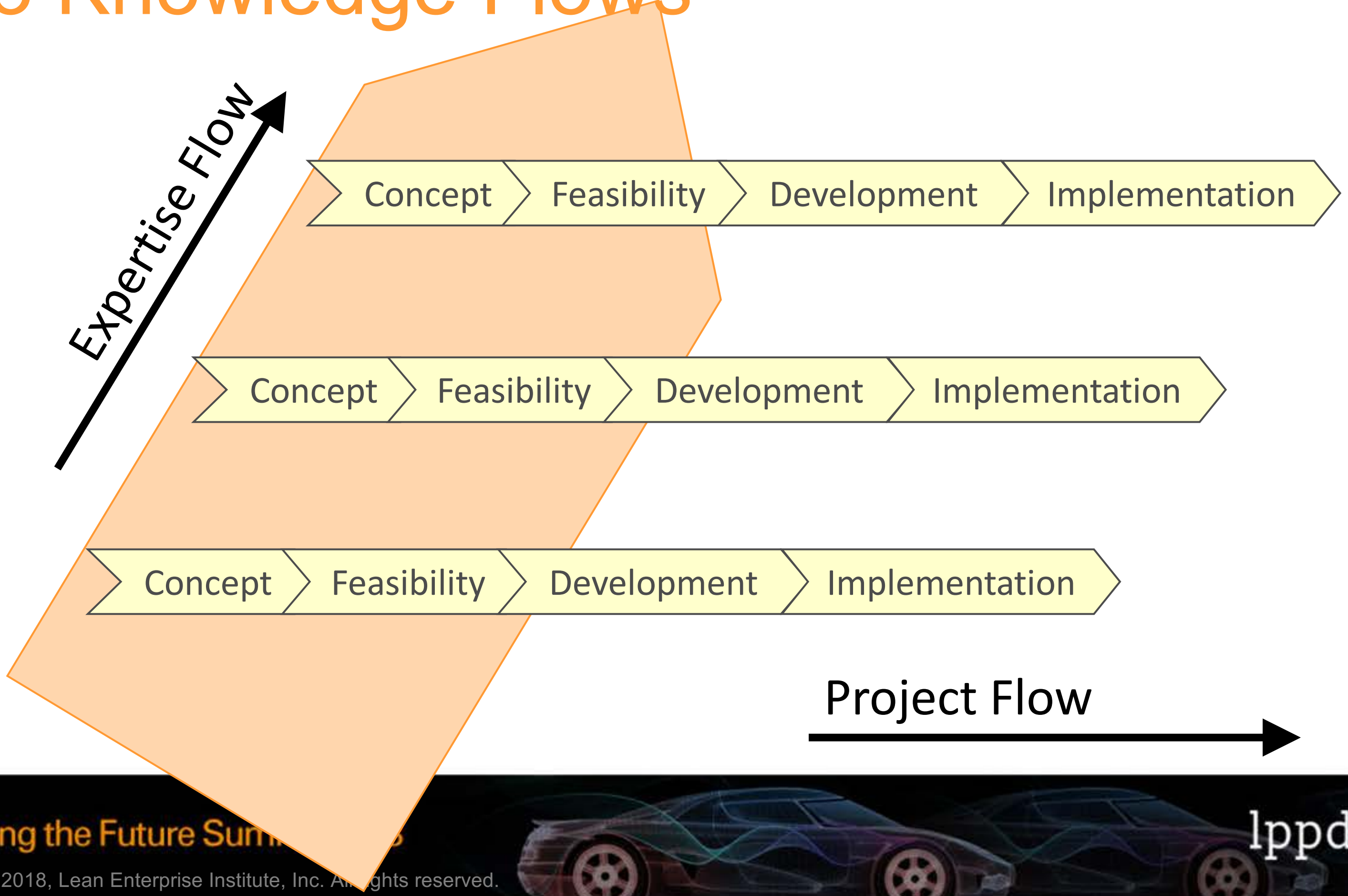
Often we see PD this way...



When it’s really more like this.



Two Knowledge Flows



"Value added" in product development is creating **(re)useable** knowledge and hardware/software.

Four LPPD Principles

1. Deeply understand what your product needs to be.
2. Create flow and eliminate waste for speed to market.
3. Learning is what creates new value.
4. LPPD is all about people.

Source: https://www.lean.org/leanpd/

Deeply Understand What Your Product Needs to Be

Providing customer value = first principle of Lean.

LPPD focuses on:

- Going to the source to deeply understand
- Studying users/products within specific contexts
- Set-based experimentation to look broadly at potential solutions
- Aligning the organization around a vision for the new product

Create Flow, Eliminate Waste for Speed to Market

Deliver product to your customer with speed and precision.

Manage the development process with simple, visual tools and an effective cadence.

Understand, manage, and continually improve capacity and capability.

Synchronize activities across teams and organizations.

Focus on compatibility before completion of individual elements.
Underpin these activities with a powerful system of standards.

Learning is What Creates New Value

Learn effectively and apply it to the creation of new value.

LPPD learning tools and methods include:

- Rapid learning cycles
- Scientific method/experimentation
- Structured, built-in reflection
- Design reviews by going to the source

Recognize and capture knowledge that is created with each product.

LPPD is All About People

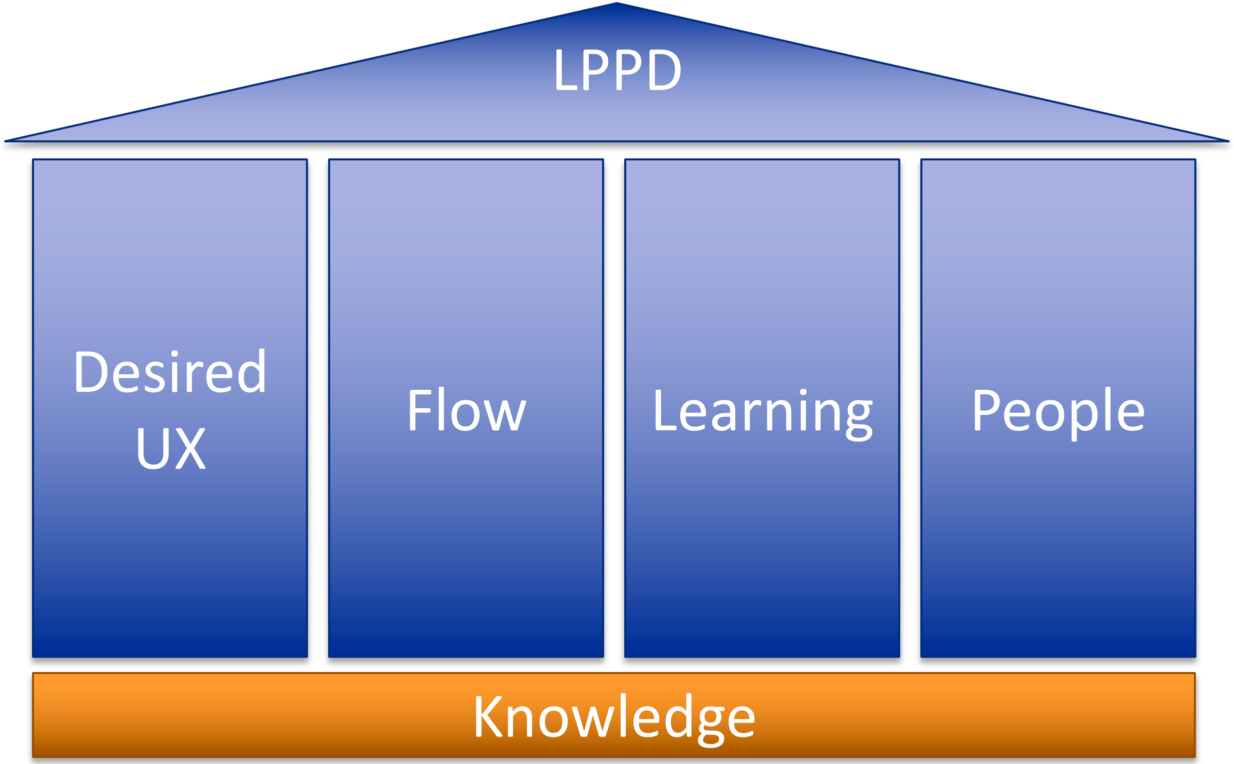
People supply the energy, imagination, and creative potential.

Encompass the extended enterprise – all internal organizations + key suppliers and other outside stakeholders.

Understand the role and power of the "entrepreneurial system designer" who works across highly skilled functions to deliver product excellence.

Strive to create a culture in pursuit of perfection.

Develop leaders who embody these principles.


LPPD
Desired UX
Flow
Learning
People
Knowledge

A lesson from history

How to Design the First Airplane

(and live to tell about it)

Would-be Inventors of Flight

Otto Lilienthal (Germany)

- 18 gliders over 10 years, 2000 test flights
- Perished in test flight crash in 1896

Clement Ader (France)

- $120K spent over 1872-1897 without success

Hiram Maxim (England)

- $200K invested in 1890's without success

Samuel Langley (US)

- $70K spend over 16 years; no manned flight achieved for longer than a few seconds

How about the Wrights?

Never attended university.

Spent about $1000.

22 months of development work, 3 people, spread over 3-4 years

First full prototype flew.

How did they do it?

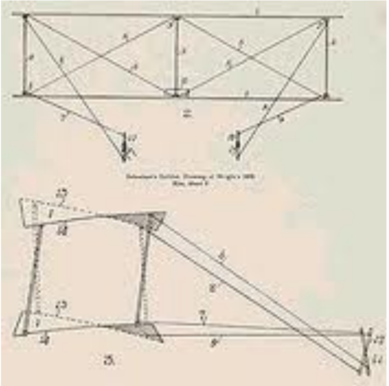
They Innovated an Entirely New Approach

Three knowledge gaps identified:

- In-flight control
- Wing design
- Propulsion

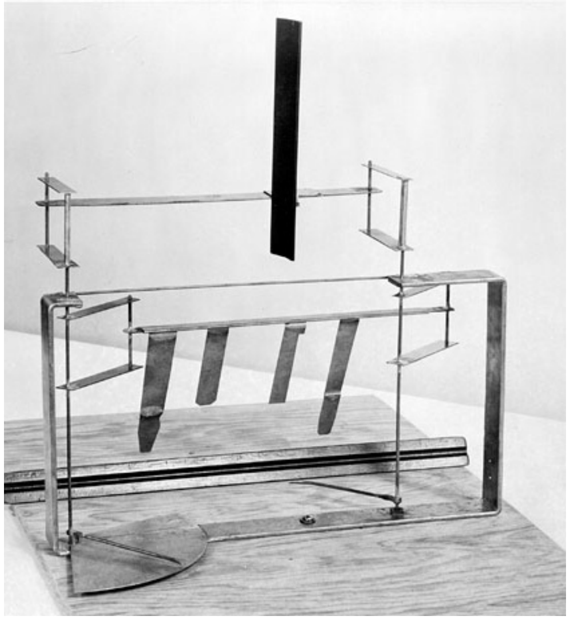
Attacked first.

