Leaning The Right Way

EAA AIRVENTURE OSHKOSH 2021

SAVVY

Your presenter…

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National Aviation Maintenance Technician of the Year (2008)

President — Savvy Aviation, Inc.

Mo 1000 #7	The EGT Myth
Mo 1300 #7	How Healthy Is Your Engine?
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Tu 1000 #7	Leaning The Right Way
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We 0830 #7	Cylinder Break-In: Do It Right
We 1130 #7	What Is Preventive Maintenance?
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Fr 1300 #7	Benefits of Running Oversquare
Sa 1000 #7	How Mags Work…and Fail
Sa 1300 #7	Predictive Maintenance

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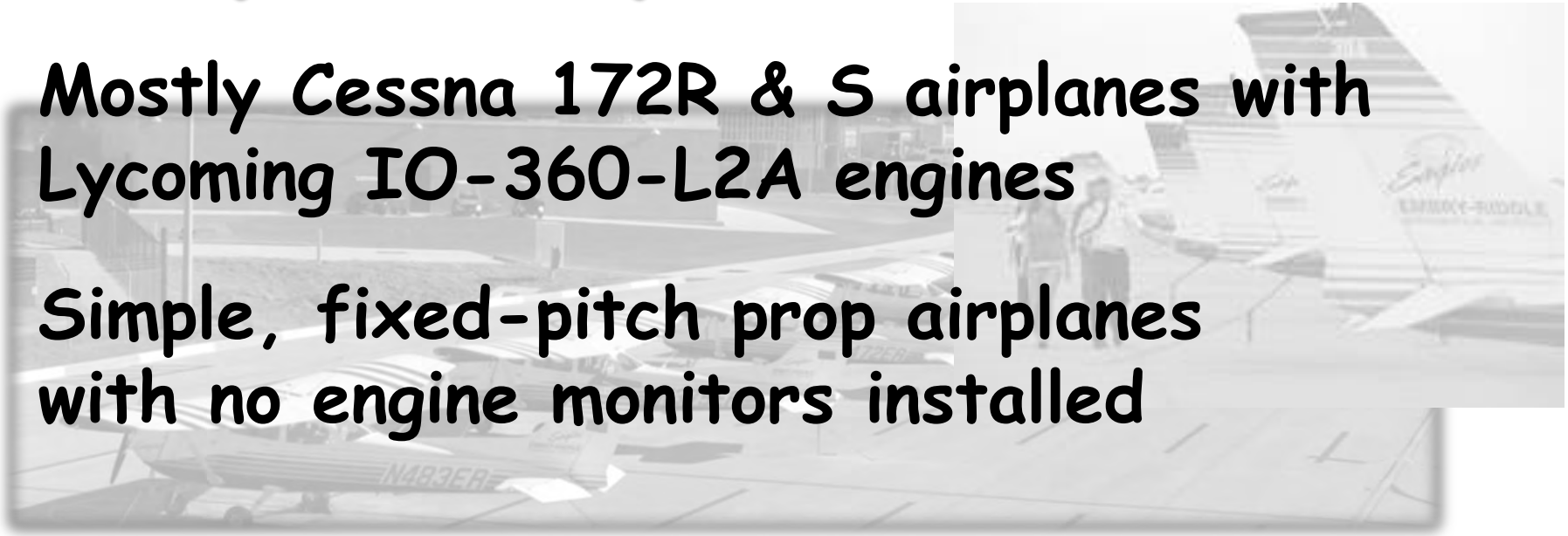
World's largest fleet of primary trainers



Mostly Cessna 172R & S airplanes with Lycoming IO-360-L2A engines

Simple, fixed-pitch prop airplanes with no engine monitors installed

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EAA AIRVENTURE OSHKOSH 2021 Savvy

ERAU CFIs were generally taught not to distract primary students with mixture management, and to leave the red knob alone except above 5,000'.

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY

EAA AIRVENTURE OSHKOSH 2021 Savvy

In winter 1998-99, EARU grounded most of its Cessna 172R & S fleet when the airplanes were plagued by:

- Engine hesitations
- Rough running engines
- Fouled spark plugs

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY

EAA AIRVENTURE OSHKOSH 2021 SAVVY

Cessna & Lycoming came to investigate, and discovered that the instructors and students were running the engines **waaay too rich!**

Cessna

POWERED BY LYCOMING

TEXTRON Lycoming

Lycoming Service Instruction #1497

- Minimum prime during engine start
- Lean to max RPM during ground ops (including run-up)
- Lean during all climbs above 3,000'
- Lean during cruise at all altitudes

In other words,

lean at all times

except:

- **Engine start**
- **Takeoff**
  (at density altitudes below 3,000')

A minimal leaning checklist

Full-rich mixture should be used only for cold-starting and max-power operation…

…and then only for a minute or two at most

For all ground ops including preflight runup **lean for maximum RPM…**

…max RPM gives you best-power mixture

For takeoff and climb <u>below</u> 3,000' density alt., operate full-rich…

…this assumes a fixed-pitch prop

For takeoff and/or climb <u>above</u> 3,000' density alt., **lean for maximum RPM…**

…this assumes a fixed-pitch prop

For cruise at any altitude, lean to the onset of engine roughness, then richen just barely enough to restore smooth operation

In Summary…

- **Full-rich:** only for start and takeoff
- **Ground ops:** lean for max RPM
- **Takeoff below 3000':** full-rich
- **Takeoff above 3000':** lean for max RPM
- **Climb above 3000':** lean for max RPM
- **Cruise:** lean to onset of roughness

Why full-rich is WAAAY TOO rich

Why full-rich is WAAAY TOO rich

A horrendously rich mixture is necessary…

- …so the engine can be started cold (because aircraft engines don't have a choke)
- …to obtain adequate detonation margin during full-power operation (takeoff)

Why full-rich is WAAAY TOO rich

Using full-rich mixture in any other context is like forgetting to push in the choke on your antique car (or modern lawnmower)

Thought experiment…

Drop a burning match in a pail of gasoline.

The match goes out.

(Too rich to burn. "Flooded.")

Thought experiment…

Saturate a rag and drop a burning match on the rag.

Presto, it burns!

(Not intense, dirty.)

Thought experiment…

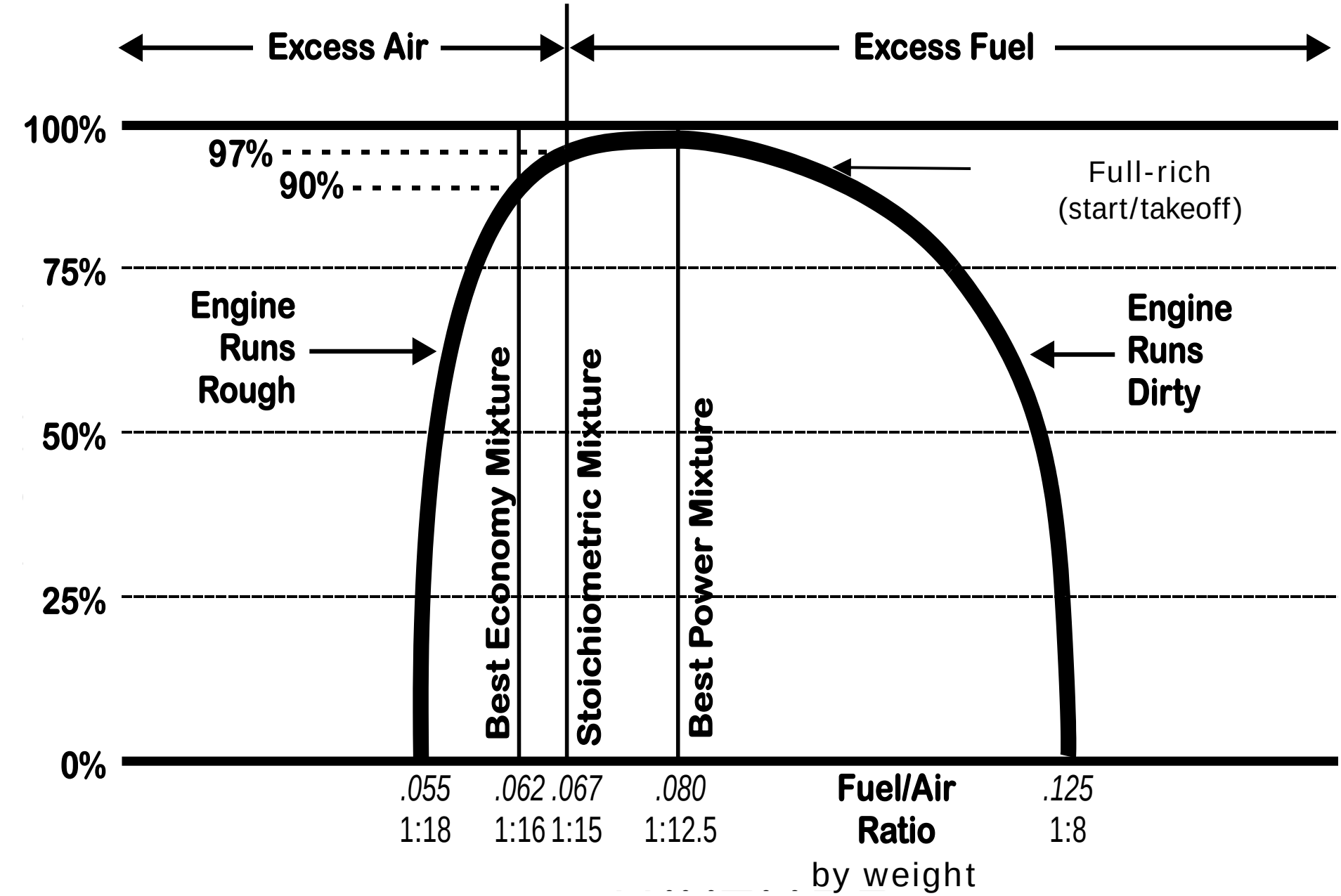
Blow air on the rag ("fan the flames")

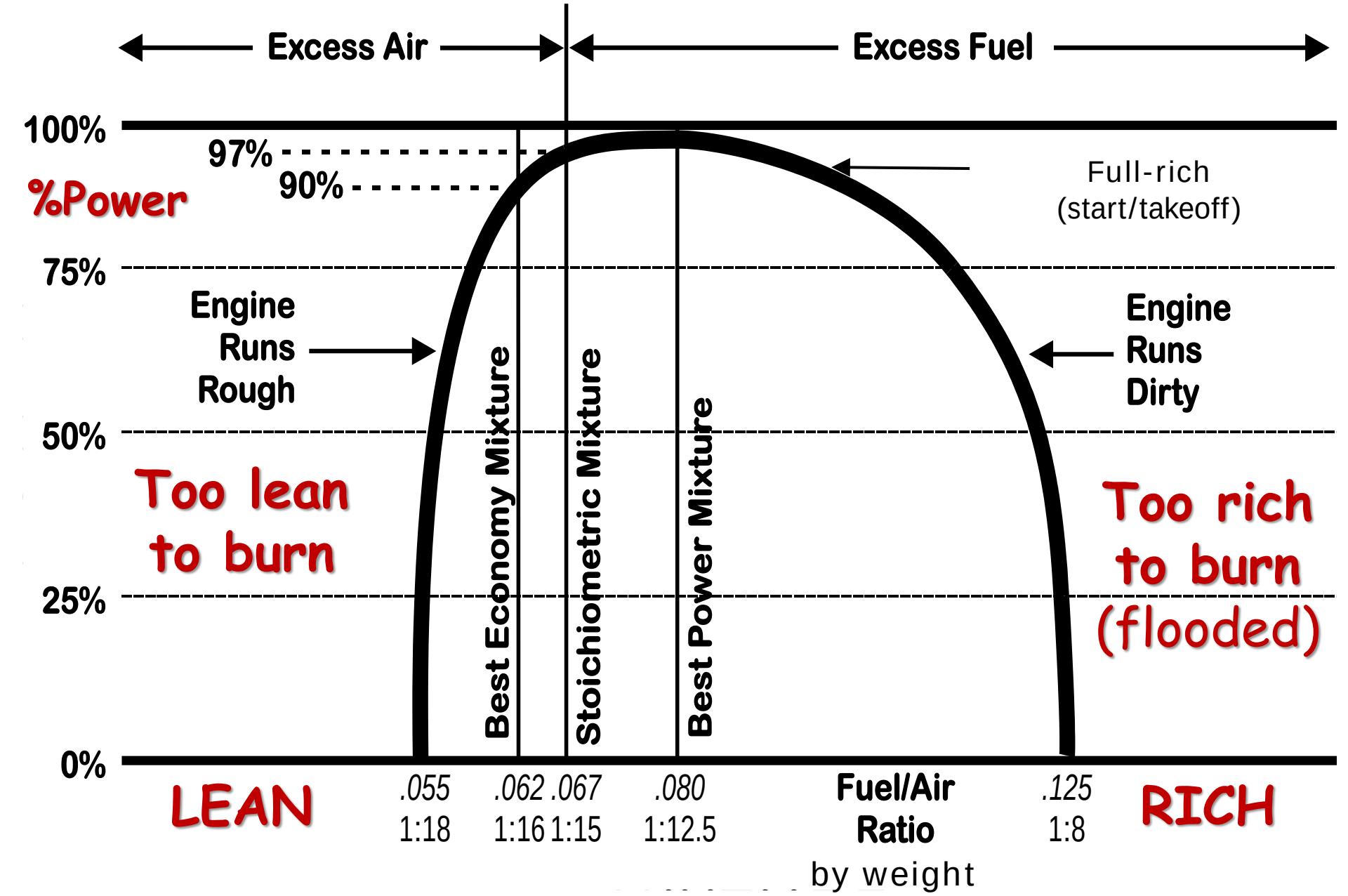
Combustion is much more intense, and much cleaner.

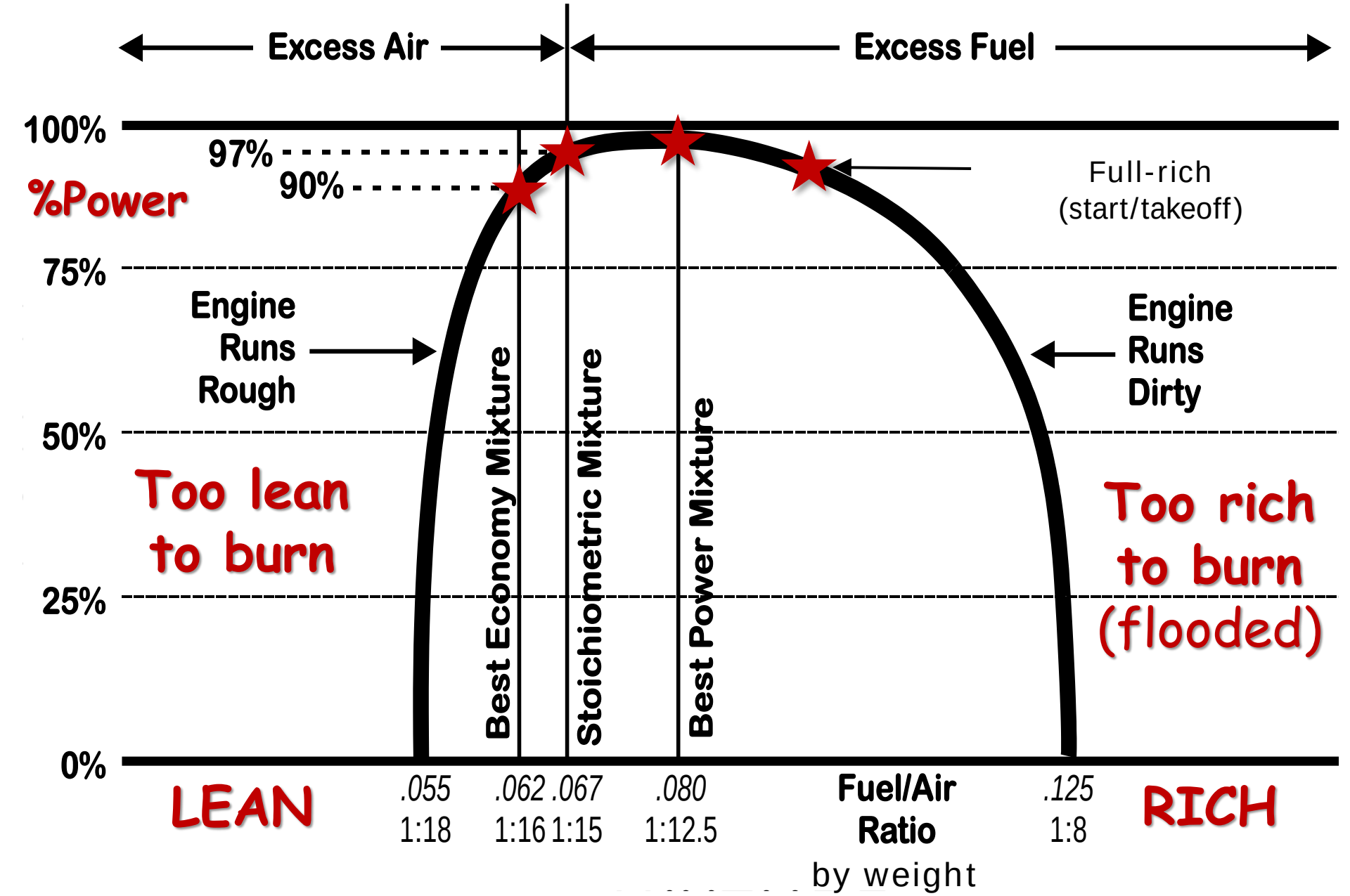
Thought experiment…

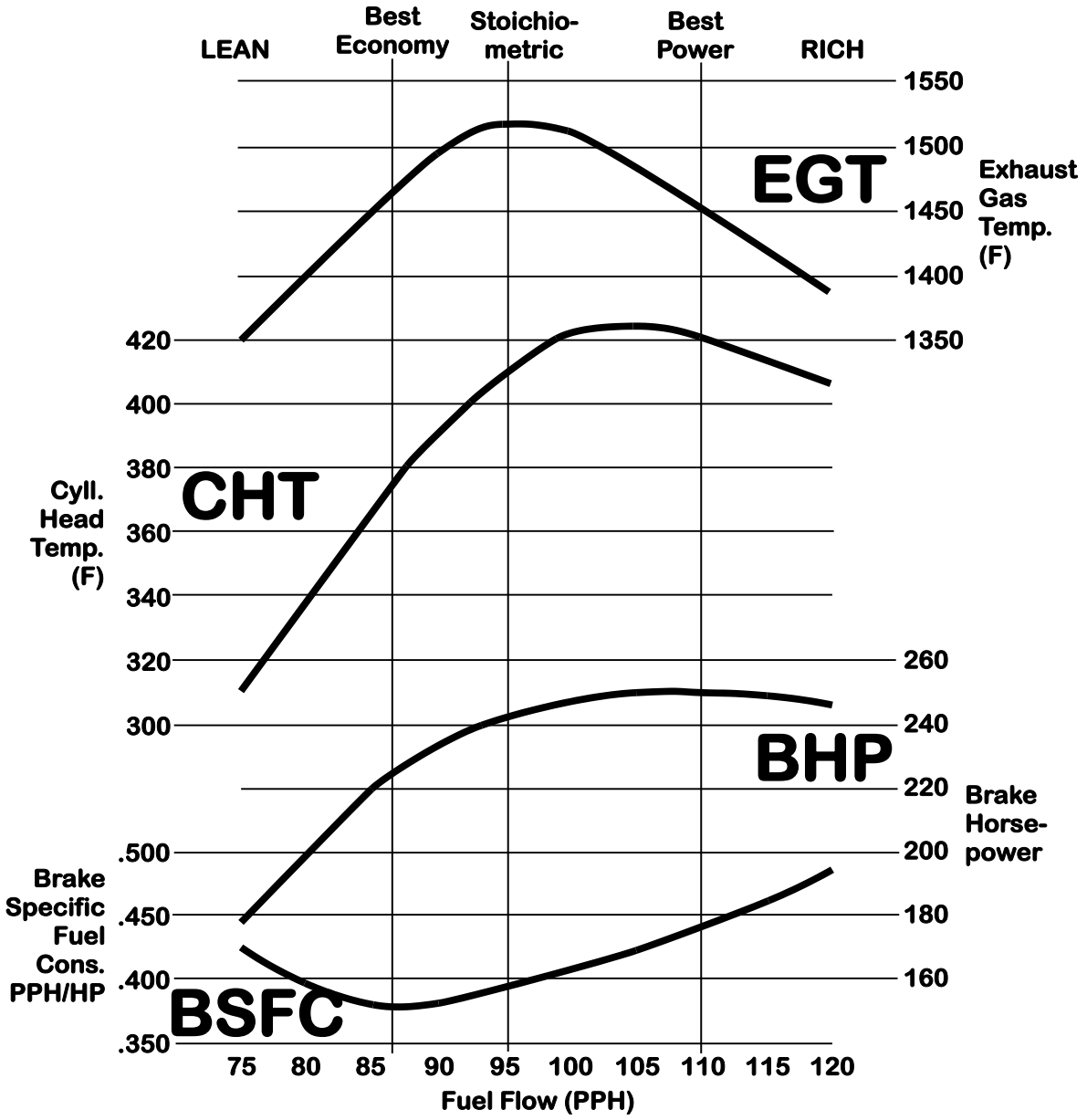
Best to light the rag first, then turn on the fan.

(We need a rich mixture for starting.)