- Systemic testing of control ideas in kites, gliders.
- Discovered need to control yaw.
- Discovered that existing lift tables were wrong…

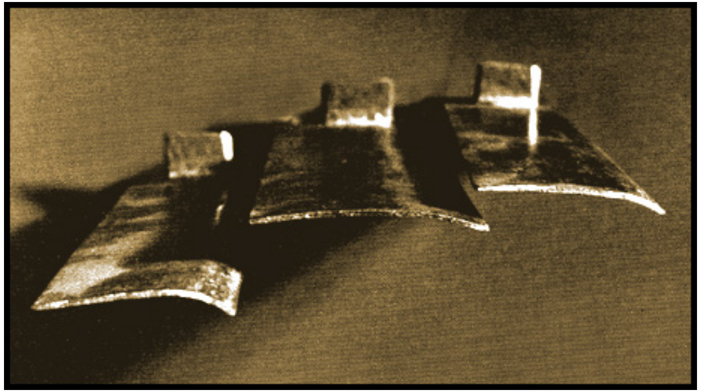


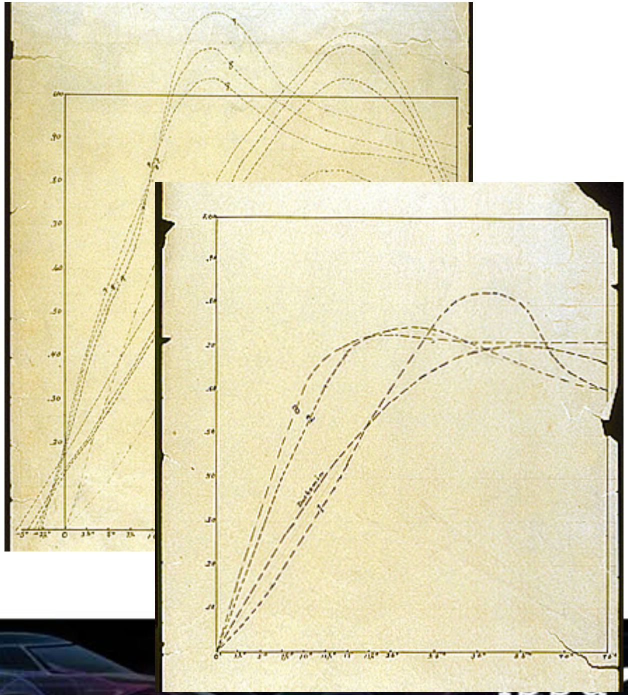
Closing the wing design gap

Wind Tunnel



Lift Balance





Wind tunnel data confirmed in a subsystem test

Closing the Propulsion Gap

Breakthrough Realization:

"It was apparent that a propeller was simply an aeroplane (wing) travelling in a spiral course. As we could calculate the effect of a wing traveling in a straight course, why should we not be able to calculate the effect of a wing travelling in a spiral course?"

Reusable Knowledge!

Reused Knowledge

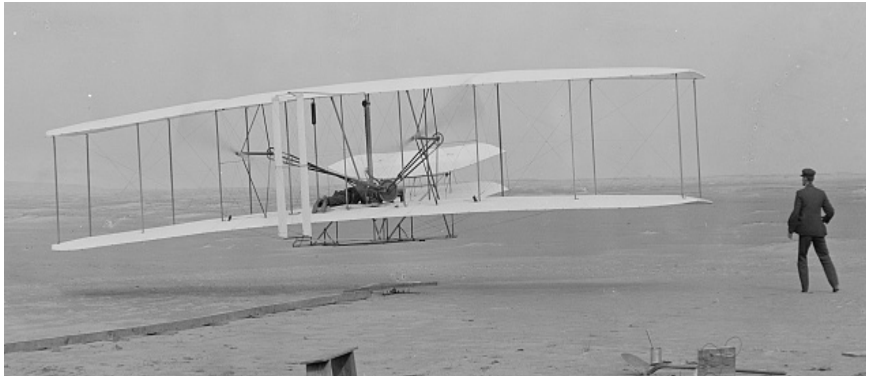
Airfoil knowledge curves used to design novel propeller.

Highly efficient propeller allowed a small motor.

They closed the propulsion gap!

"Success assured."

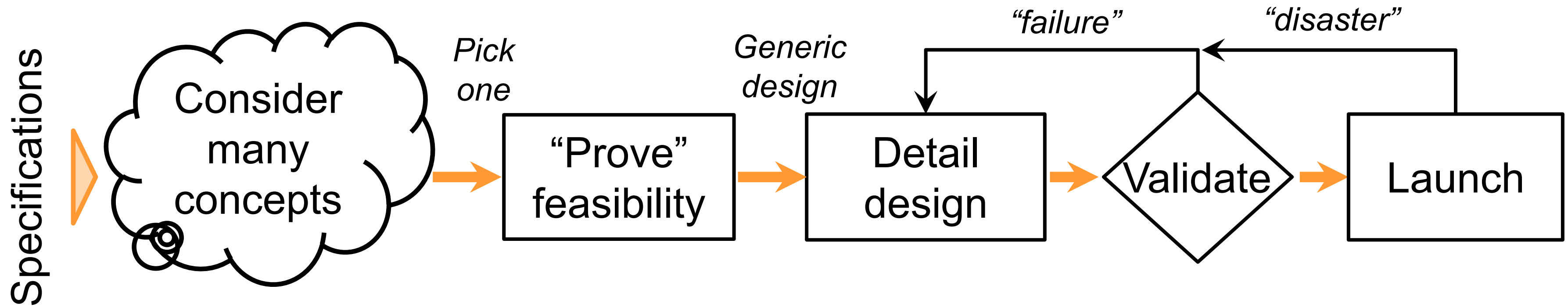
With the knowledge gaps now closed…
A full system prototype was built…
Transported to Kitty Hawk…
And flew,
with no design changes!



Take-aways

1. Design-build-test vs. learning first

Conventional Development

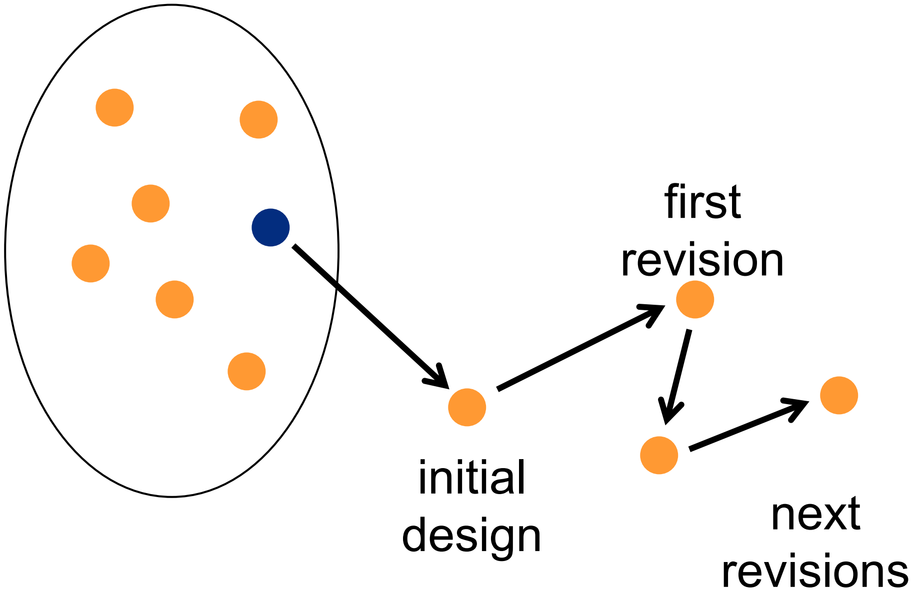


Research ("the fuzzy front end")

Advanced Development

Analyze, Simulate, Prototype & Test

Iteration on a “Point” Solution



Problems

When will you find a design that works?

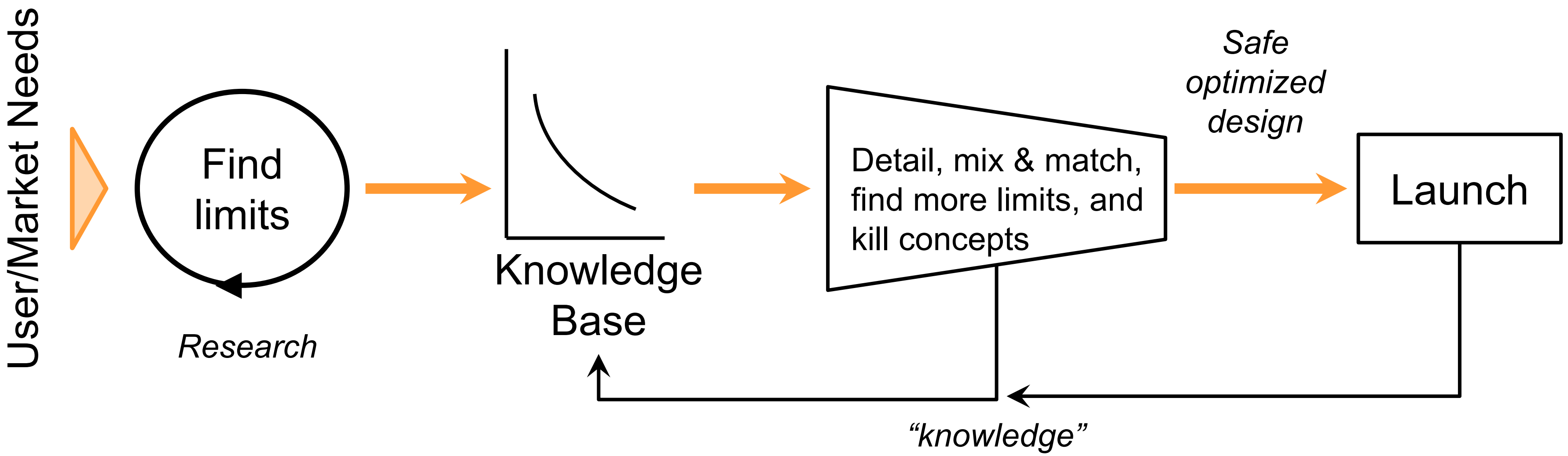
Where to go next?

How far are you from a “cliff”?

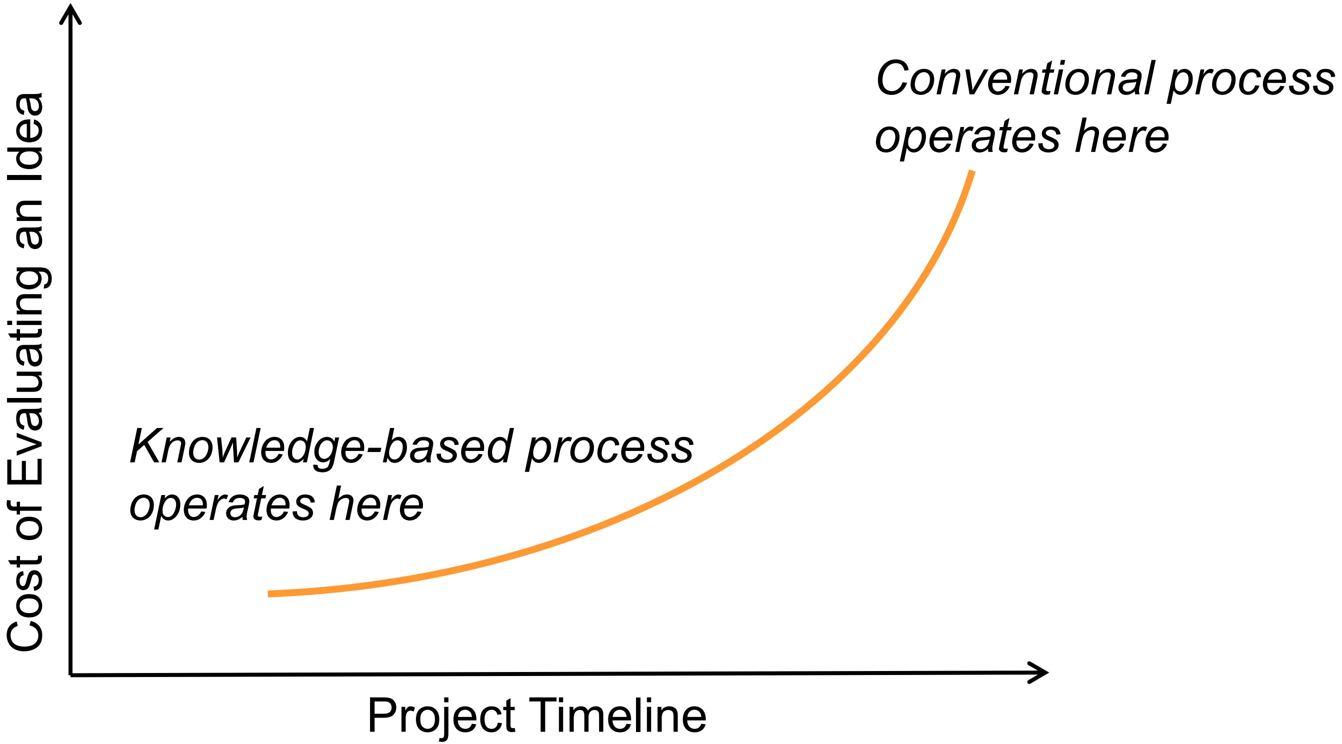
Have you produced any reusable knowledge?

How can teams work concurrently?

Knowledge-based Development



Is it More Expensive?