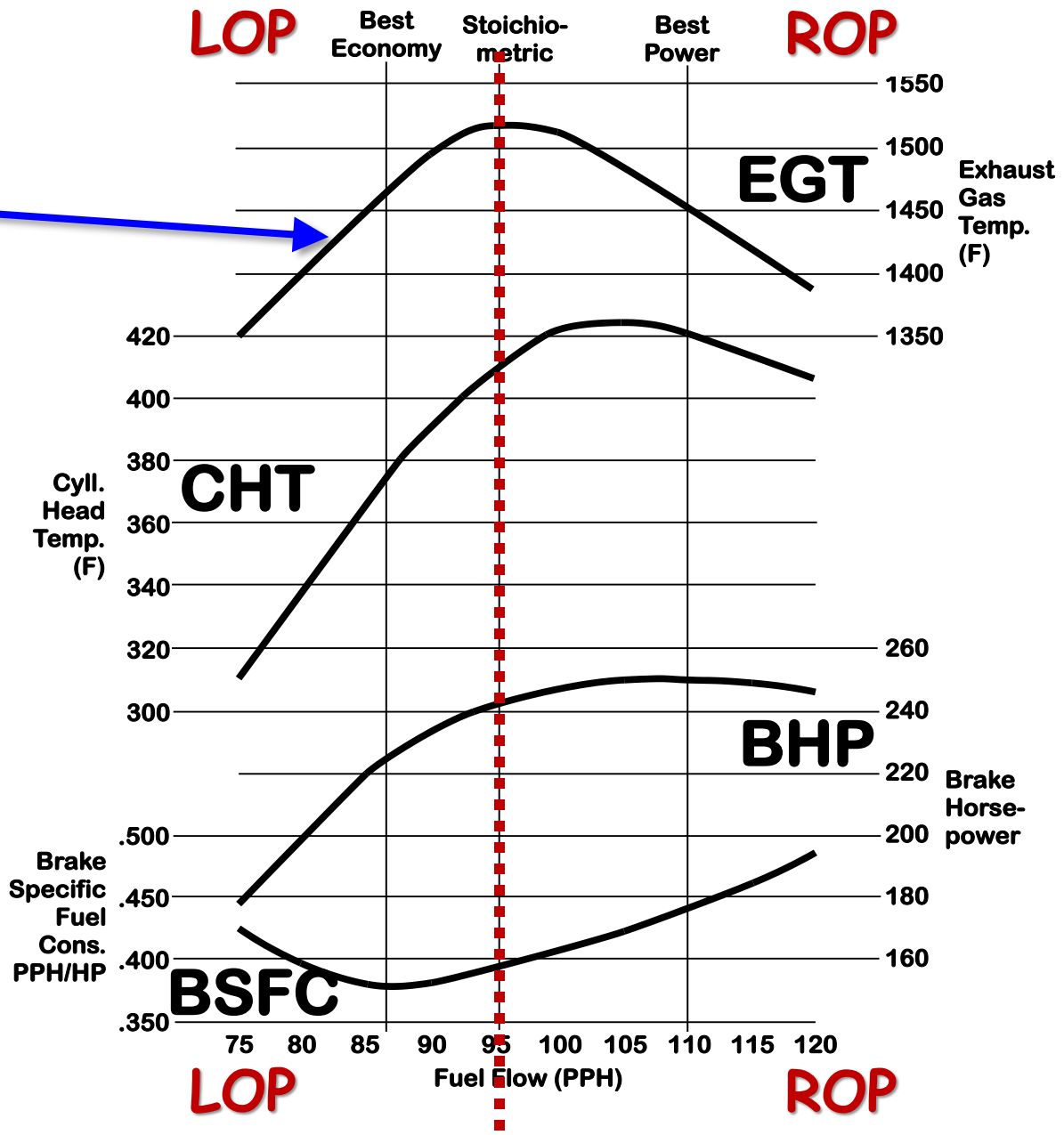






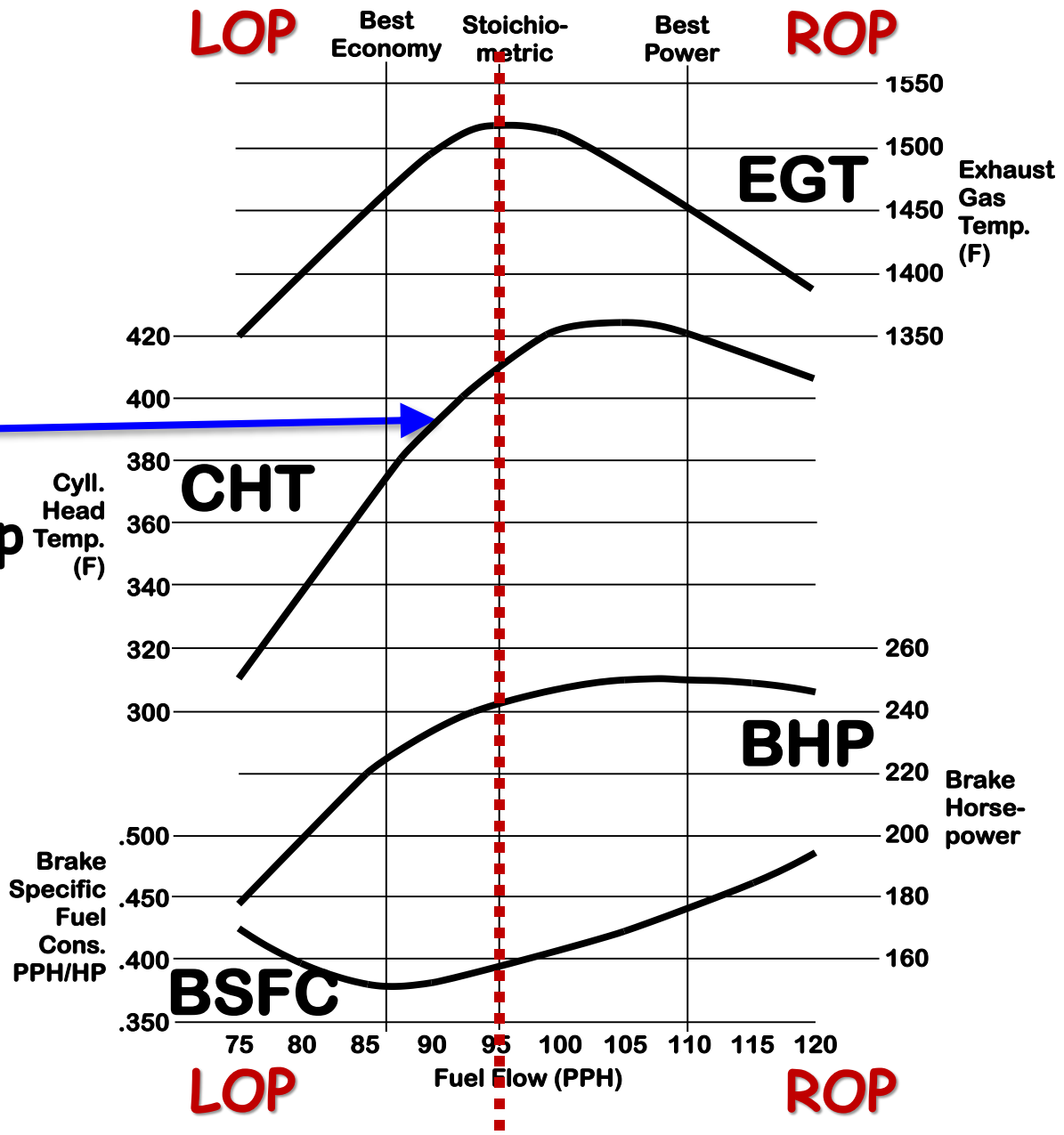
EGT

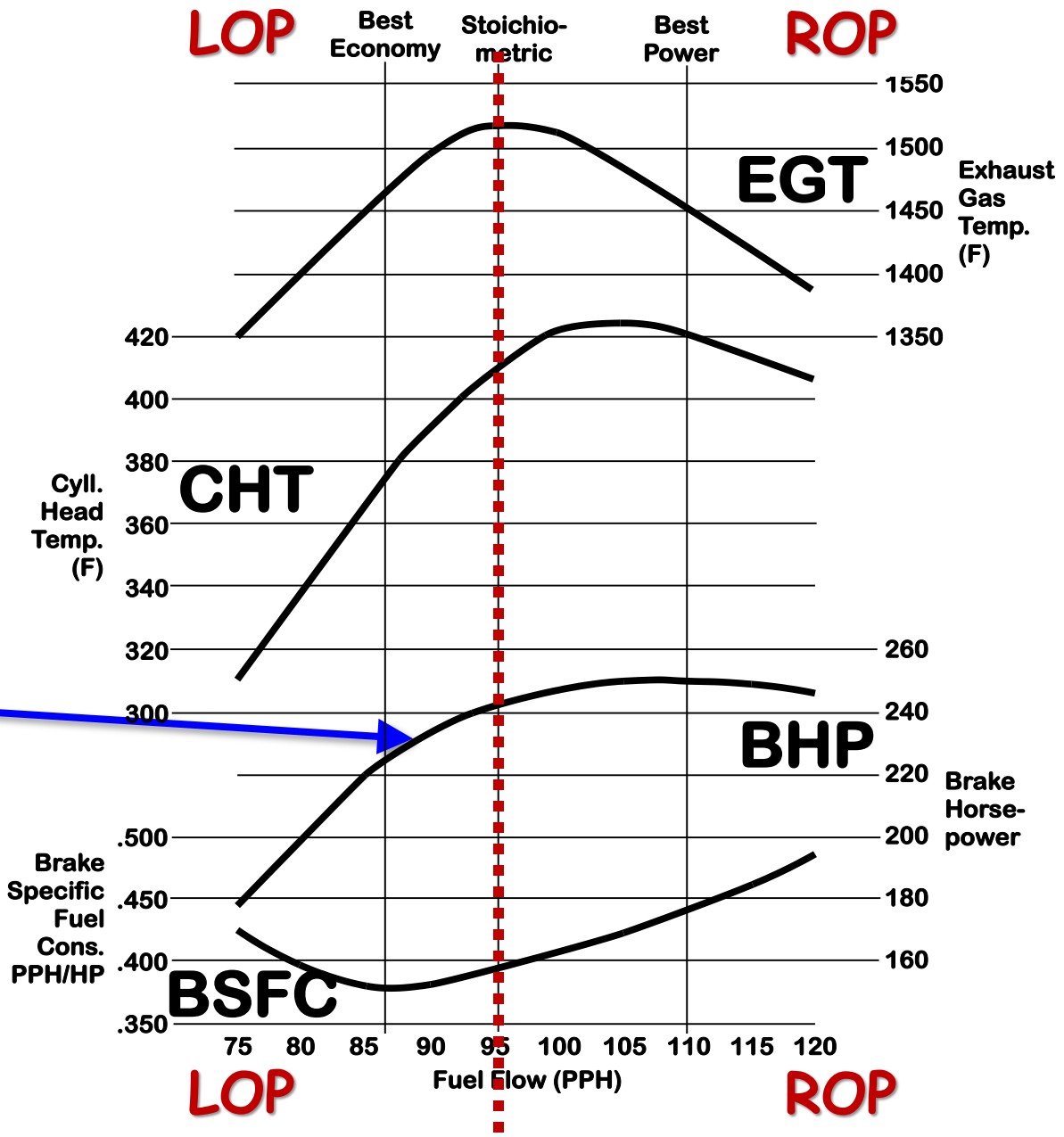
Exhaust gas temp



CHT

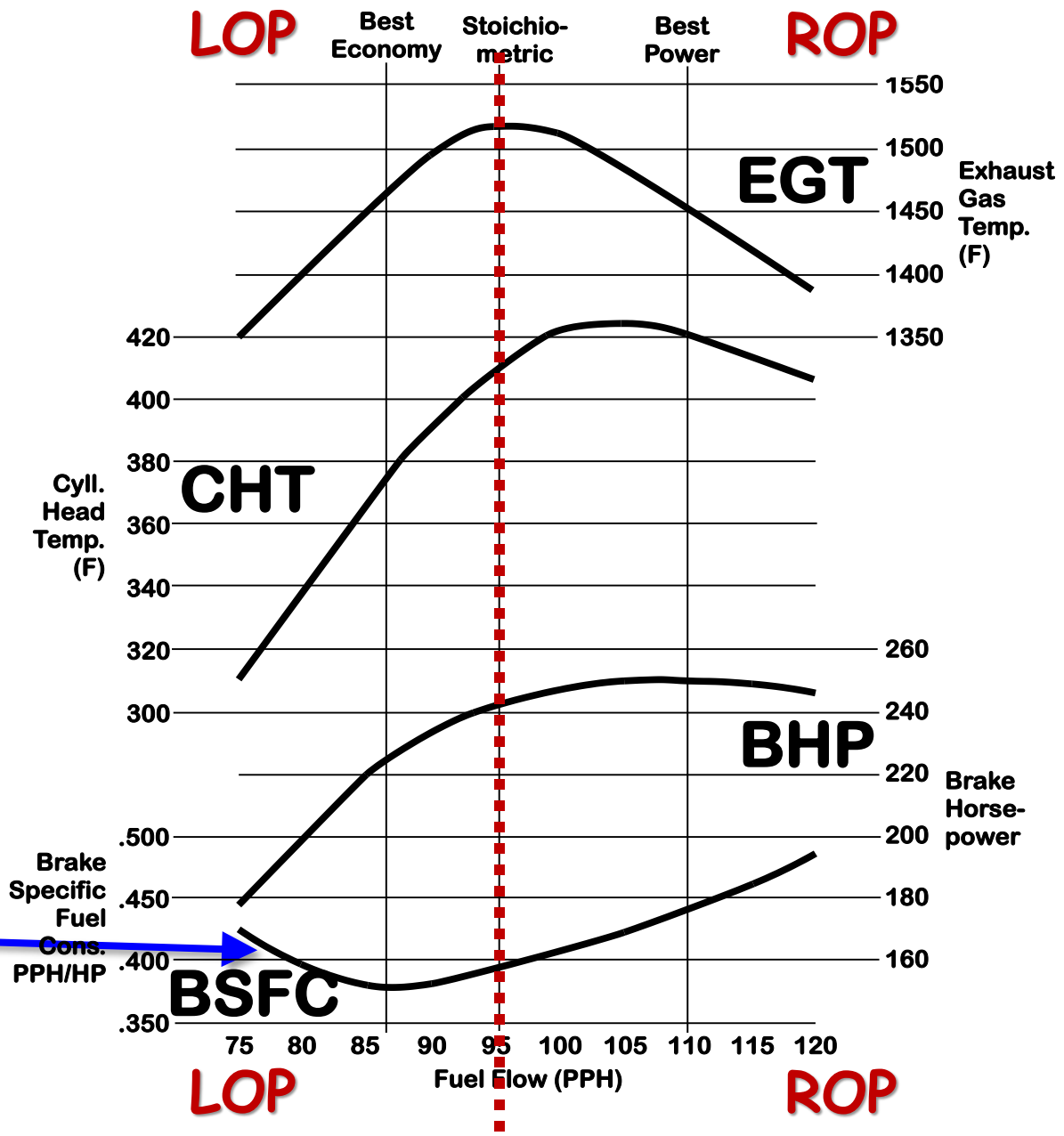
Cylinder head temp





BHP

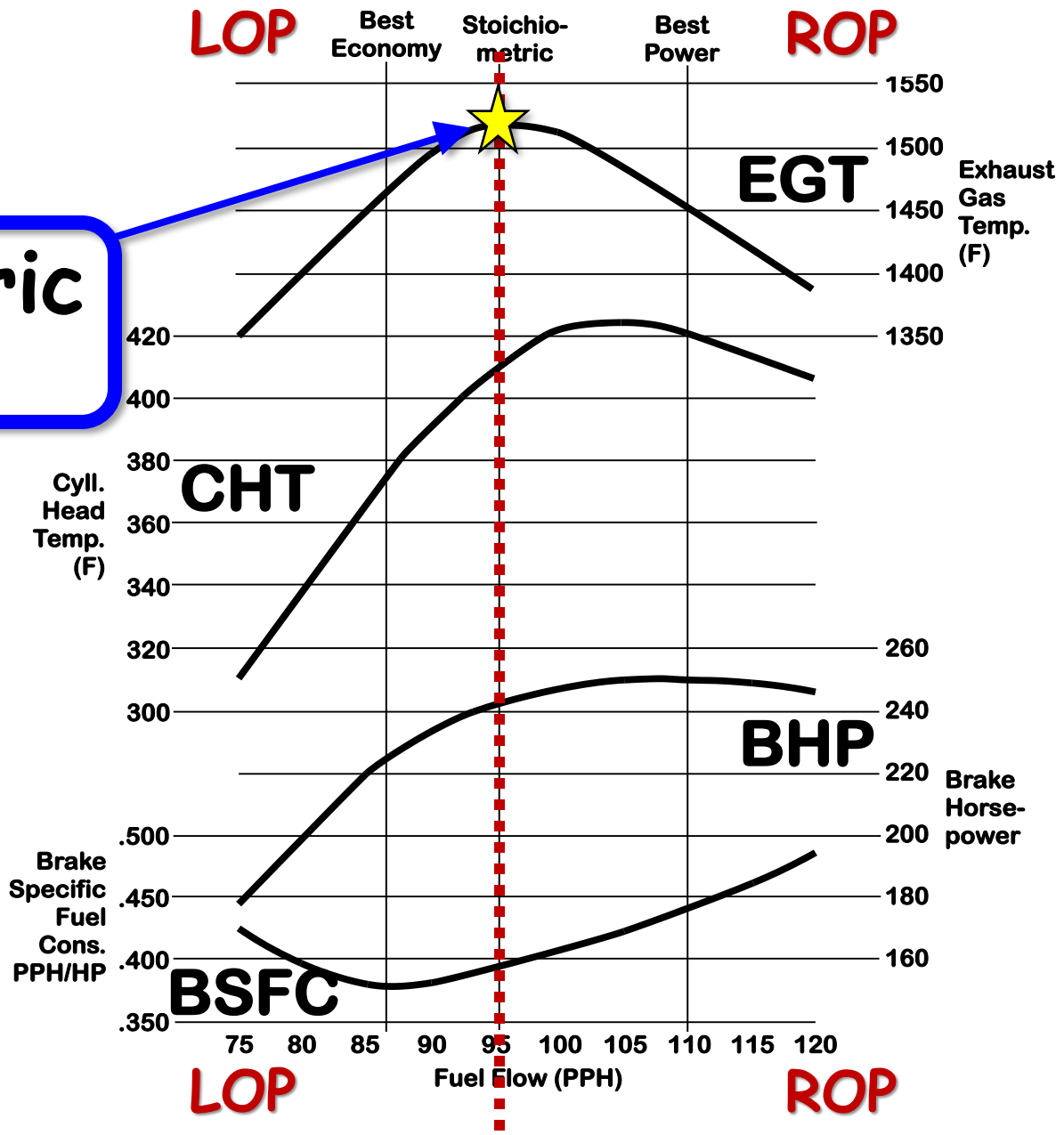
Brake horsepower



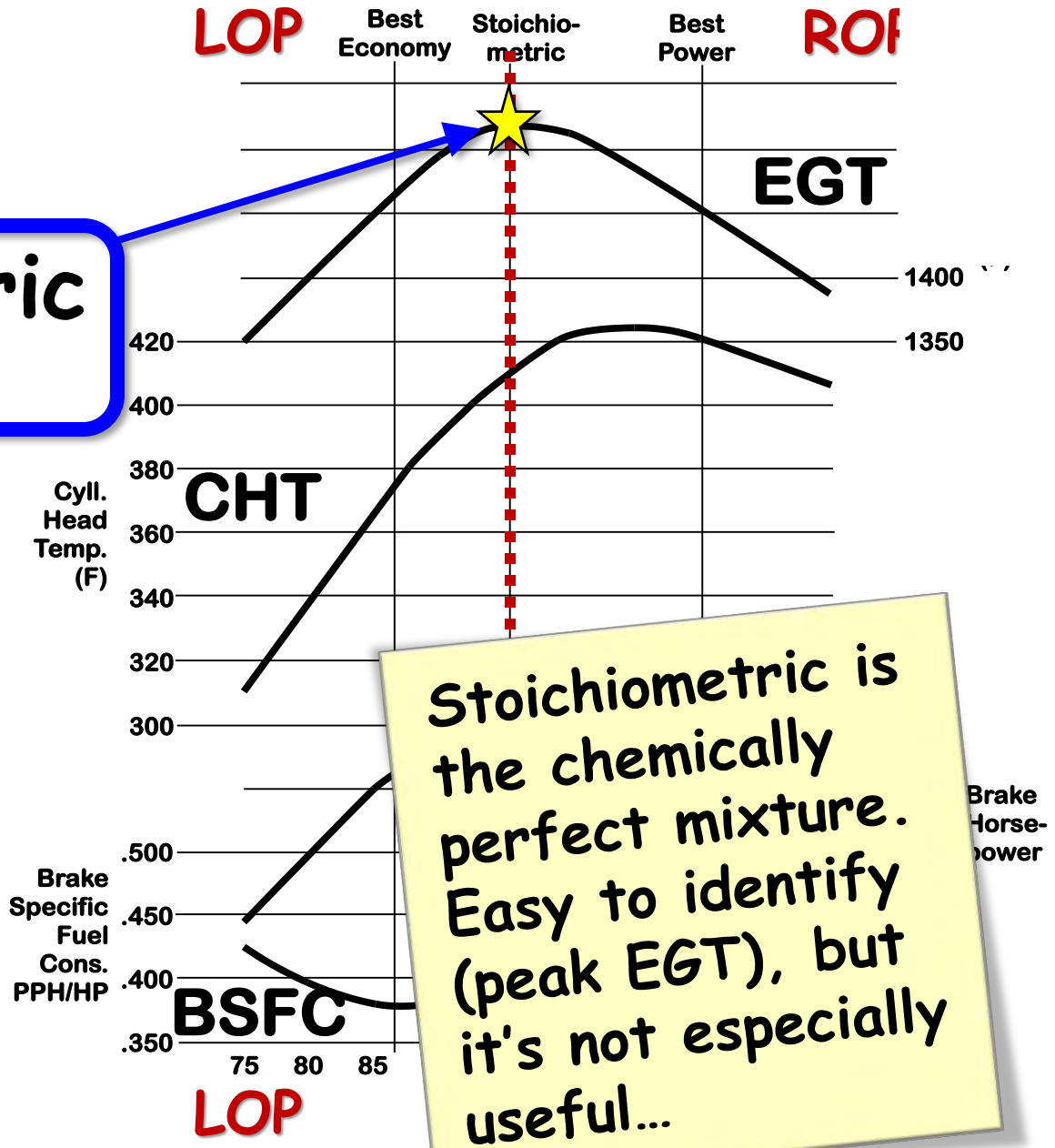
BSFC

Brake specific fuel consumption

Stoichiometric
Peak EGT



Stoichiometric
Peak EGT



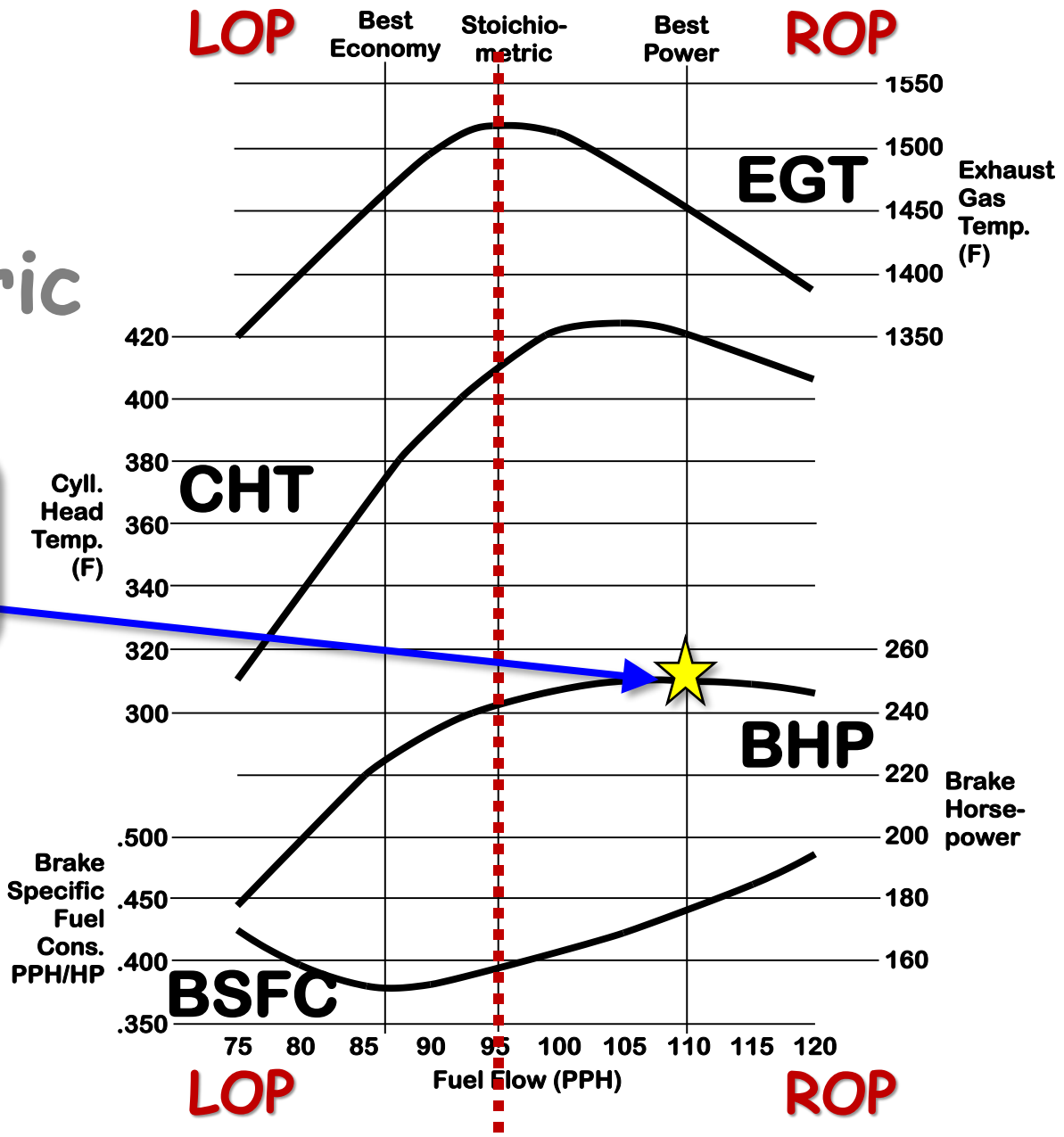
Stoichiometric is the chemically perfect mixture. Easy to identify (peak EGT), but it's not especially useful...