Take-aways

1. Design-build-test vs. learning first
2. Re-usable "visible" knowledge

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

REPORT No. 460

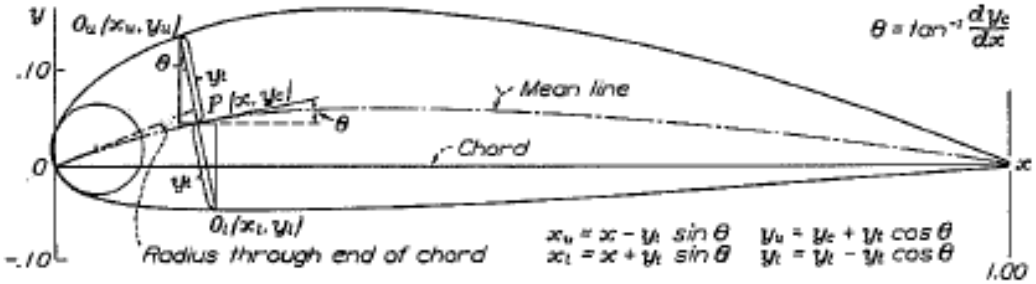
THE CHARACTERISTICS OF
78 RELATED AIRFOIL SECTIONS FROM TESTS
IN THE VARIABLE-DENSITY WIND TUNNEL

By EASTMAN N. JACOBS, KENNETH E. WARD
and ROBERT M. PINKERTON

REPRINT OF REPORT No. 460, ORIGINALLY PUBLISHED NOVEMBER 1933

1935

Source:
http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19930091108_1993091108.pdf



Sample calculations for derivation of N.A.C.A. 6321

x	y_t	y_c	$\tan\theta$	$\sin\theta$	$\cos\theta$	$y_t \sin\theta$	$y_t \cos\theta$	x_u	y_u	x_l	y_l
0	0	0	[1] 0.40000	0.37140	0.92840	0	0	- - - - -	- - - - -	0	0
0.01250	0.03314	0.00489	.38333	.35793	.93375	0.01186	0.03094	0.00064	0.03583	0.02436	−0.02605
.30000	.10503	.06000	0	0	1	0	.10503	.30000	.16503	.30000	−.04503
.60000	.07986	.04898	−.07347	−.07327	.99731	−.00585	.07965	.60585	.12803	.59415	−.03067
1	.00221	0	−.17143	−.16897	.98562	−.00037	.00218	1.00037	.00218	.99963	−.00218

[1] Slope of radius through end of chord.

FIGURE 2.—Method of calculating ordinates of N.A.C.A. cambered airfoils.

115 airfoils tested!

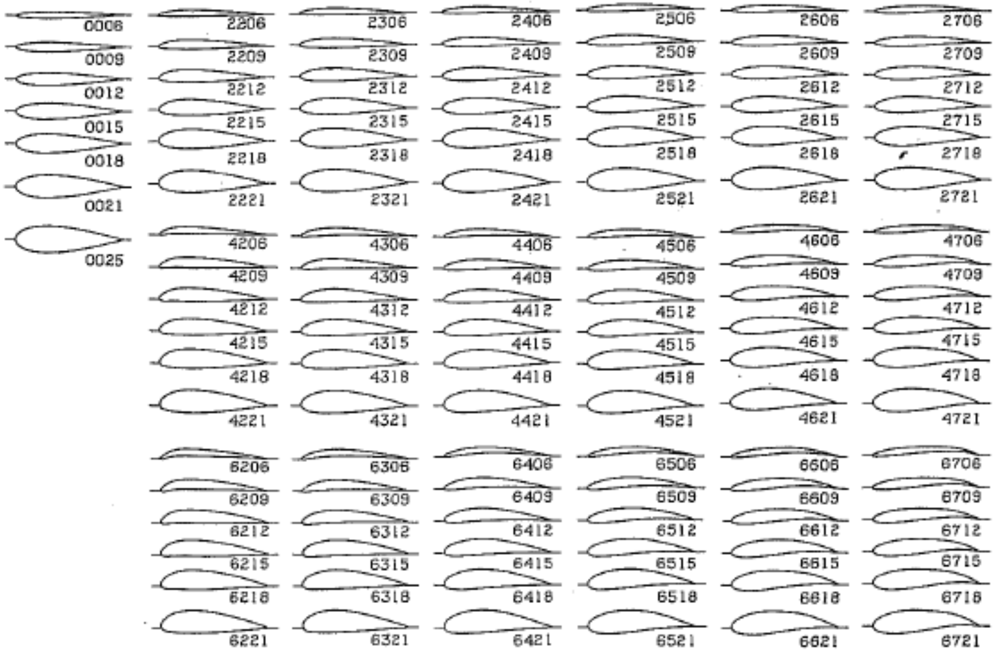
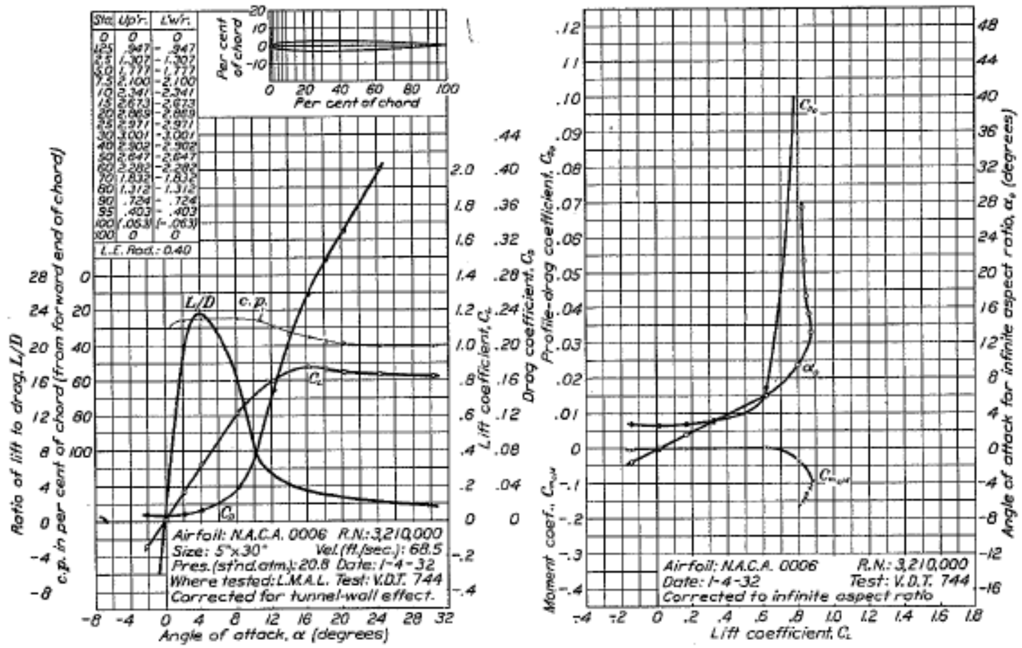


FIGURE 3.—N.A.C.A. airfoil profiles.



Sta.	Up'r.	L'w'r.
0	0	0
1.25	.947	-.947
2.5	1.307	-1.307
5.0	1.777	-1.777
7.5	2.100	-2.100
10	2.341	-2.341
15	2.673	-2.673
20	2.869	-2.869
25	2.971	-2.971
30	3.001	-3.001
40	2.902	-2.902
50	2.647	-2.647
60	2.282	-2.282
70	1.832	-1.832
80	1.312	-1.312
90	.724	-.724
95	.403	-.403
100	(.063)	(-.063)
100	0	0

FIGURE 4.—N.A.C.A. 0006 airfoil.

P-51 Mustang

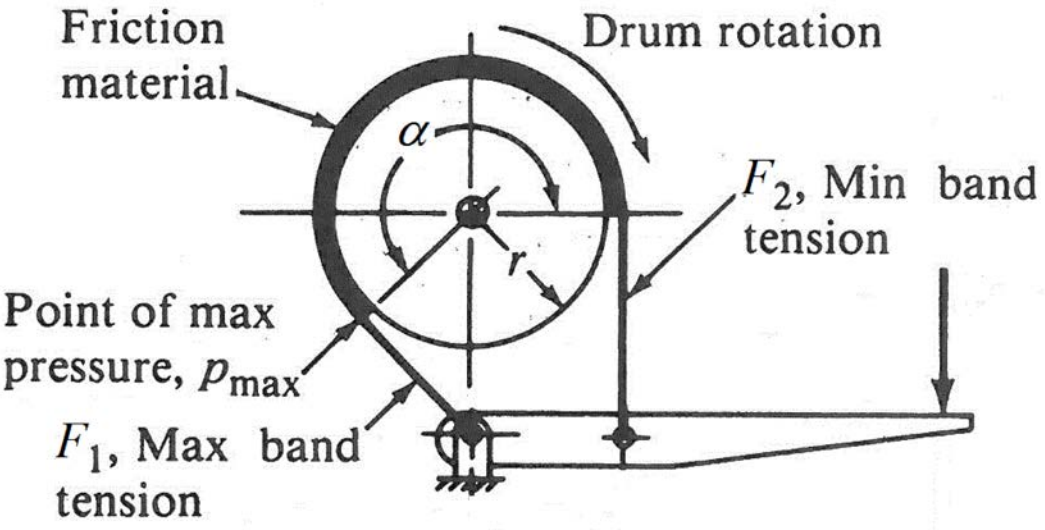
Take-aways

1. Design-build-test vs. learning first
2. Re-usable “visible” knowledge
3. Other?

Let's try this idea on a simple design problem…

Co-developed with Göran Gustafsson, Chalmers University of Technology

Band Brake Theory



Braking torque:

$$M = r(F_1 - F_2)$$

$$\frac{F_1}{F_2} = e^{f\propto}$$

$$F_1 = rbp_{max}$$

Design a Band Brake

Desire a braking torque of 80 Nm, ±5%.

Determine values for:

- Drum radius (r)
- Angle of band coverage (α)
- Band width (b)
- Lining material properties (f and p_{max})

Use a woven material for brake lining:

- Coefficient of friction (f): [0.25, 0.45]
- Allowable pressures (p_{max}): [345 kPa, 690 kPa]

Conventional Approach

a) Select a value for f.

b) Specify a trial design by selecting values for r, α, and b.

c) Find F_1 assuming p_{max} = 350 kPa.

$$F_1 = rbp_{max}$$

d) Find F_2.

$$F_2 = F_1 e^{-f\propto}$$

$$(2\pi = 360°)$$

e) Compute M.

$$M = r(F_1 - F_2)$$

Let's try it….

a) Select a value for f. $f = 0.45$

b) Specify a trial design: $r = 15\text{cm}$, $\alpha = 240^o$, $b = 2\text{cm}$

c) Find F_1 assuming p_{max} = 350 kPa.

$$F_1 = rbp_{max} = (0.15)(0.2)(350000)$$
$$F_1 = 1050 \text{ N}$$

d) Find F_2.

$$F_2 = F_1 e^{-f\propto} = (1050)e^{-(.45*4.19)} = 159N$$

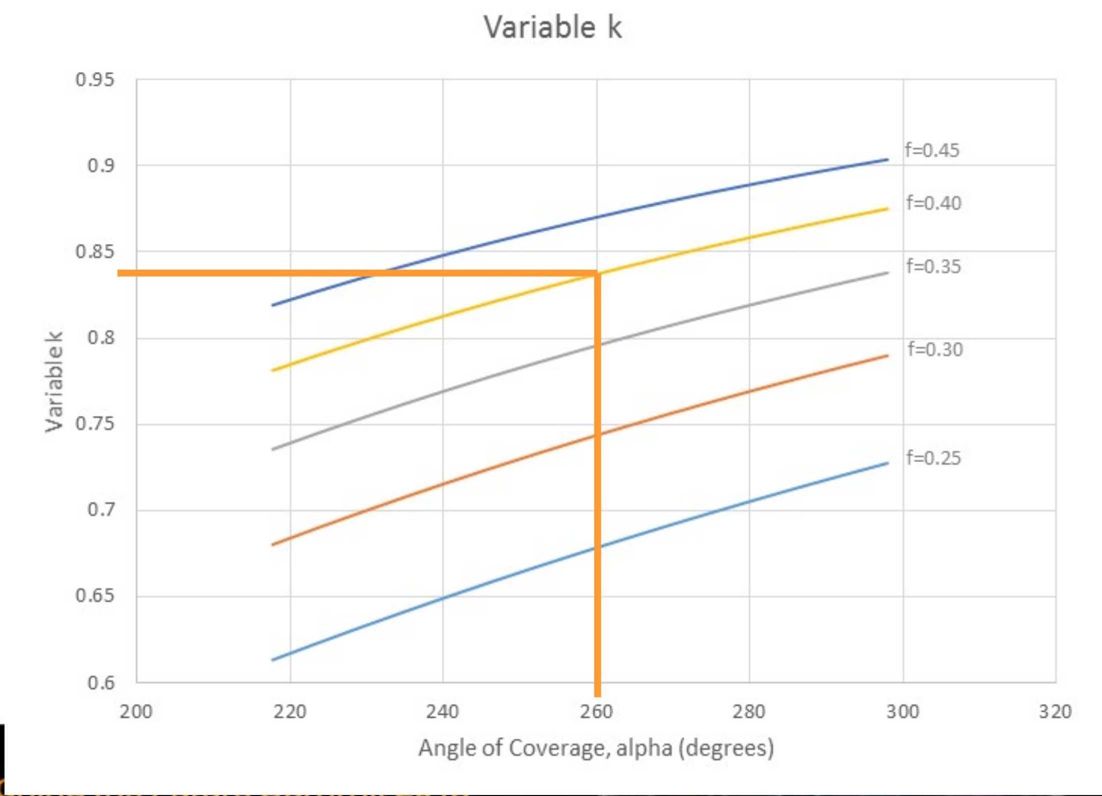
e) Compute M.

$$M = r(F_1 - F_2) = (.15)(1050 - 159) = 134Nm$$

>80 Nm

What if we had "visible knowledge" for the band brake problem…?