Stoichiometric

Peak EGT

Best Power

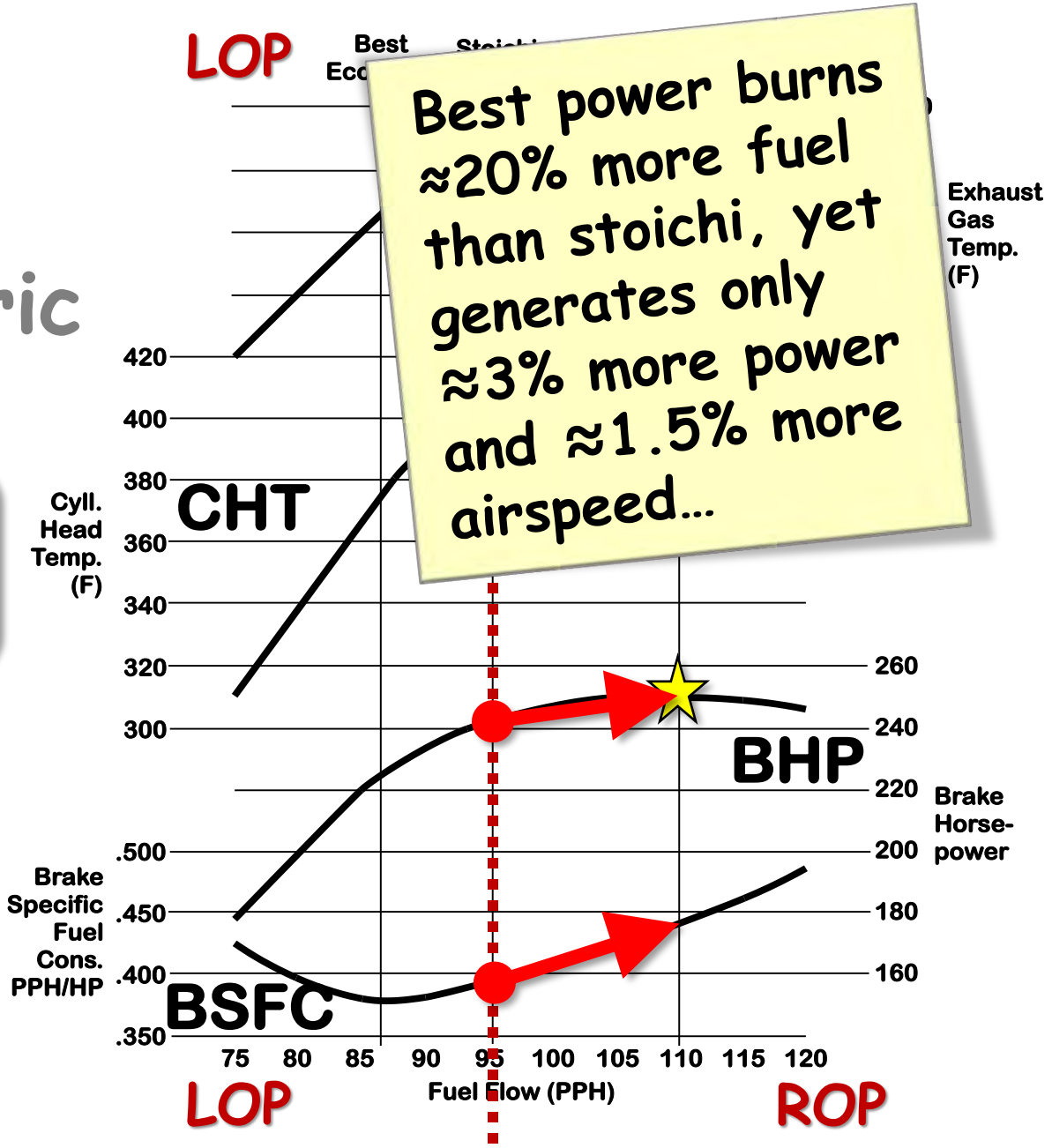
75°F-100°F ROP



Stoichiometric

Peak EGT

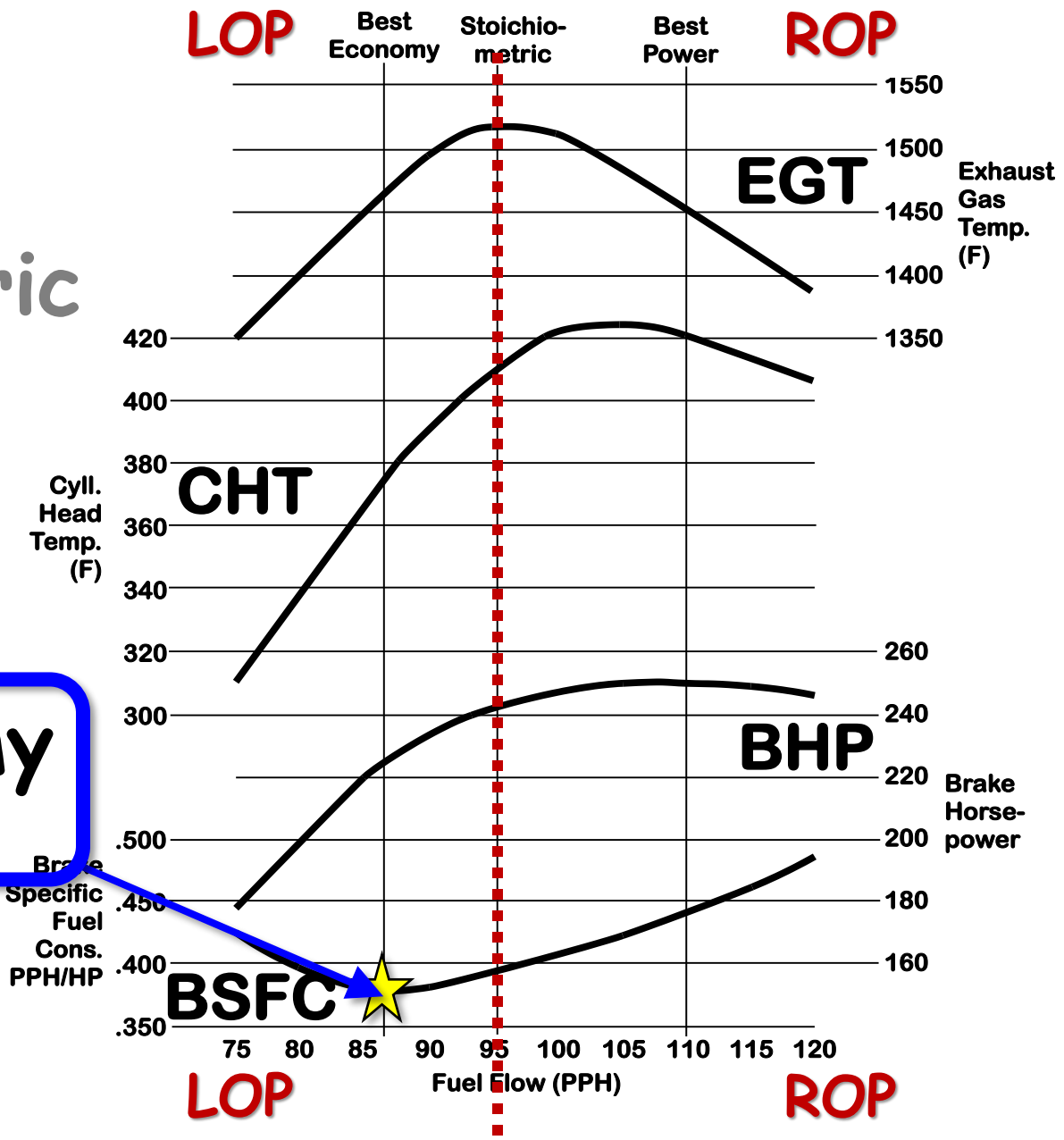
Best Power
75°F-100°F ROP



Stoichiometric
Peak EGT

Best Power
75°F-100°F ROP

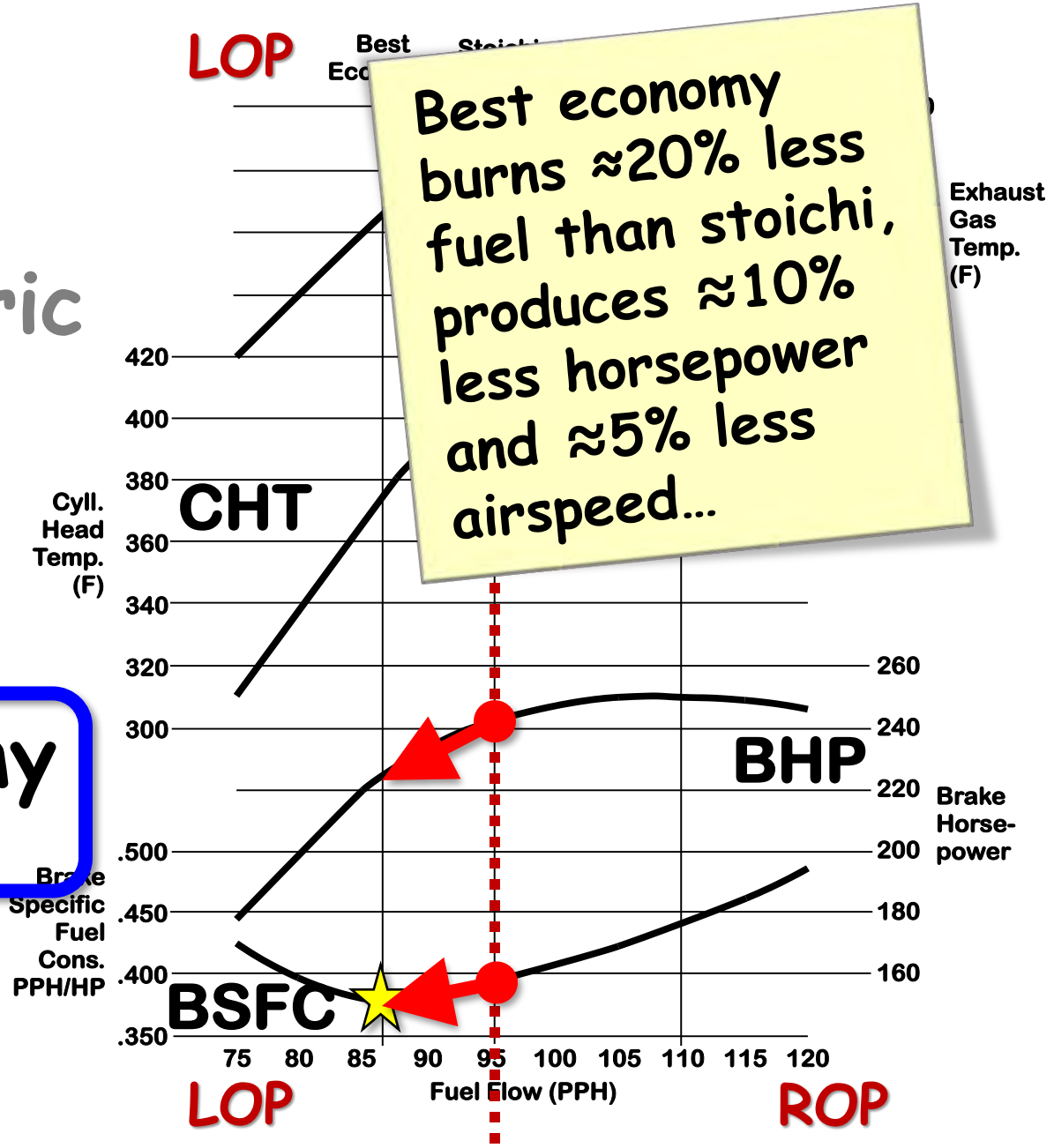
Best Economy
30°F-70°F LOP



Stoichiometric
Peak EGT

Best Power
75°F-100°F ROP

Best Economy
30°F-70°F LOP

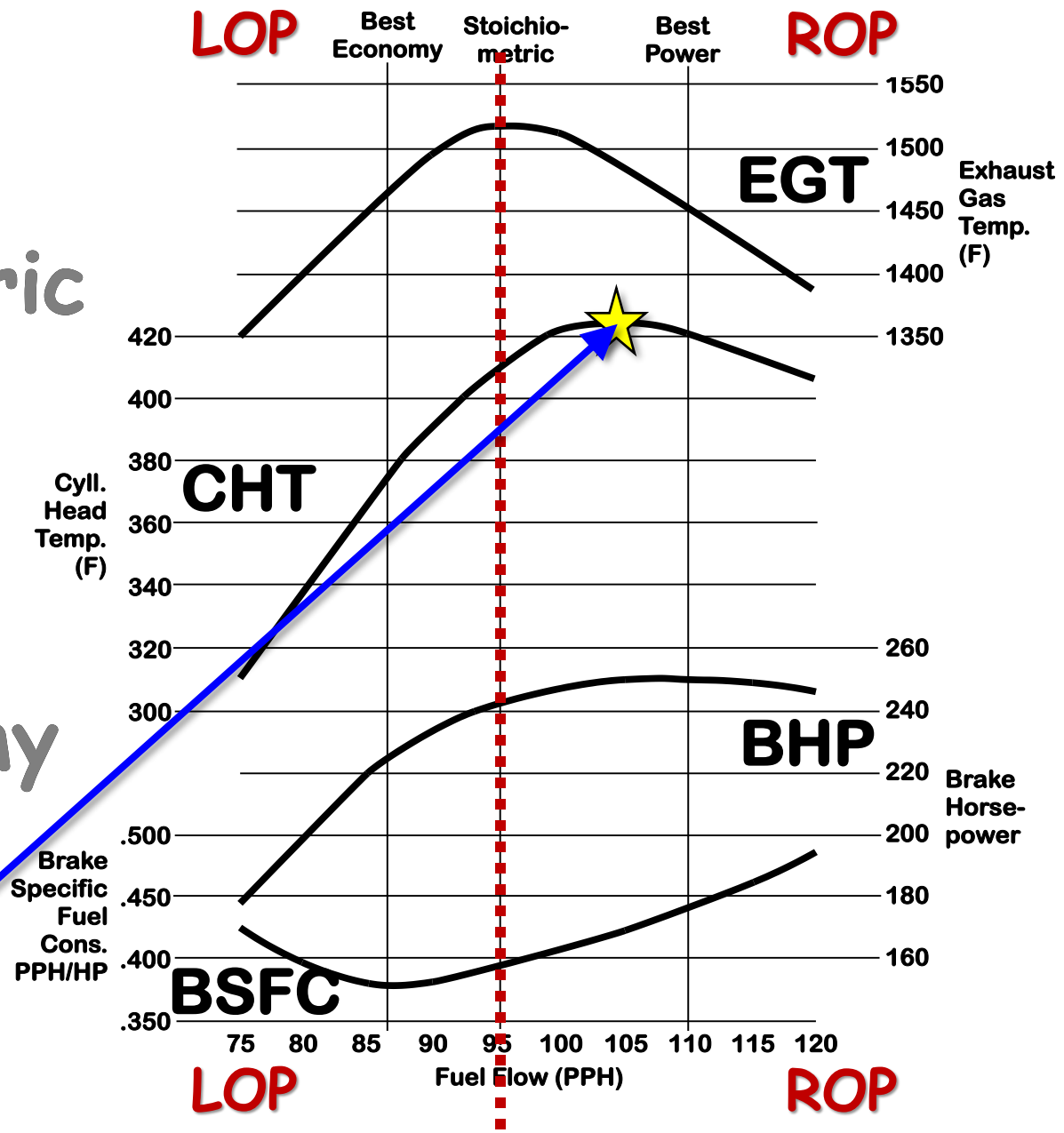


Stoichiometric
Peak EGT

Best Power
75°F-100°F ROP

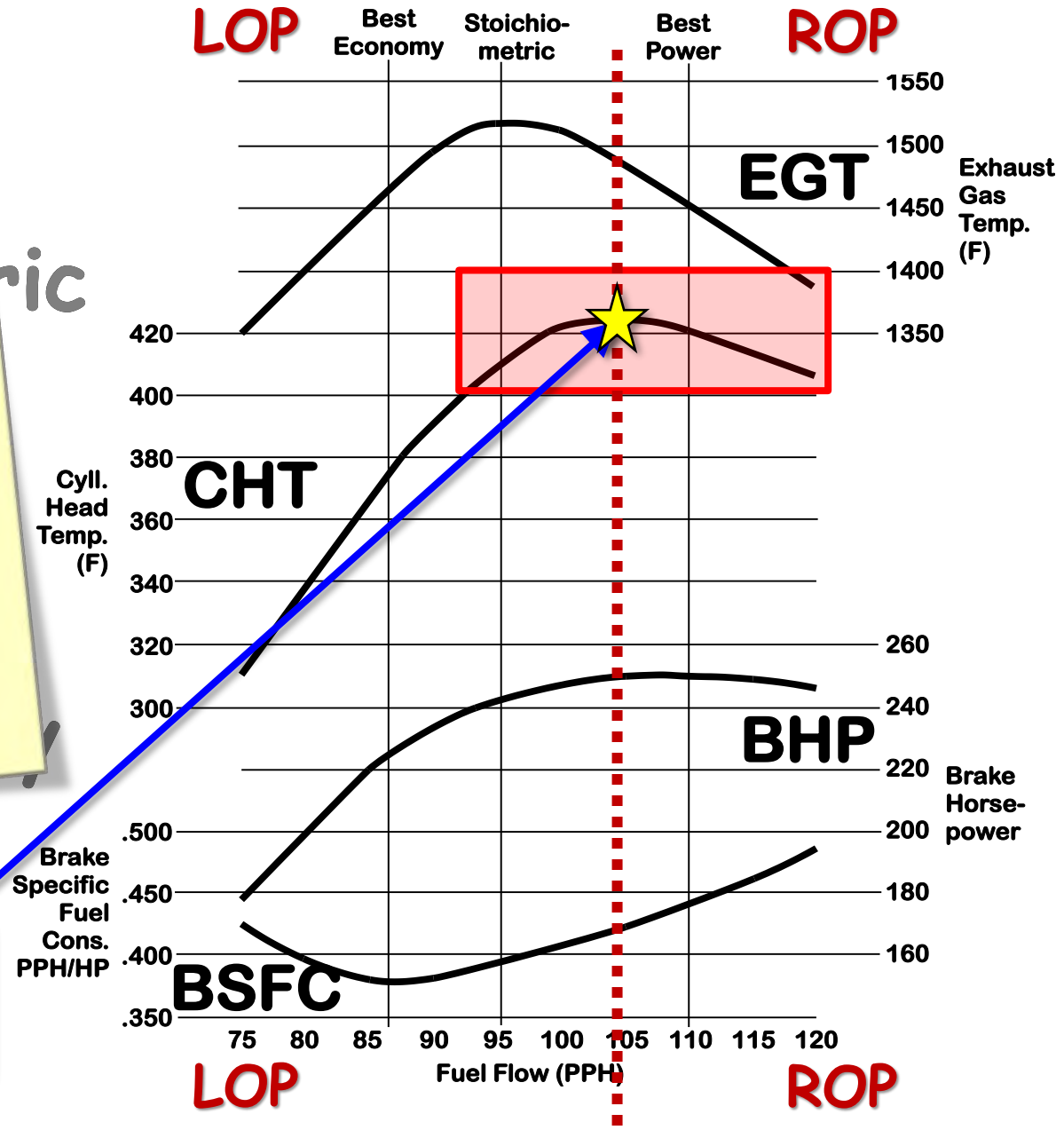
Best Economy
30°F-70°F LOP

Max Abuse
40°F-50°F ROP