A Knowledge-based Approach



Determine

f, α, and k.

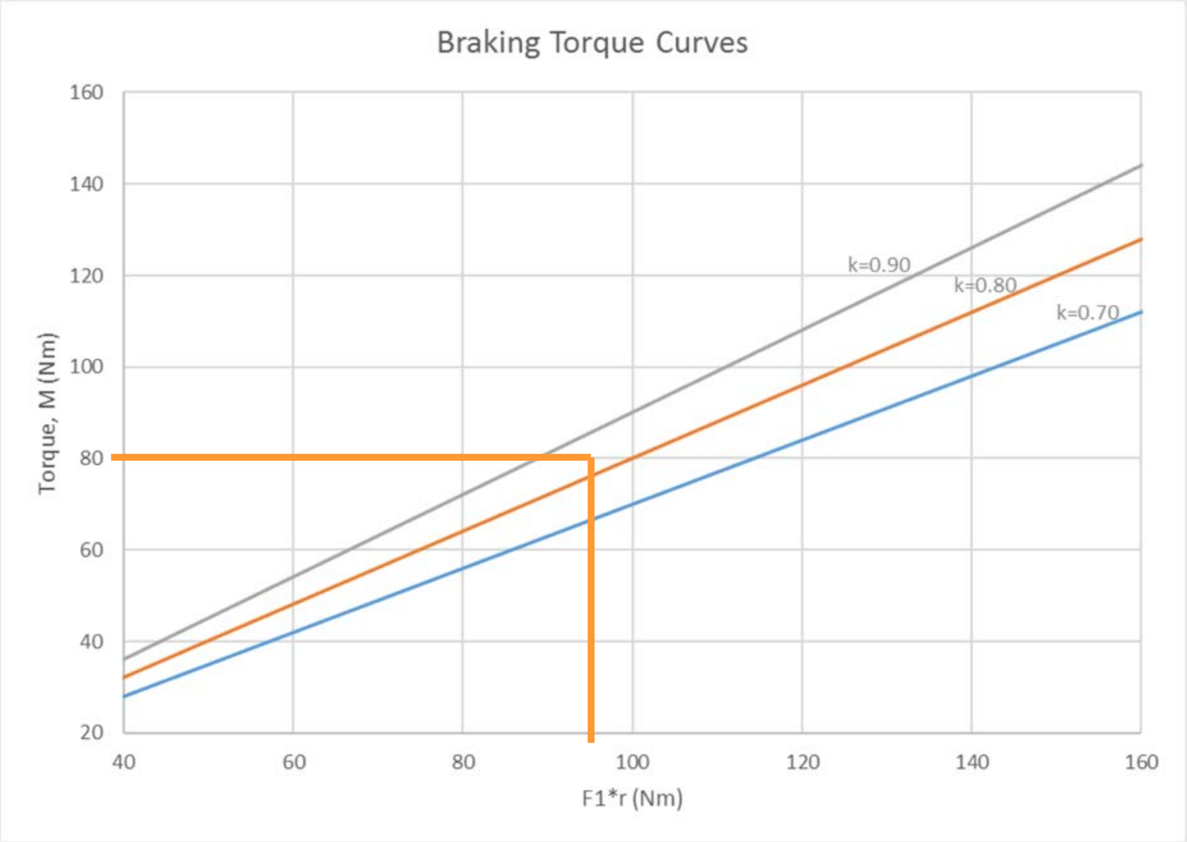
$f = 0.40$

$\alpha = 260^o$

k = 0.84

A Knowledge-based Approach, cont.

Find $F_1{*}r$
for M = 80
and k value
selected.

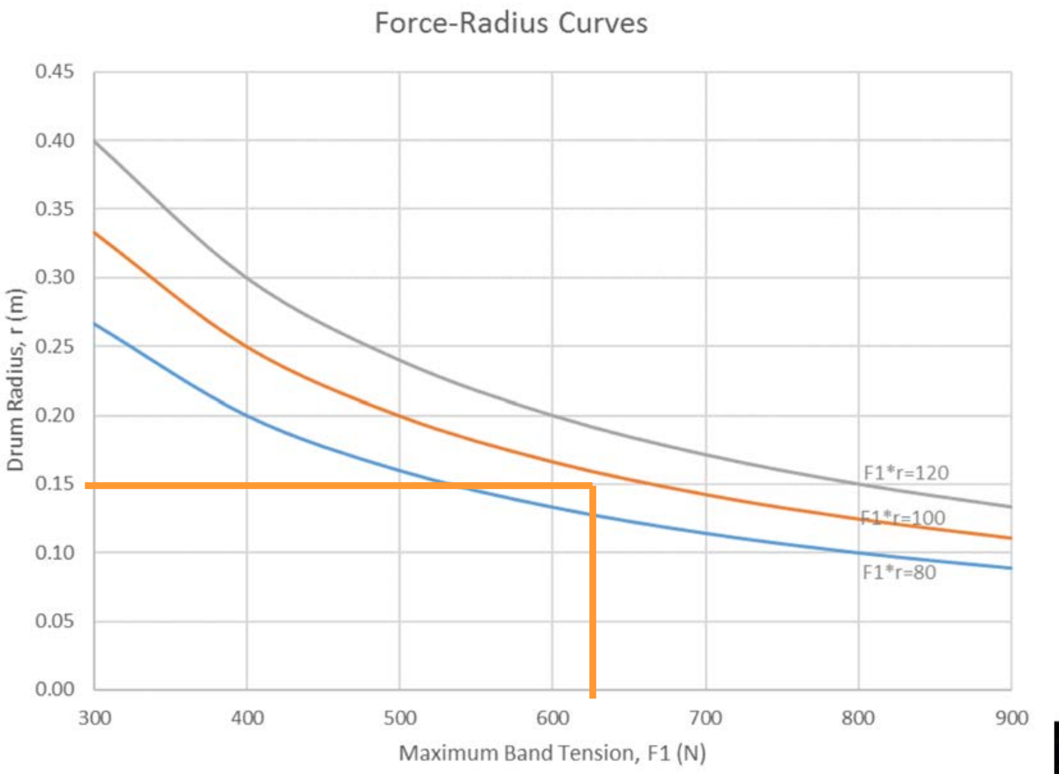


$F_1{*}r$ = 95

A Knowledge-based Approach, cont.

Determine values for F_1 and r.

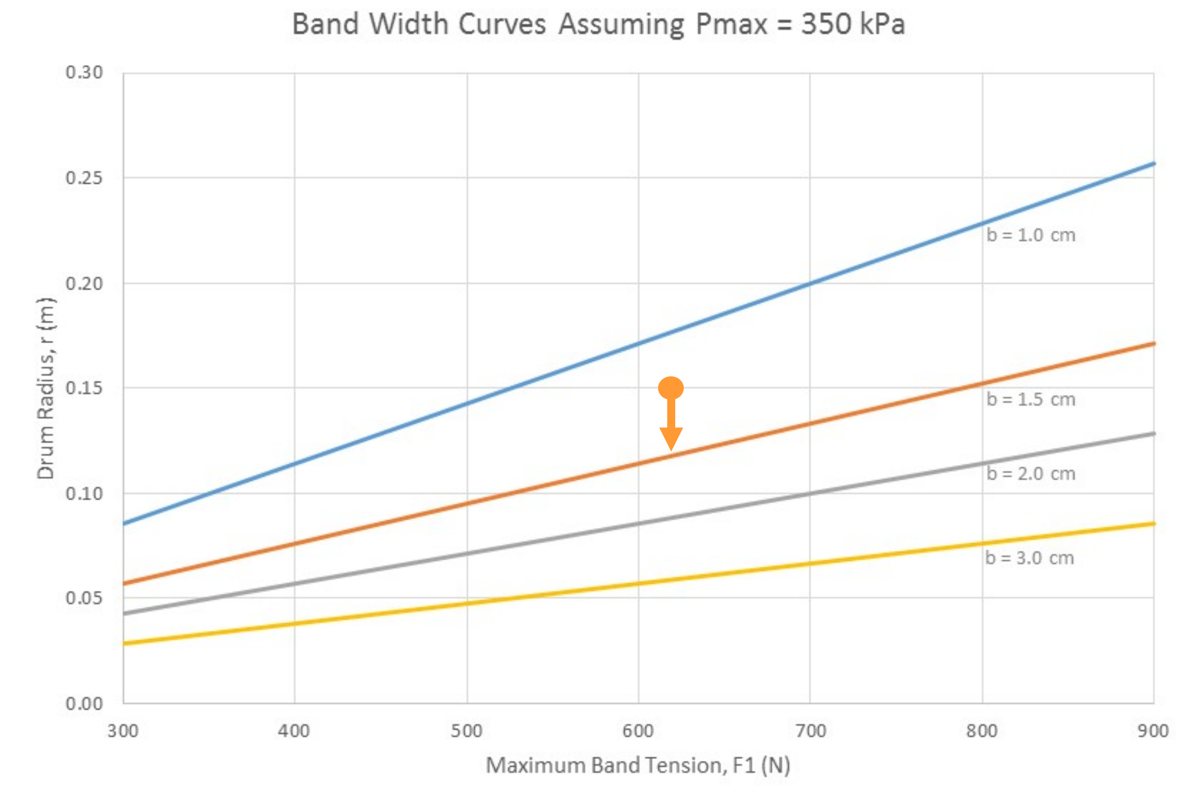
Note: all values on the curve solve this problem!



r = 0.15 m

F_1 = 625 N

A Knowledge Curve Approach, cont.



Plot (F_1, r).

Select b such that (F_1, r) is above its line.

b = 1.5 cm

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Finished!

You've completed the design!

r = 15 cm, α = 260º, b = 1.5 cm, f = 0.40

Now, let's see if the procedure produced a good design….

$$p_{max} = F_1/rb = \frac{625}{0.15 * 0.015} = 278\,kPa$$ **< 350 kPa**

$$F_2 = F_1 e^{-f\propto} = (625)e^{-.4*4.54} = 102N$$

$$M = r(F_1 - F_2) = (.15)(625 - 102) = 78.5Nm$$ → **80 Nm, ±5%.**

Questions…

Which approach is easier? More intuitive?

Which gave you a better understanding of brake dynamics?

What if requirements or constraints changed?

Other observations?

How do you develop visible knowledge?

Allen Ward Procedure

1. State the issue
2. Draw a picture
3. Create a causal diagram
4. Find data and create curves
5. Develop countermeasures

Let's try this together….

Handout

Issue:

Picture of System:

Causal Diagram:

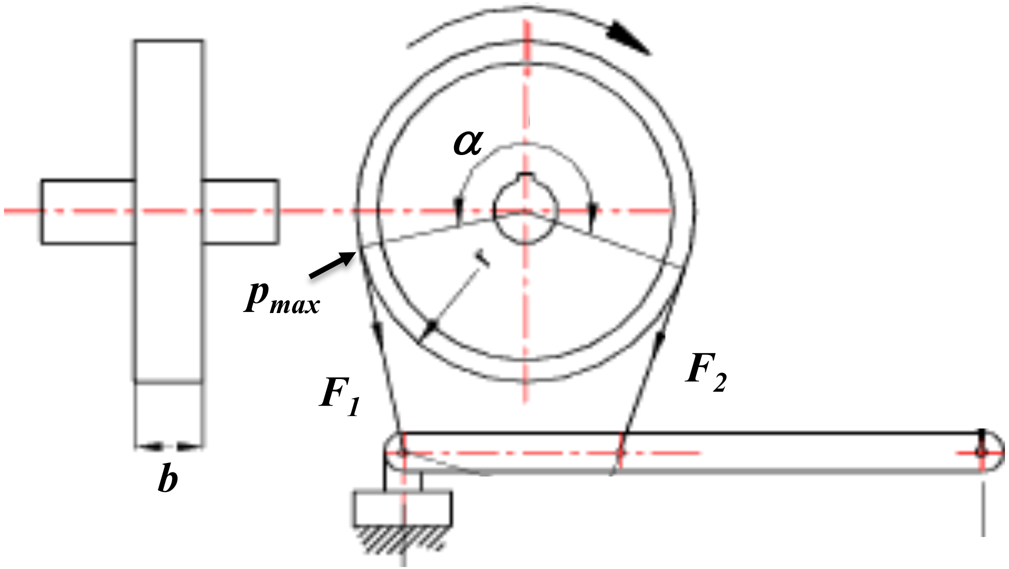
Hypothesized Relationships and Equations:

1. With a partner, state the issue.

Which of these do you like best?

a. Better band brakes.
b. Band brake design for specific braking torque requirement.
c. Braking problems.
d. Woven bands give better braking performance than metallic.

2. Sketch a band brake.



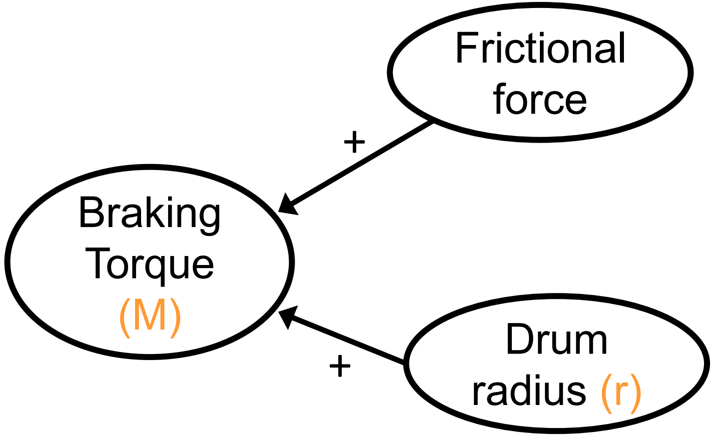
Variables:

- r = drum radius (m)
- α = coverage angle (rad)
- F_1 = max. band tension (N)
- F_2 = min. band tension (N)
- b = band width (m)
- f = band coef. of friction
- p_{max} = max. pressure btn. band and drum (Pa)

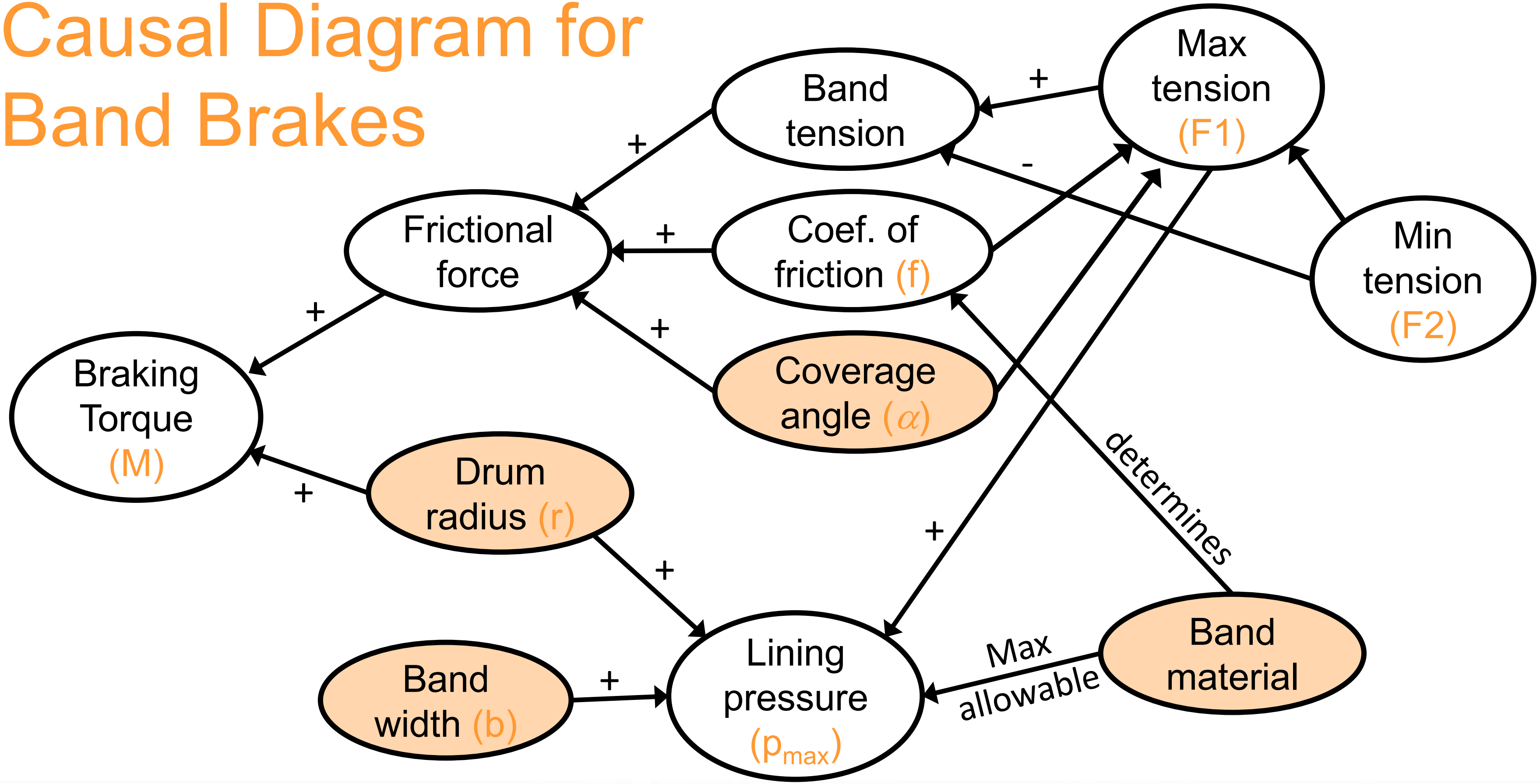
3. Create a causal diagram.

A. On the left, write the result variable we want to influence.
B. Just to the right, write the variables that directly affect that result.
C. Draw arrows that show directionally what affects what.
D. Label arrows with “+” or “-” to show positive or negative relationship.
E. Repeat substeps B-D until you reach variables that are **directly controllable**.

Start of Causal Diagram for Band Brakes



Causal Diagram for Band Brakes



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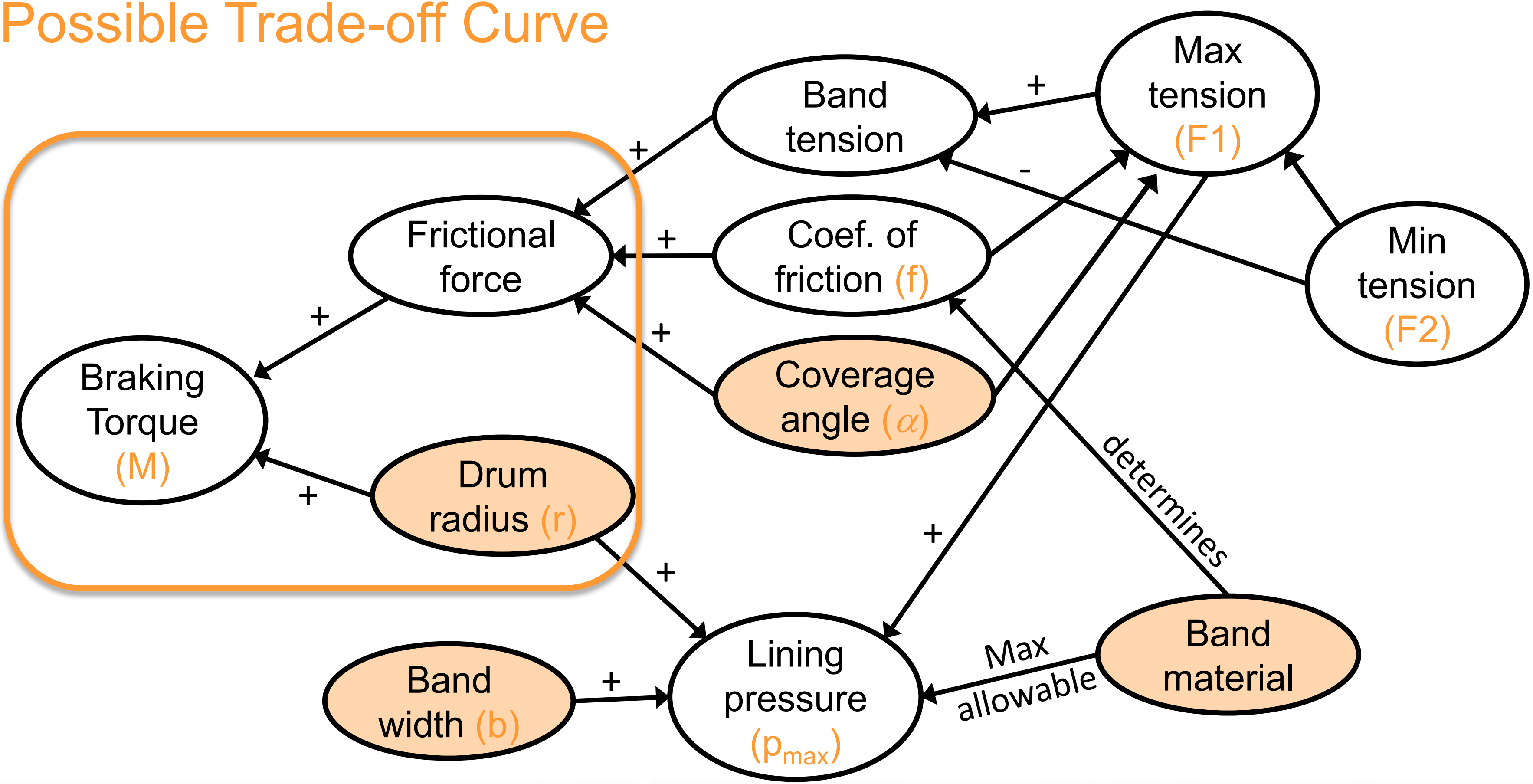
4. Find data and create curves.

A. Identify clusters of variables that we can handle analytically.
B. Hypothesize relationships among the variables graphically.
C. Find or derive equations relating the variables.
D. Combine equations into compact, generalized parameters.
E. Input parameter values over appropriate ranges and plot curves.

In place of C, D and E you may be able to use historical data or conduct a designed experiment (virtual or physical).