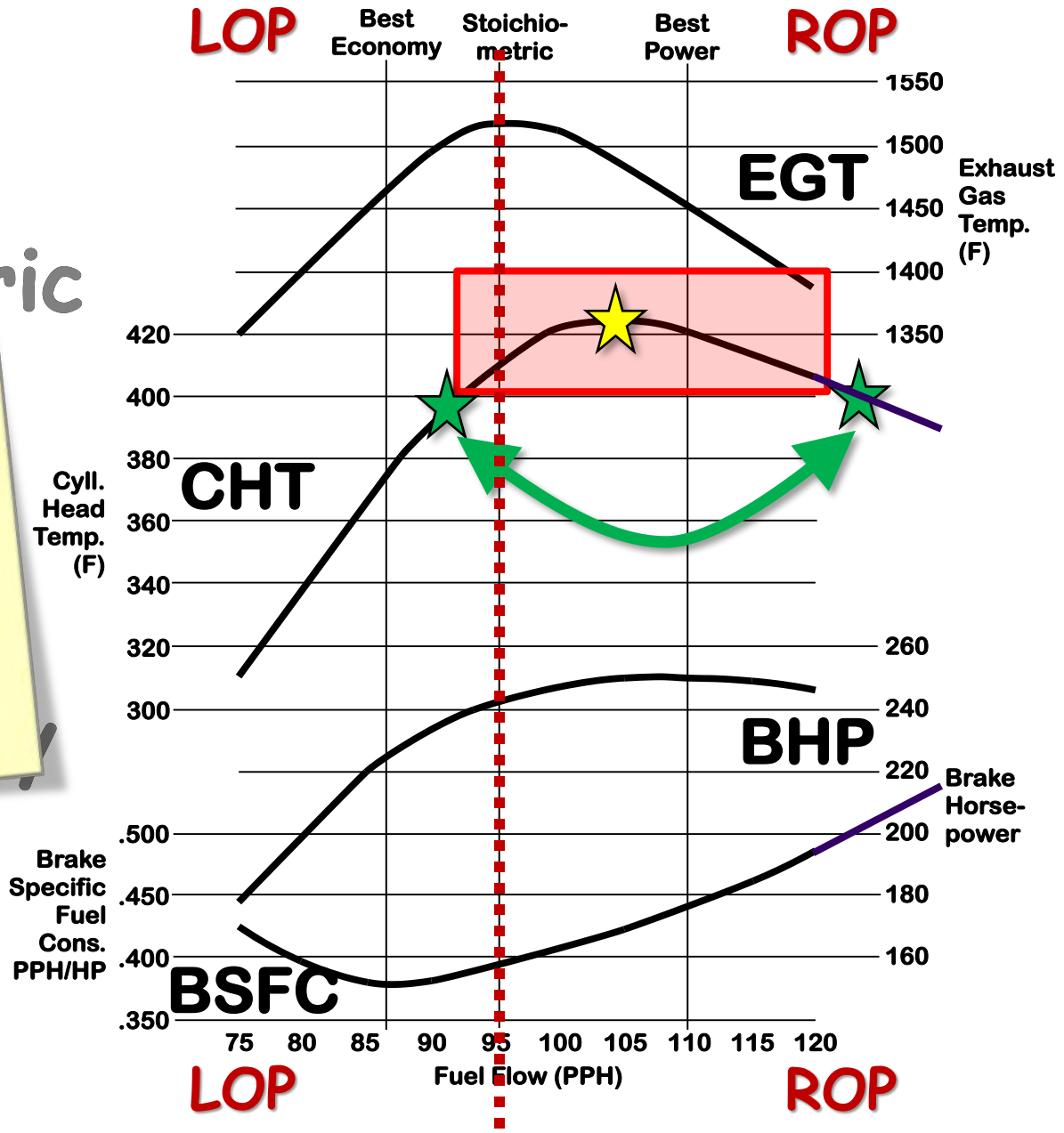
To avoid abuse and maximize longevity, we need to avoid this abusive zone that we call the "red box"…

Max Abuse
40°F-50°F ROP



To stay clear of the "red box" at high cruise HP, we need to operate either slightly LOP or very ROP…

Max Abuse
40°F-50°F ROP



Either one will keep you out of the "red box"…

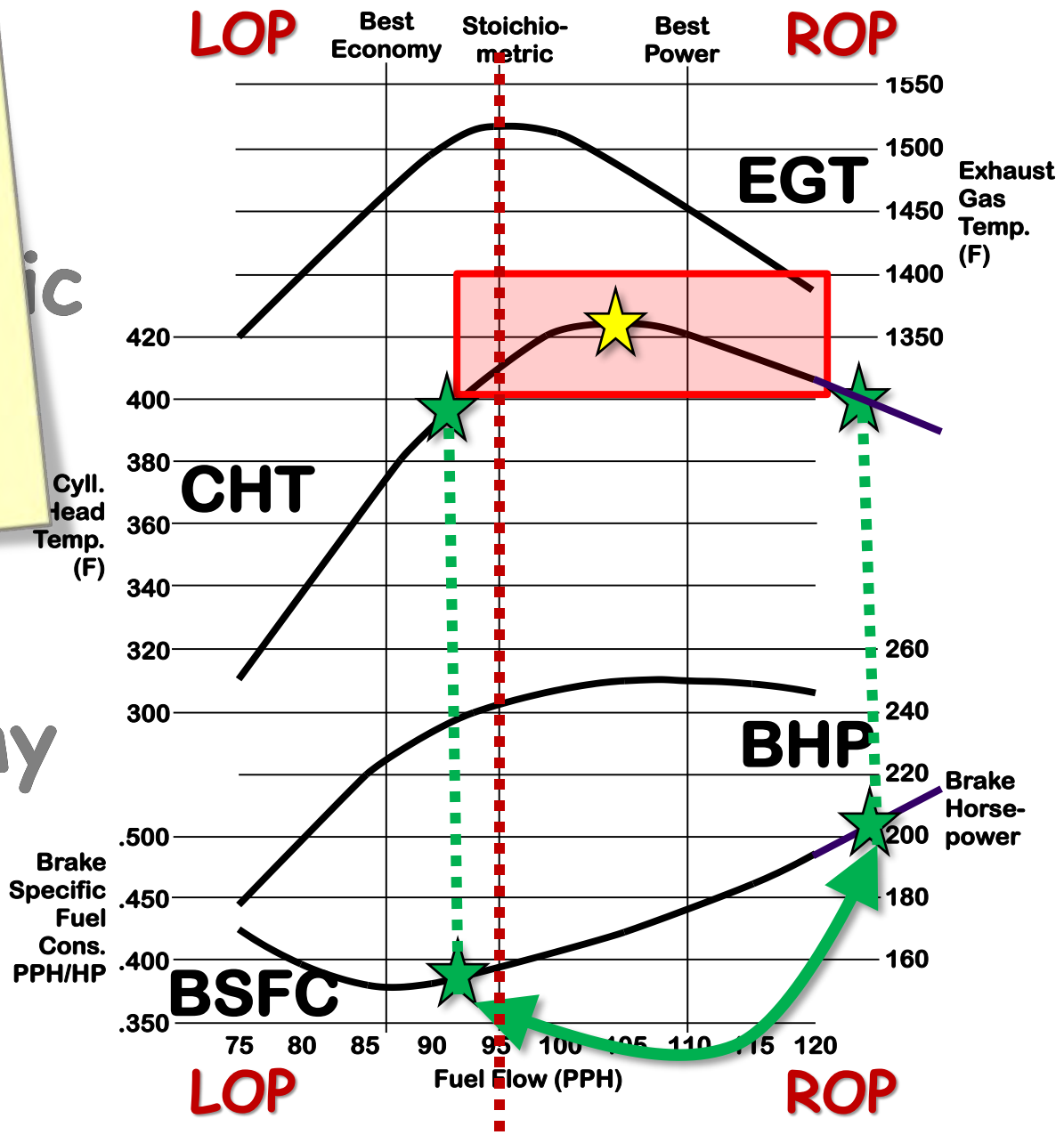
75°F-100°F ROP

Best Economy

30°F-70°F LOP

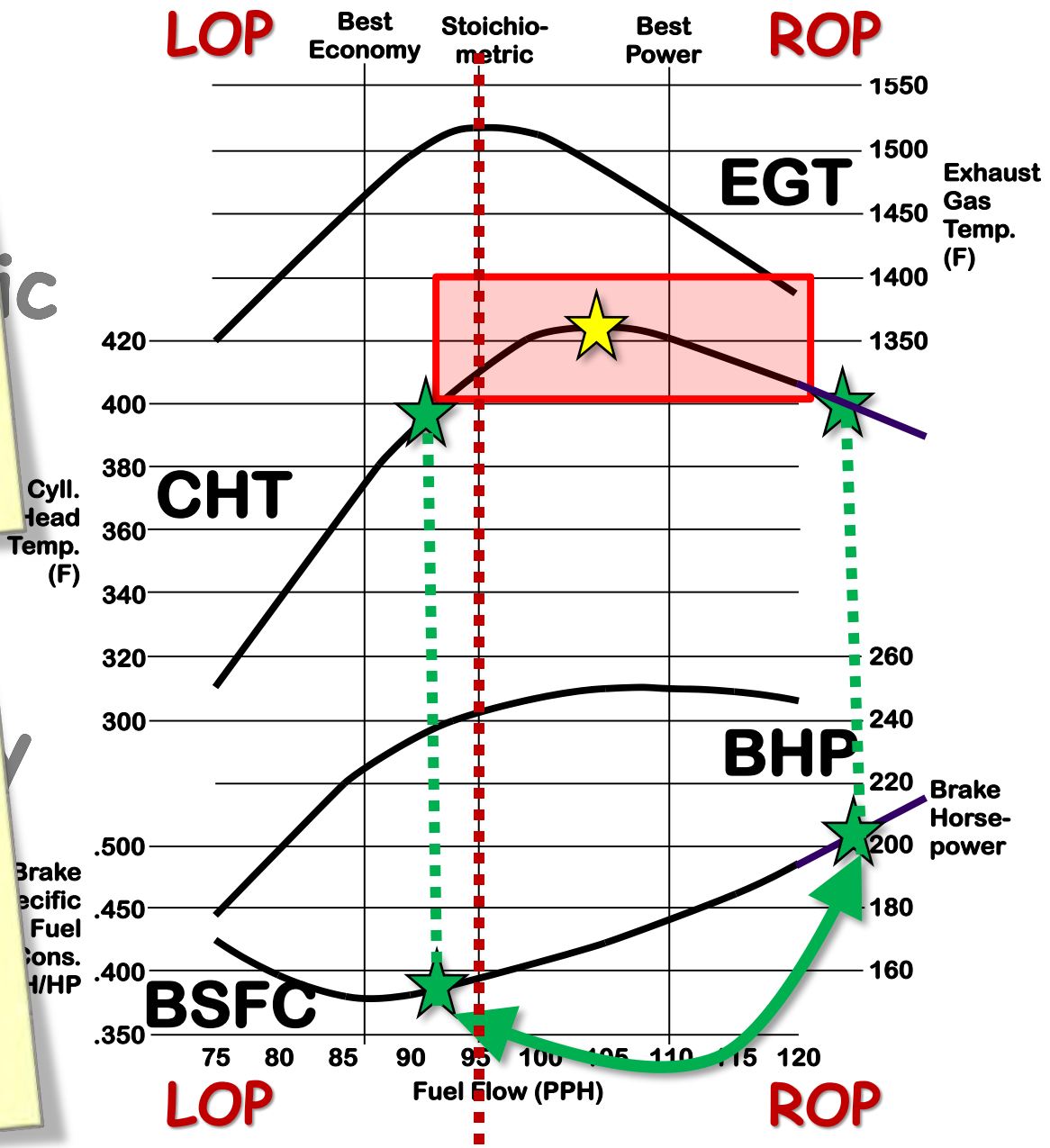
Max Abuse

40°F-50°F ROP



Either one will keep you out of the "red box"…

…but LOP uses a lot less fuel, and is a lot cleaner!