Possible Trade-off Curve



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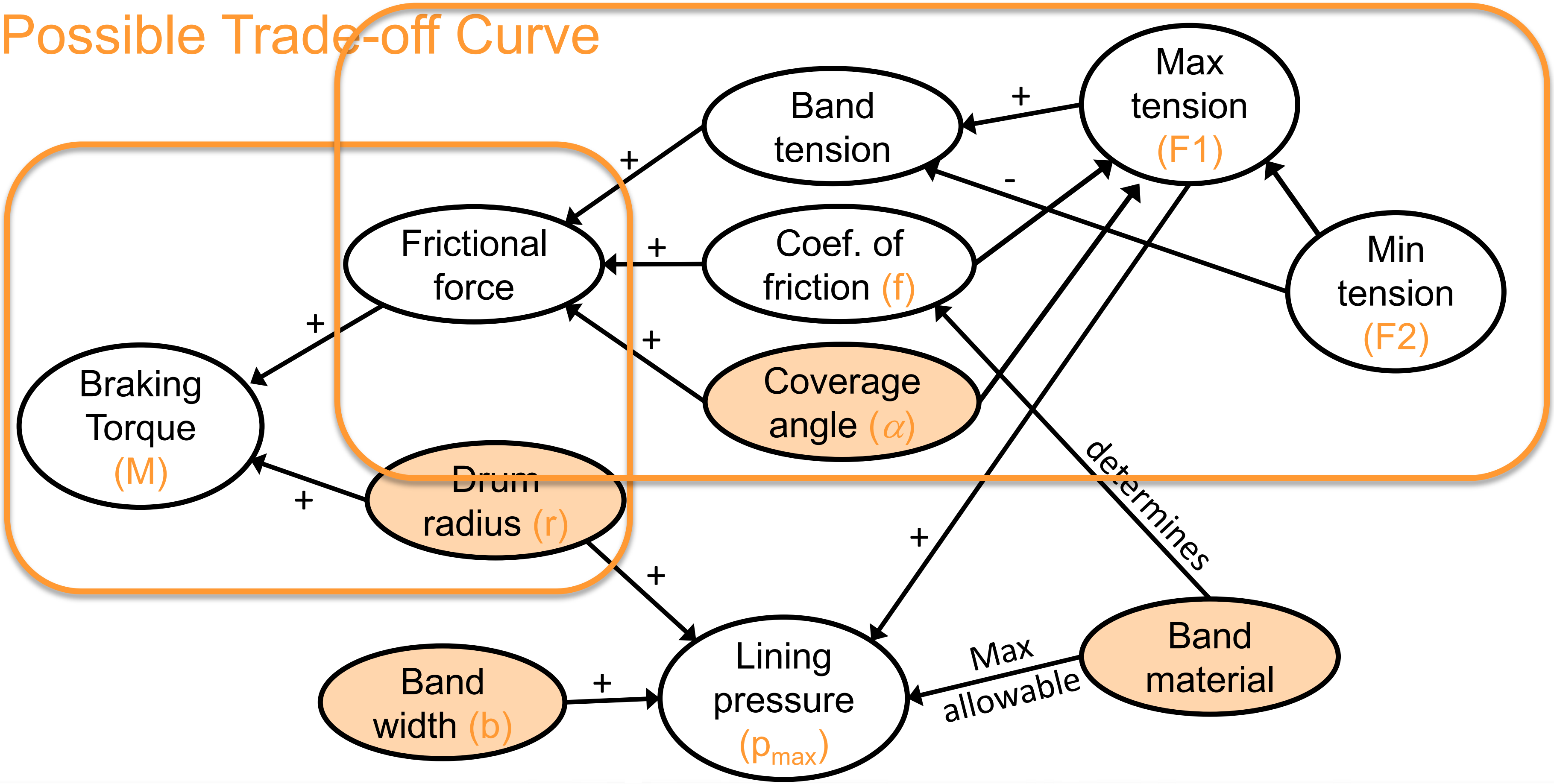

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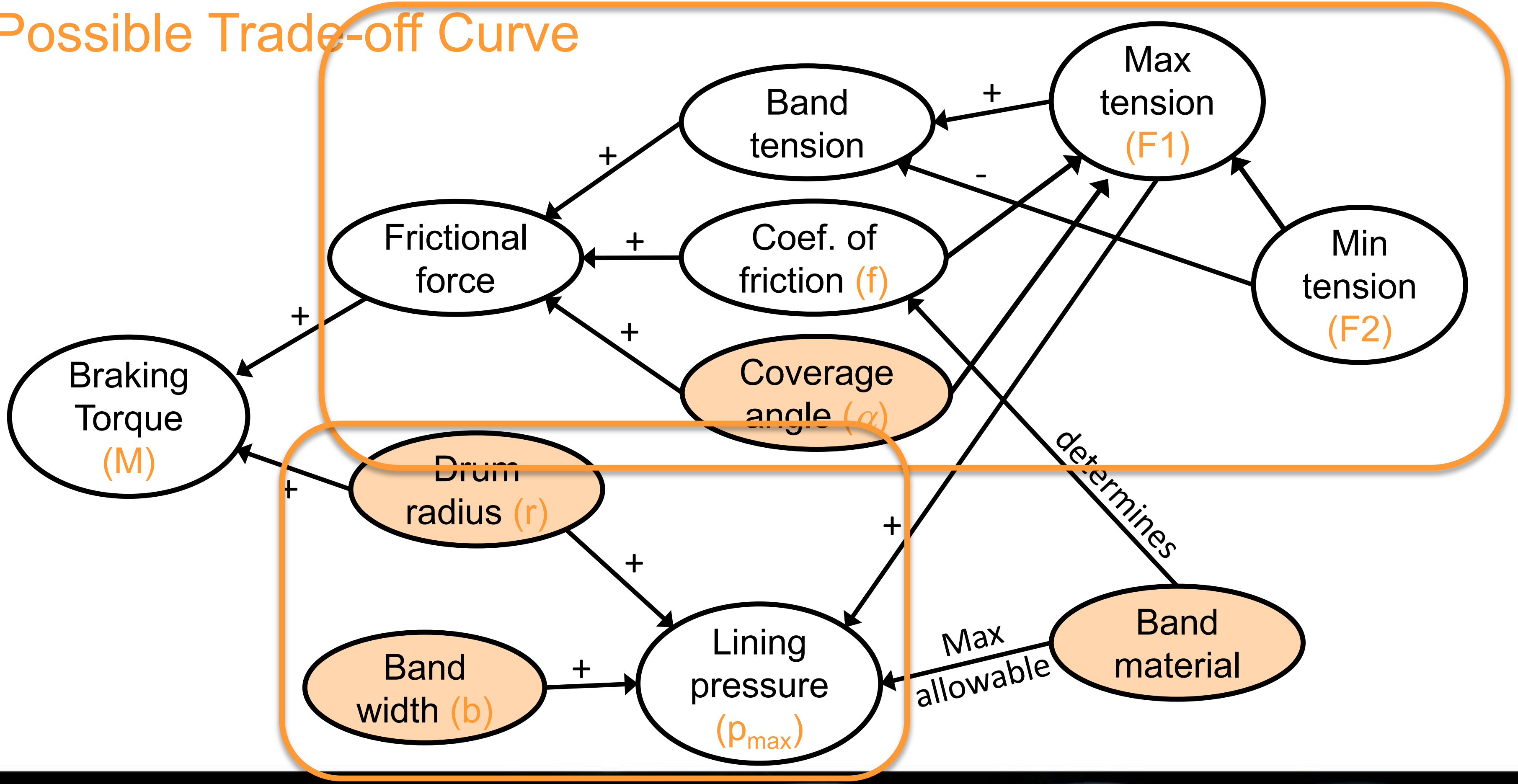
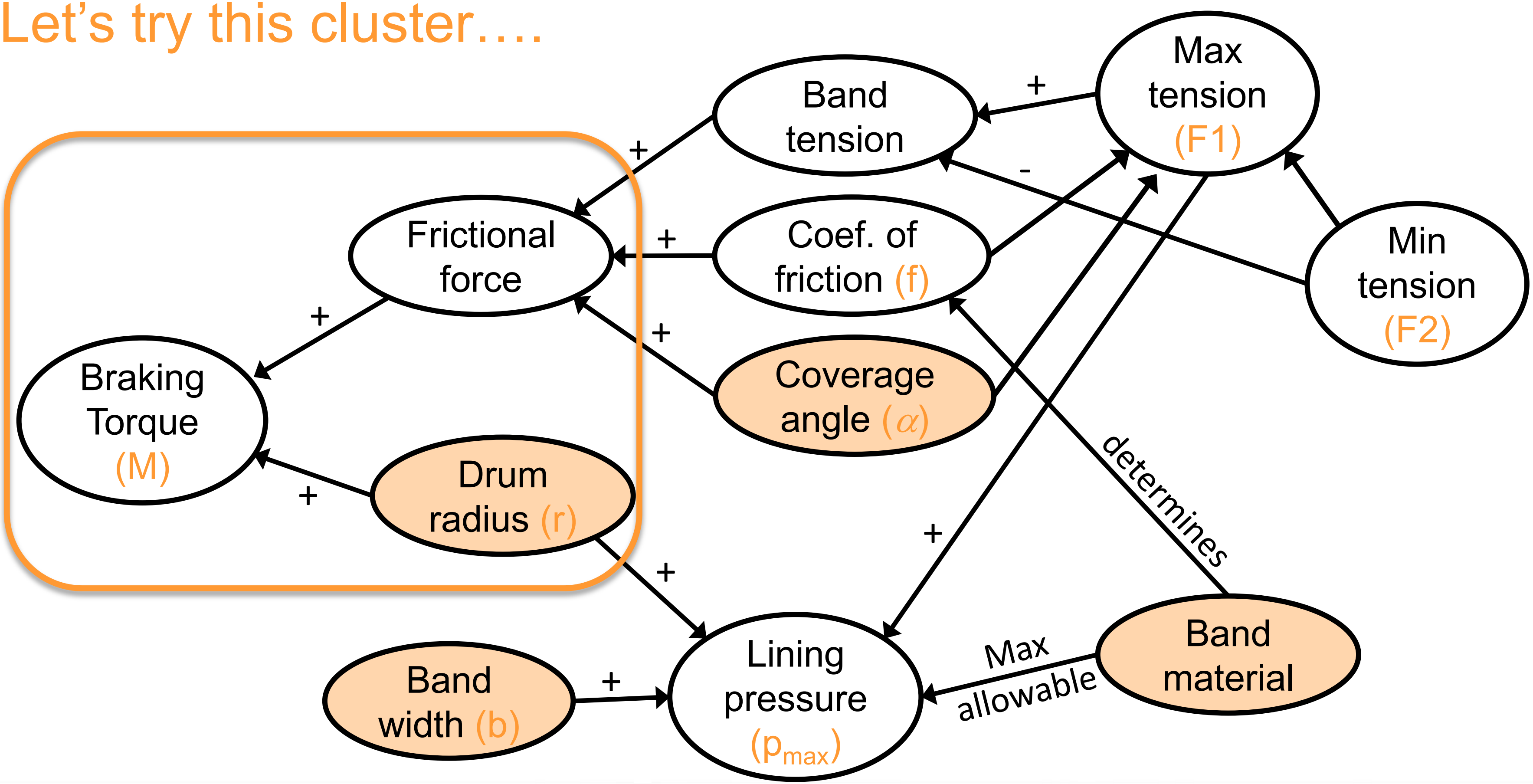
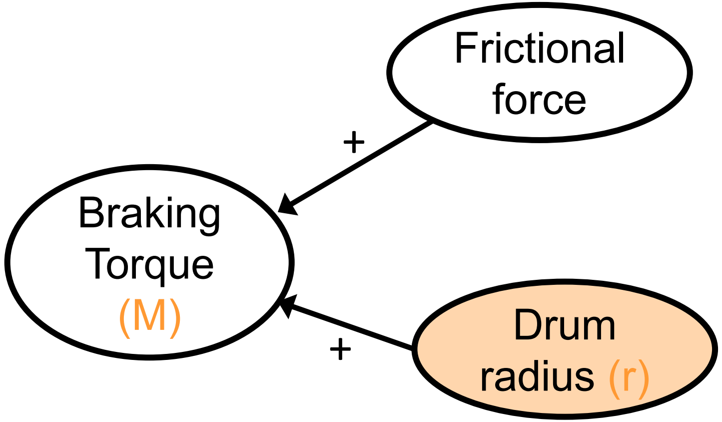


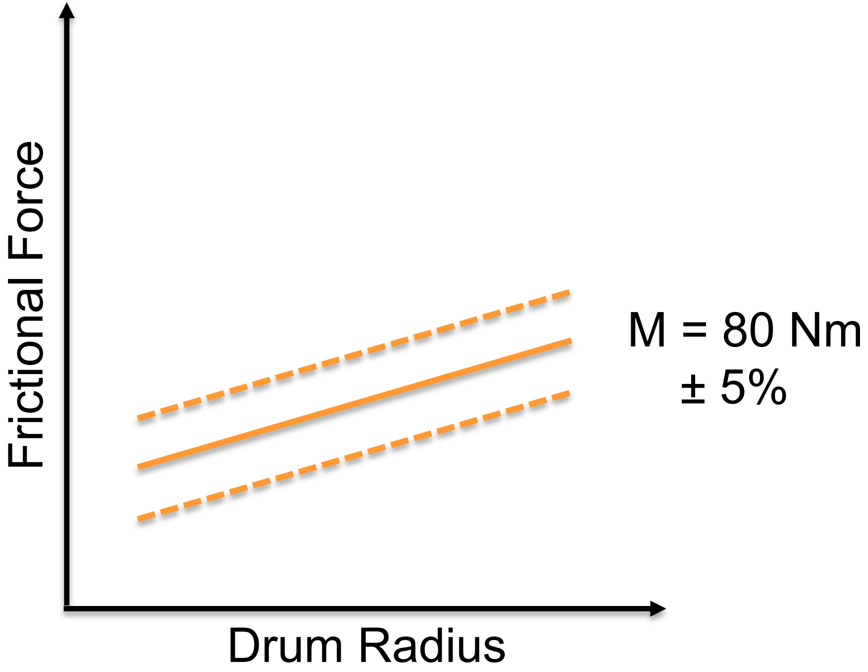
Let's try this cluster….



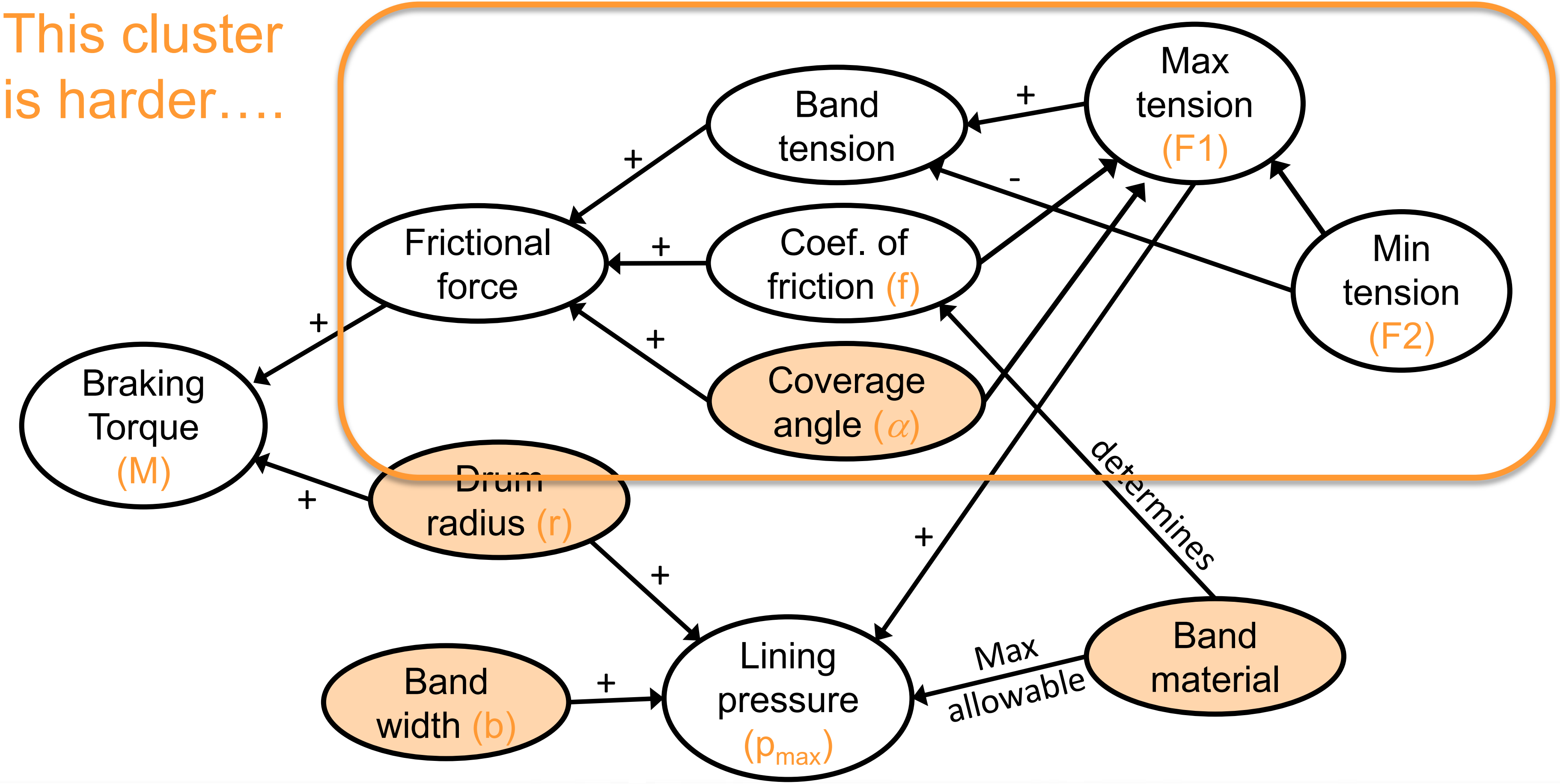
Hypothesize relationship



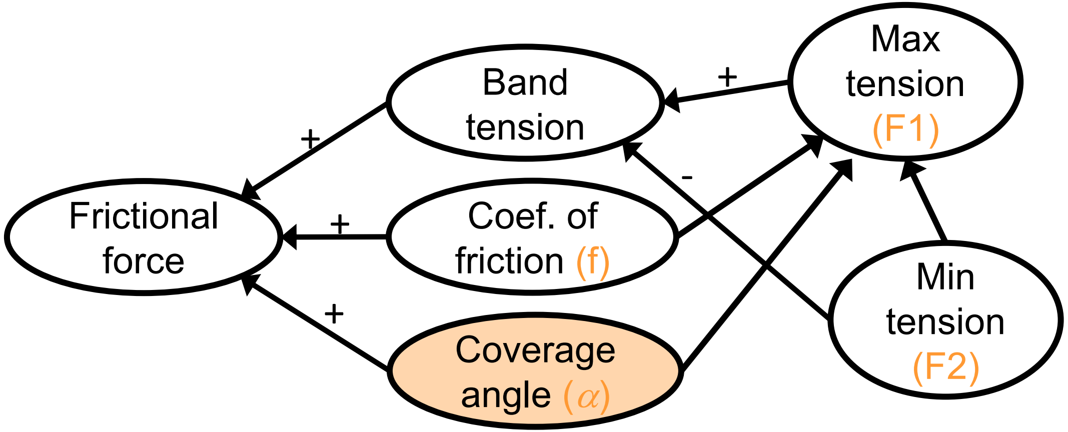
$$M = (Frictional\ force)r$$



This cluster is harder….



Hypothesize these relationships…



$$Frictional\ force = F_1 - F_2$$

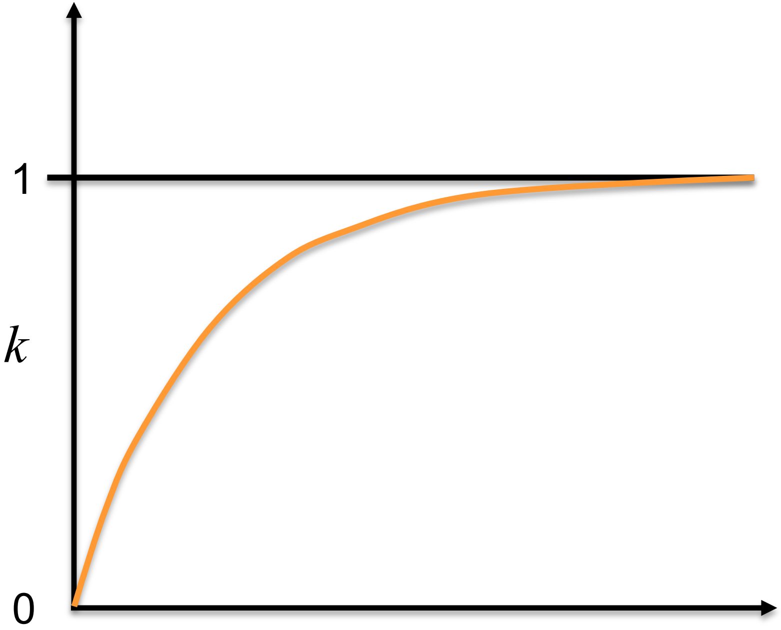
$$F_2 = F_1 e^{-f\propto}$$

$$Frictional\ force = F_1 - F_1 e^{-f\propto}$$

$$Frictional\ force = F_1\left(1 - e^{-f\propto}\right) = F_1 k$$

What does trade-off curve for *k* look like?