Some key takeaways…

Except for start and takeoff,
mixture should be between best power and best economy

Except for low power (≈60% or less) the "red box" zone surrounding ≈40°F ROP should be avoided

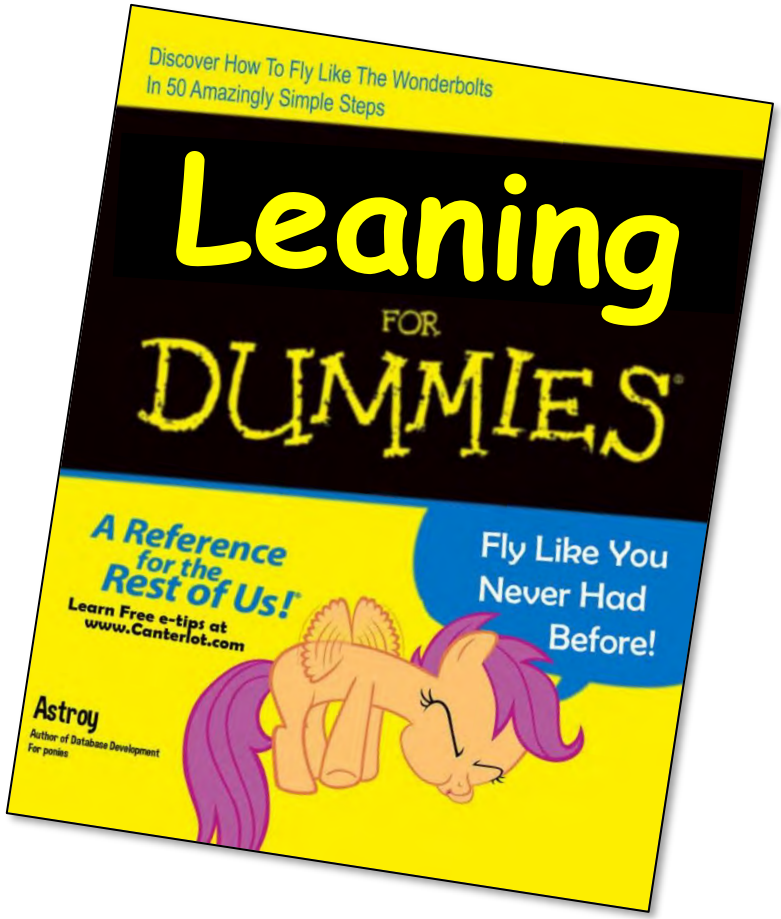
Leaning from best power to stoichiometric

reduces FF by 20%
and TAS by 1.5%

Leaning from stoichiometric to best economy (LOP)

reduces FF by
an additional 20%
and TAS by an additional 5%

Leaning made simple



for complex airplane w/constant-speed prop

Starting, taxi, ground ops

- Mixture full-rich when engine is cold
- Lean to maximum RPM for taxi
- Remain at maximum RPM for runup

Takeoff (normally aspirated)

All takeoffs are at full-rich mixture, max RPM, and full throttle

(except for high-density-altitude takeoffs)

For high density altitude TOs, lean mixture to achieve same EGT as in sea-level TOs

Takeoff (turbocharged)

All takeoffs are at full-rich mixture, max RPM, full throttle

Do not try to compensate for MAP or FF over red-line by using less than full throttle or full-rich mixture!

Accept short-term overboost…it's okay. Anything worse, have the turbosystem adjusted.

Climb

- **Max power to at least 1,000' AGL**
- **Then reduce to lower "cruise-climb" power if you wish**
- **You can climb either ROP or LOP**

  LOP climbs are tricky, I don't recommend them

Climb

If normally-aspirated, reduce RPM but leave throttle wide-open. Mother Nature will take care of all the MP reduction you need!

If fuel system doesn't compensate for altitude, lean as you climb to keep EGT constant

Cruise

Decision time!

What do you want to do?

Do you want to cruise **ROP** or **LOP**?

Do you want to go **Fast** or go **Far**?

Cruise

To go really fast: Lean to best-power mixture (75°F-100°F ROP) and be prepared to burn a lot of fuel.

To go efficiently fast: Lean LOP, but as close to peak EGT as possible without exceeding **target max CHT**.

Target max CHT

Legacy aircraft

- 400°F for Lycoming
- 380°F for Continental

Modern aircraft

- 380°F for Lycoming
- 360°F for Continental

Target max CHT

Legacy aircraft

- 400°F for Lycoming
- 380°F for Continental

Modern aircraft

- 380°F for Lycoming
- 360°F for Continental

To reduce CHT:

Open cowl flaps

Climb less steeply

If ROP, richen more

If LOP, lean more

Cruise

To go far: Lean quickly to the onset of roughness. This will be LOP for most engines (or near peak EGT for cranky, engines with poor mixture distribution).

Then richen only enough to restore smooth operation **and no further**.

Let things stabilize and check CHT.

Cruise

Once in LOP go-far mode:

If you have a GPS-coupled totalizer that calculates fuel reserve at destination, you may richen to obtain the desired fuel reserve.

Just make sure that CHTs remain at or below target max CHT.

Descent

Lower the nose. 

Descent

Lower the nose. 

If you are turbocharged or altitude-compensated, don't touch the mixture.

Descent

Lower the nose. 

If you are normally-aspirated and non-compensated, richen as necessary in the descent to maintain constant EGT.

Descent

Lower

If you

and no

as nece

to main

If you descend LOP and forget to richen, it's no big deal:

As the engine gets leaner, CHTs will get cooler … and eventually engine will get rough to remind you.

Landing

POH says go full-rich.

Landing

POH says go full-rich. **BUT…**

POH was written by lawyers who don't trust you to go full-rich in the event of a go-around or missed-approach.

Landing

I DO NOT go full-rich…

- Abusive to the engine (remember ERAU?)
- Optimizes for the 0.5% case, not the 99.5% case
- If you don't trust yourself to go full-rich before executing a go-around or missed-approach, see your CFI!

How I fly my plane

How I fly my plane

Start: Full-rich

Taxi/Runup: Leaned "brutally"

TO: Full-rich, WOT (32" MP), max RPM (2700)

Climb: Reduce RPM to 2350-2500

Cruise: Reduce FF to 12.5 GPH (LOP 60% power), then adjust FF as desired for go-fast or go-far (typically 11.5-13.5 GPH → 55%-65% power)

Descent: Lower the nose, don't touch anything

Landing: Throttle back, lower the gear+flaps

NOTES:

I go WOT on takeoff (32" MAP), then never touch the throttle again until I land

I go LOP after level-off at altitude, then never touch the mixture again until I shut down

My turbocharged engines keeps things simple. With a normally-aspirated, non-compensated engine, I would need to adjust mixture during climb and descent. (Turbocharged engines always think they're at sea-level!)

Q: What's the right way to lean my engine?

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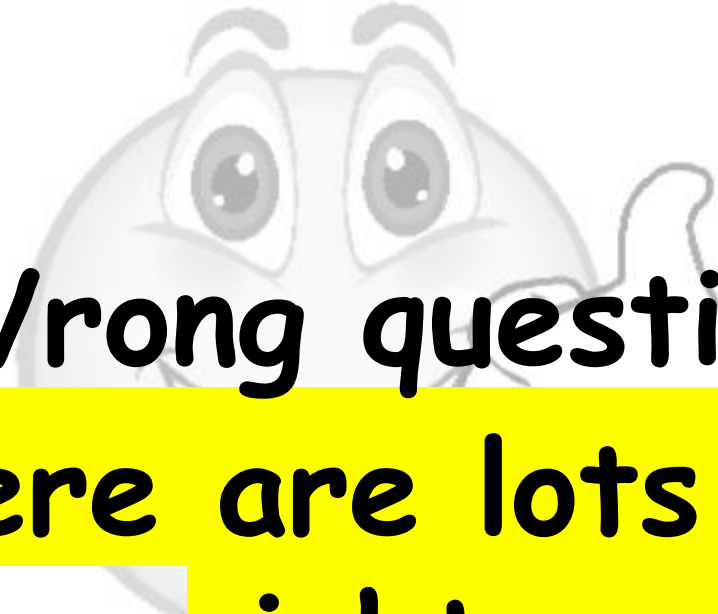


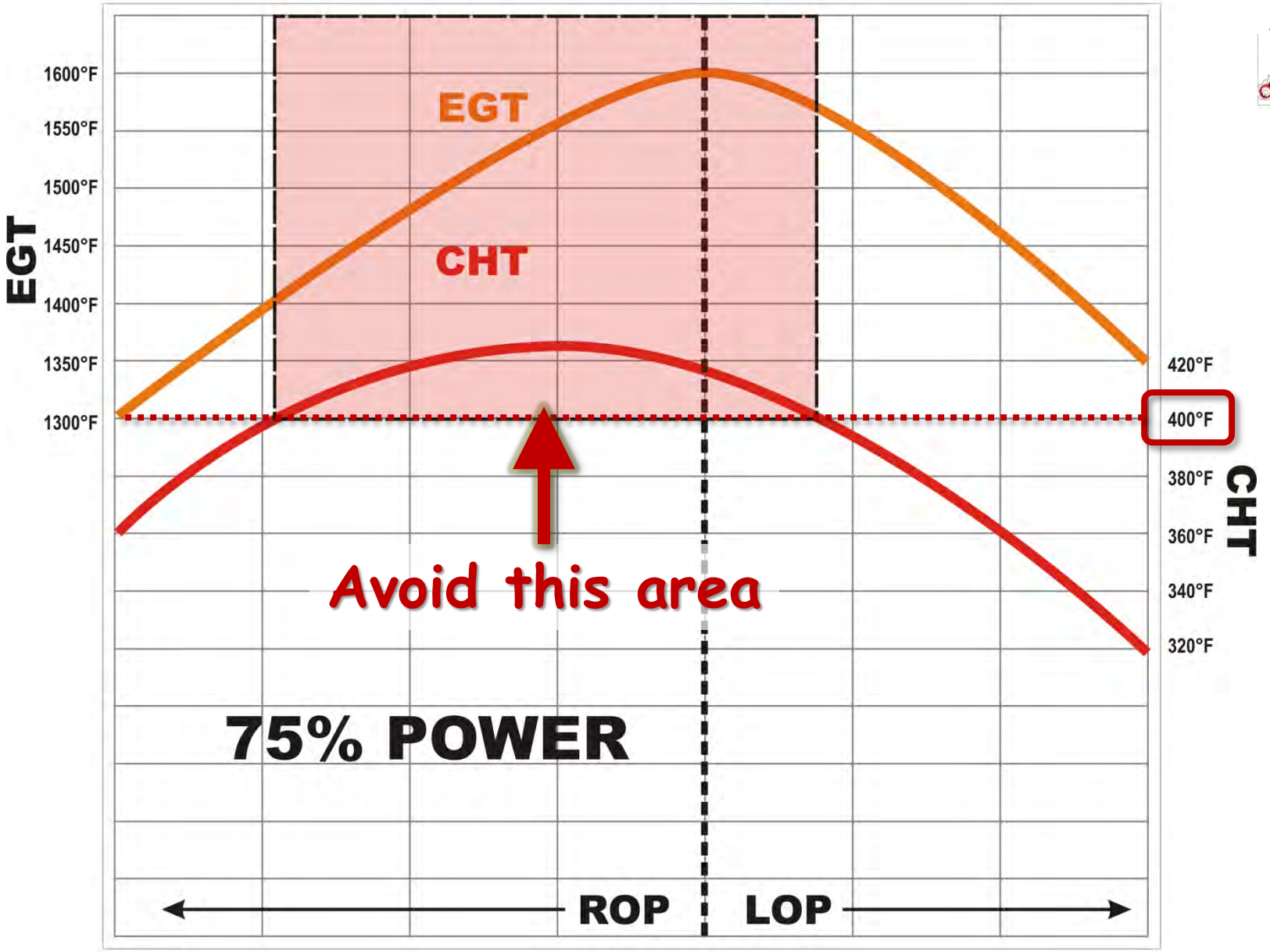
A: Wrong question!