$$k = \left(1 - e^{-f\propto}\right)$$



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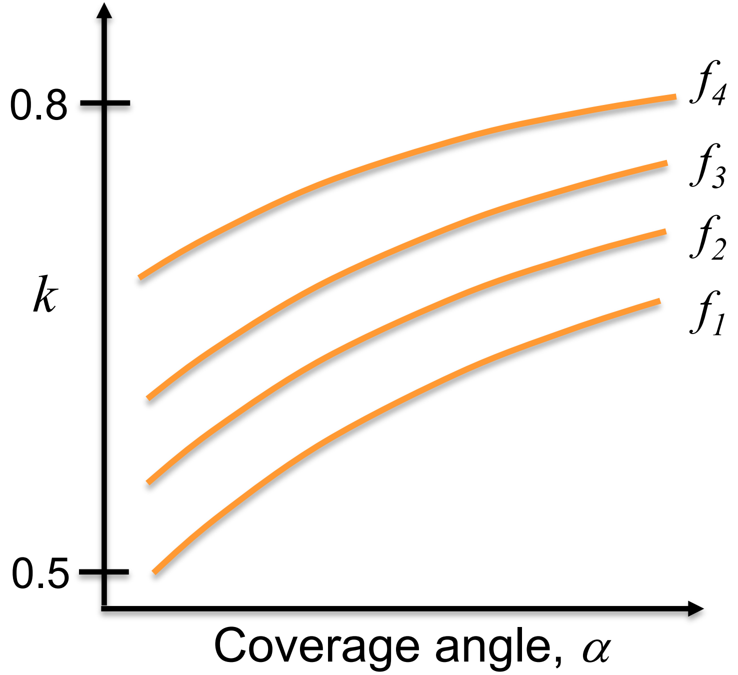
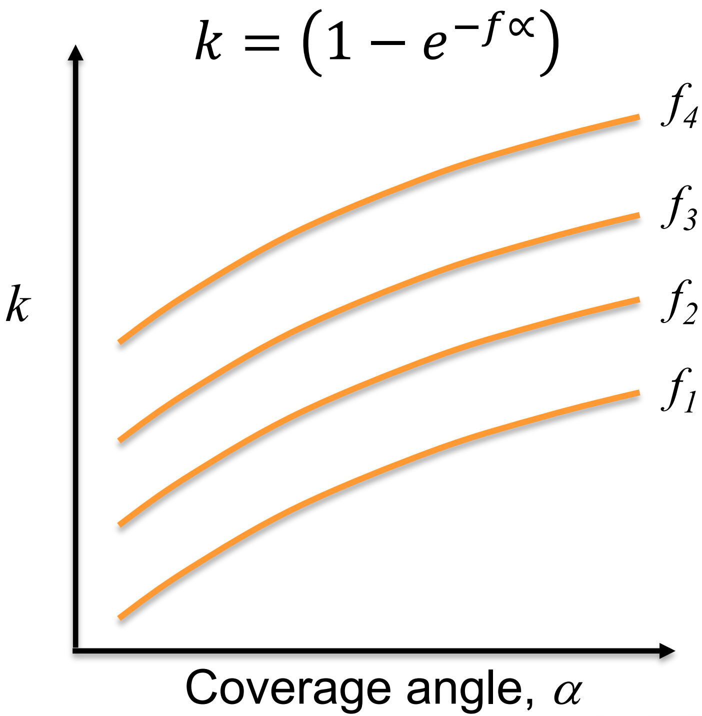
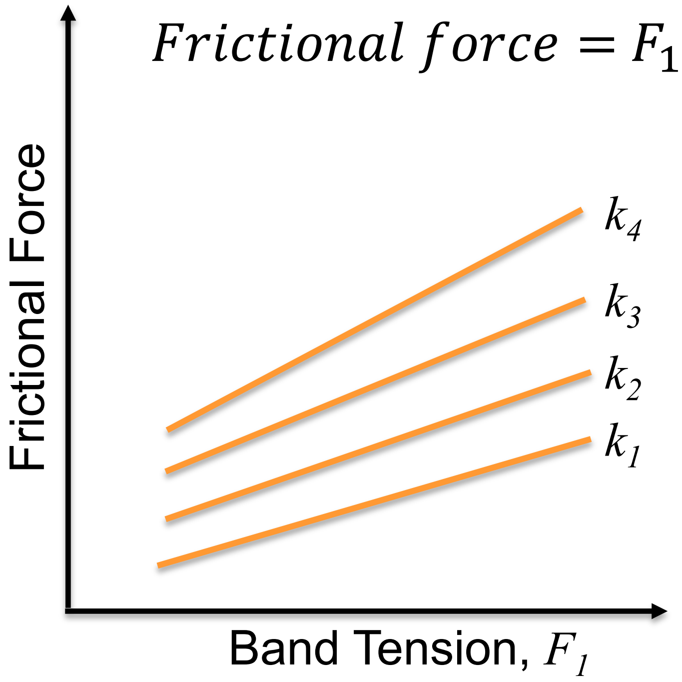
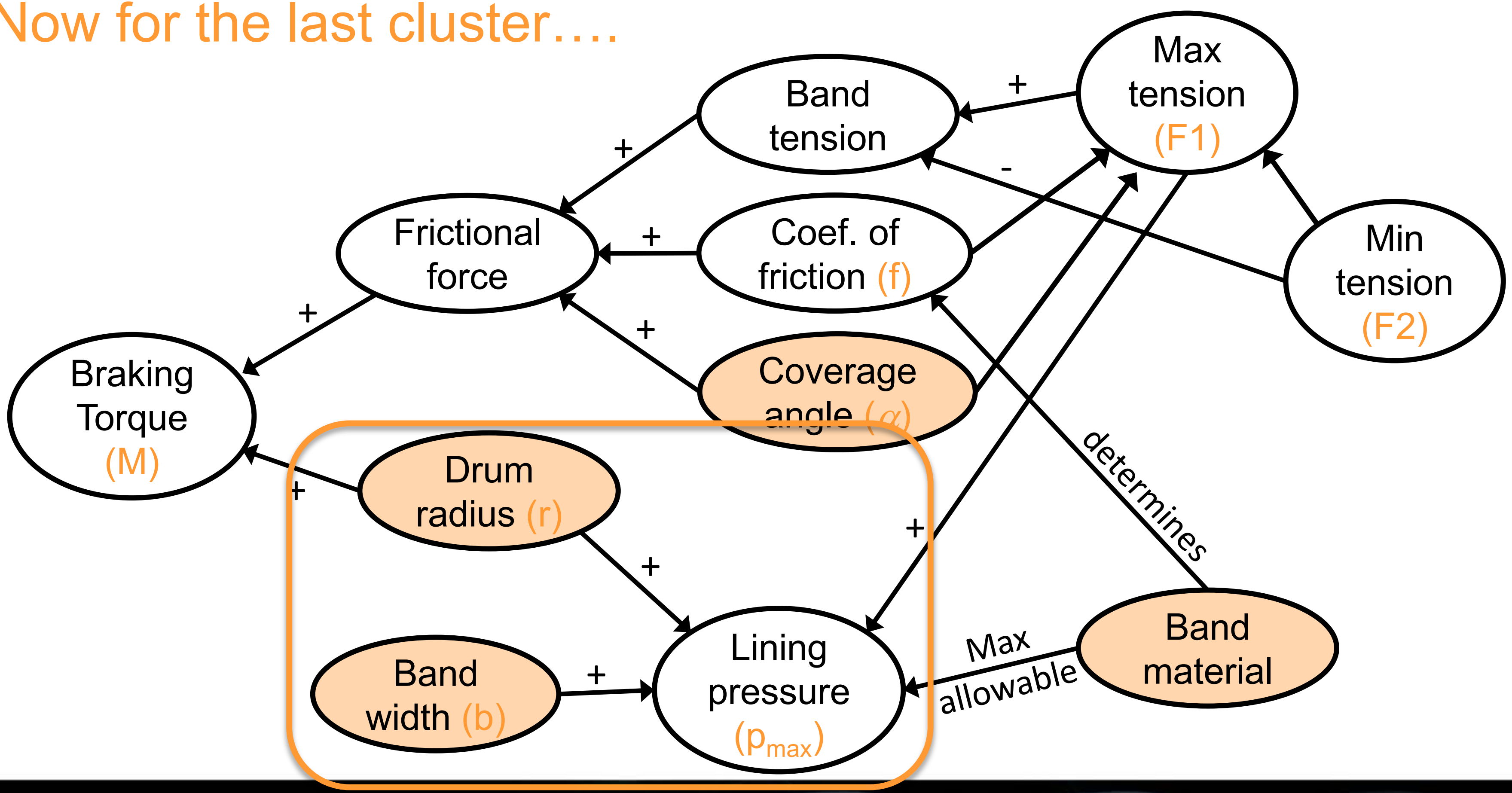


How about for frictional force and band tension?

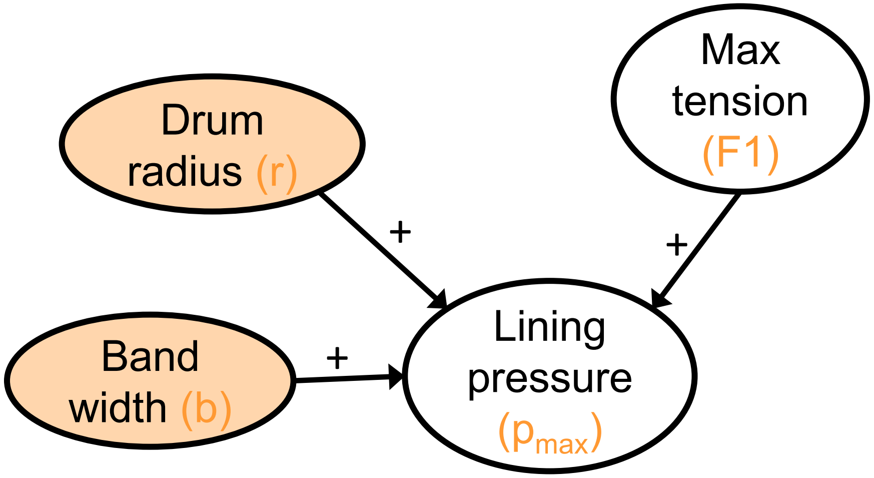




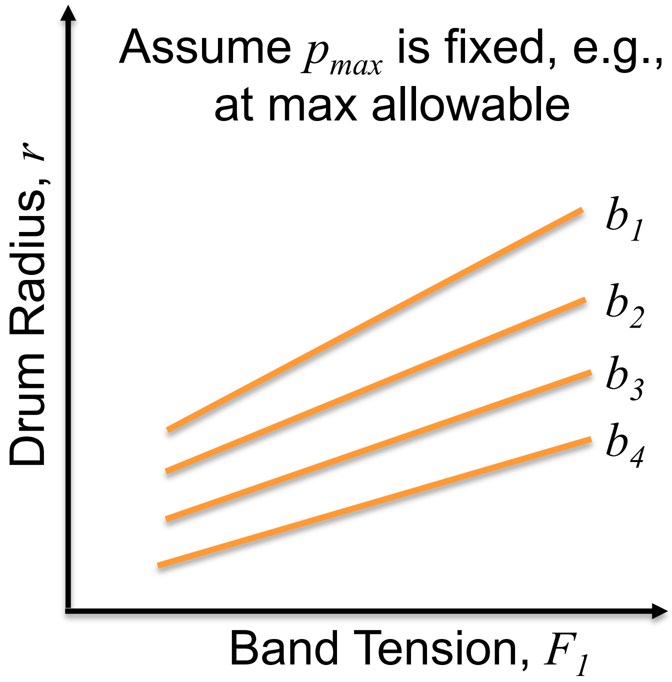
Now for the last cluster….



How about these relationships?



$$F_1 = rbp_{max}$$



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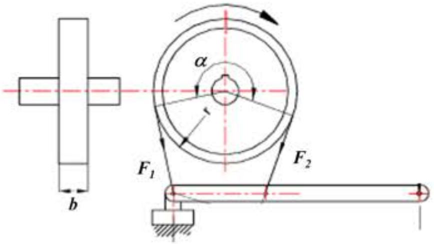
By: D. Sobek, dsobek@montana.edu Date: 19 June 2018

Issue:

Band brake design for specific braking torque requirement

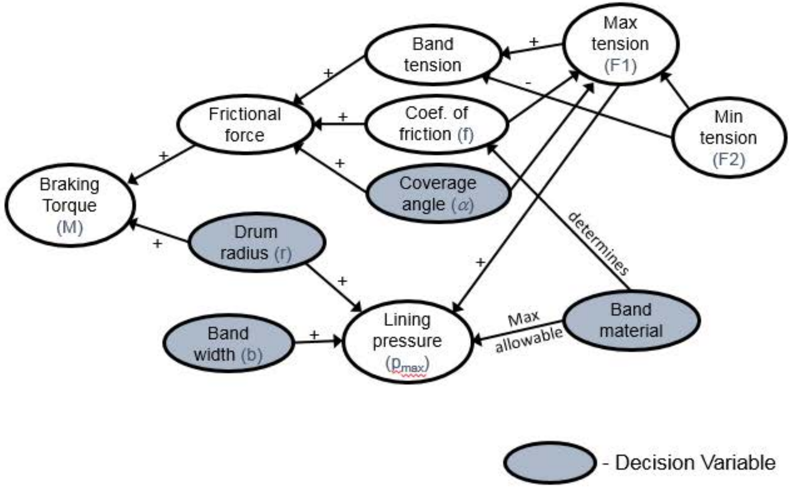
Picture of System:



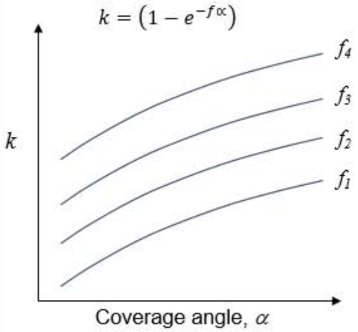
Variables:

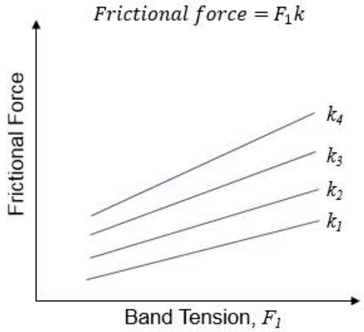
- r = drum radius (m)
- α = coverage angle (rad)
- F_1 = max. band tension (N)
- F_2 = min. band tension (N)
- b = band width (m)
- f = band coef. of friction

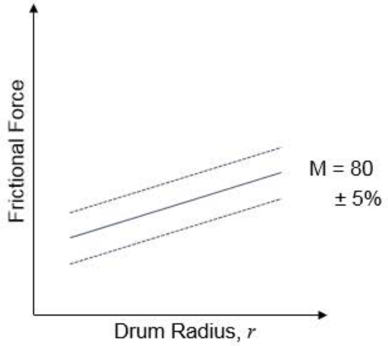
Causal Diagram:

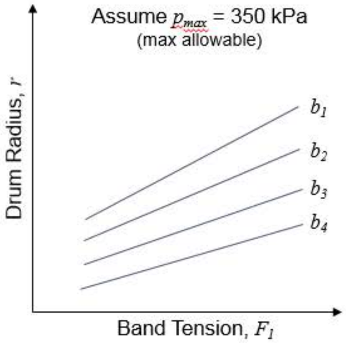


Hypothesized Relationships and Equations:









Wrap-up

Key Points

- Knowledge is a central theme within LPPD.
- Conventional "iterative" development is slow with uncertain outcome.
- Building knowledge early, before detailed design, speeds development and increases innovation.
  - Eliminates iteration from guess-and-check.
- Visible knowledge maps out the possibilities, finds the limits, and makes learning reusable.

What are your key learnings?