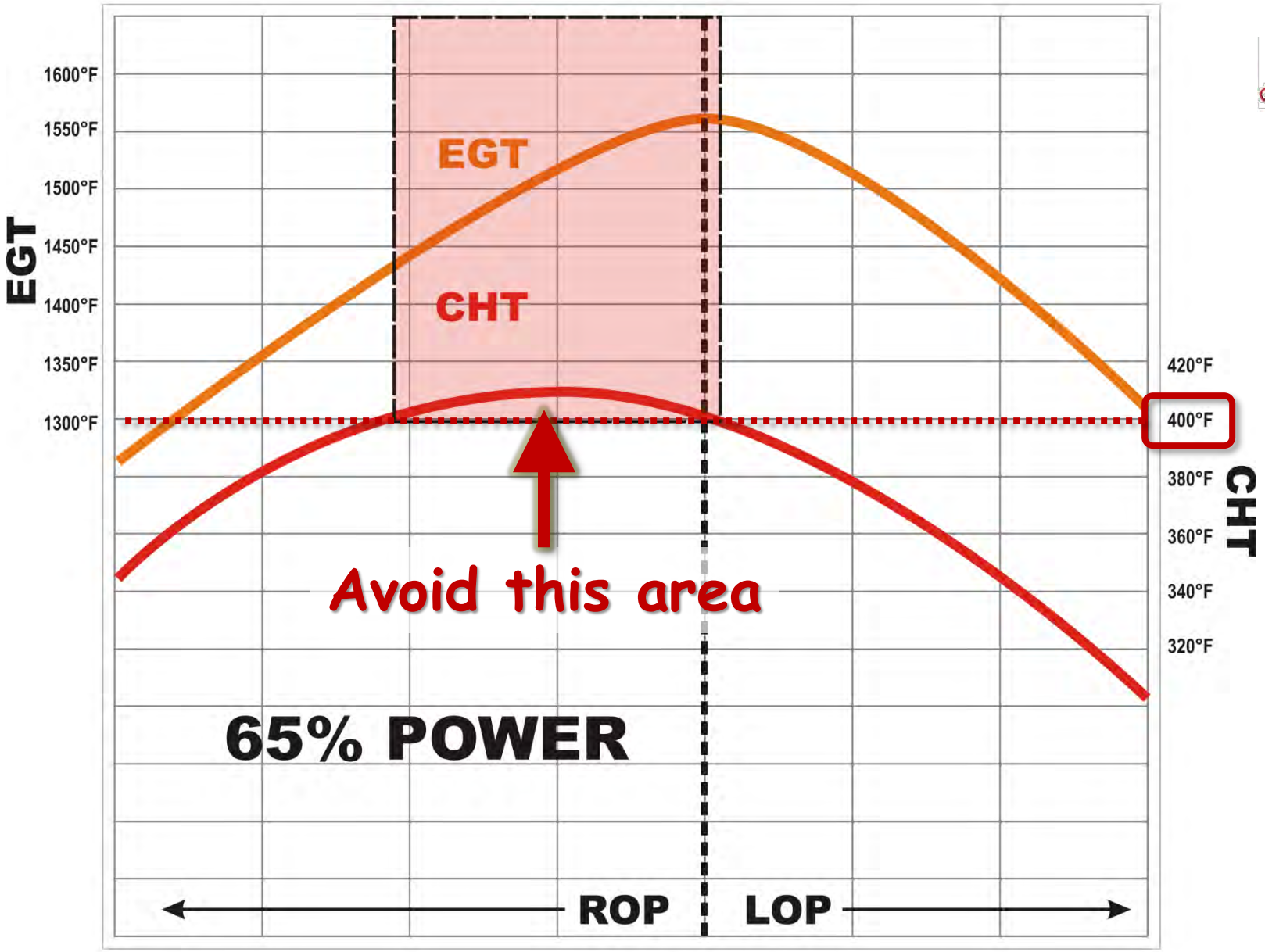
There are lots of right ways.

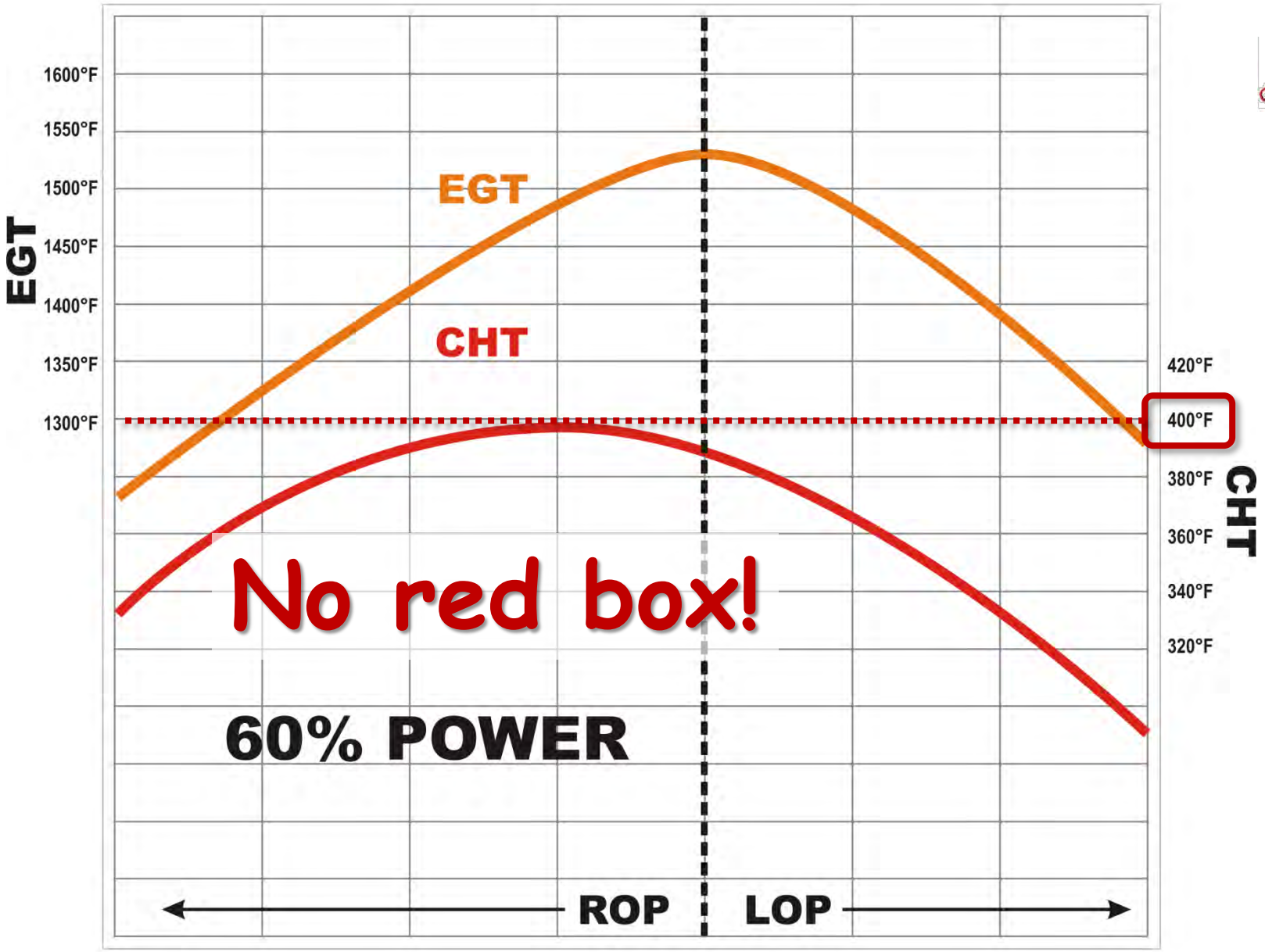
Q: What's the WRONG way to lean my engine?

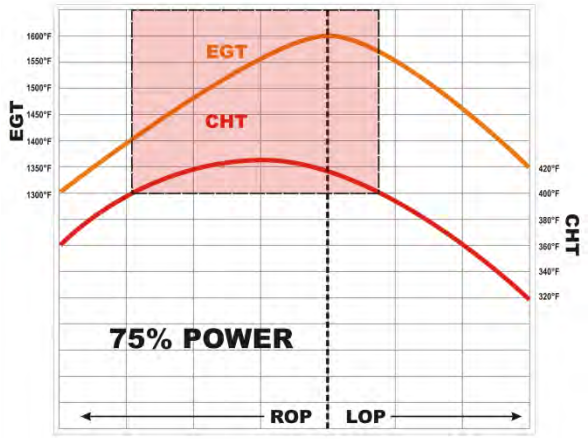
Q: What's the WRONG way to lean my engine?

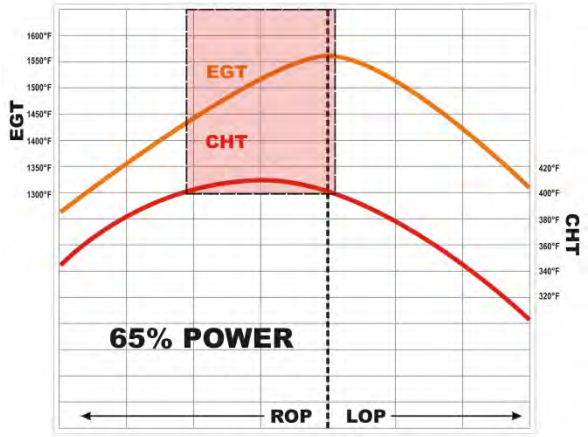
A: Operate it inside the "RED BOX"

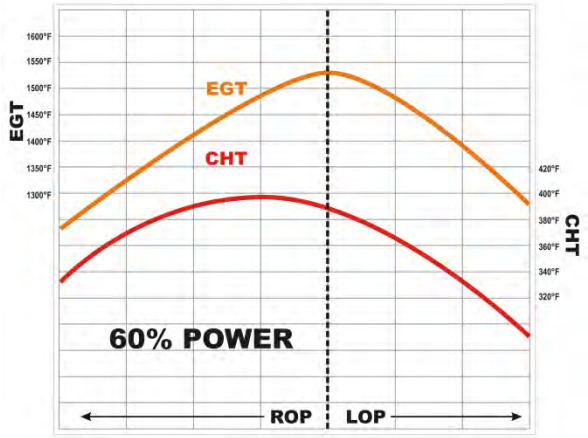










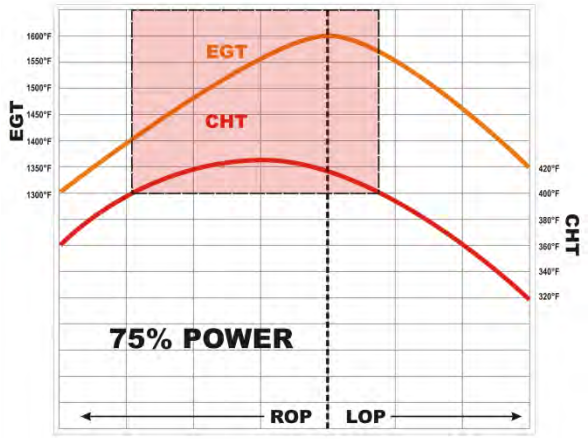


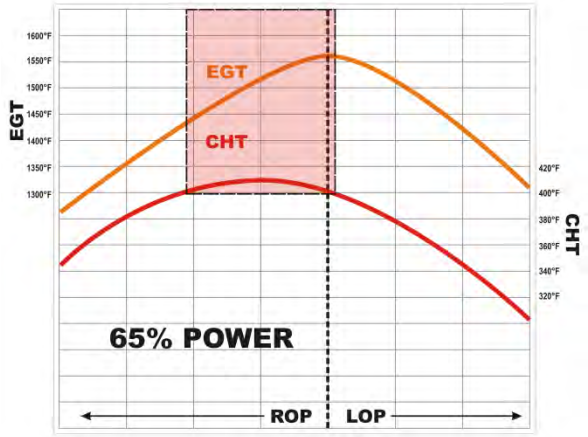
The red box denotes the range of mixtures where CHT exceeds target

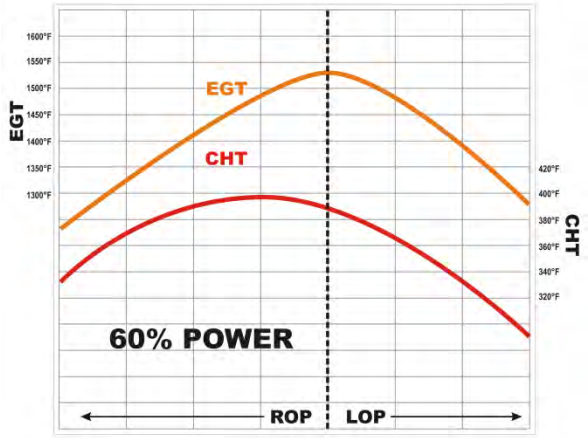
We want to stay out of the red box

The lower the power, the smaller the red box

If power is low enough, the red box vanishes





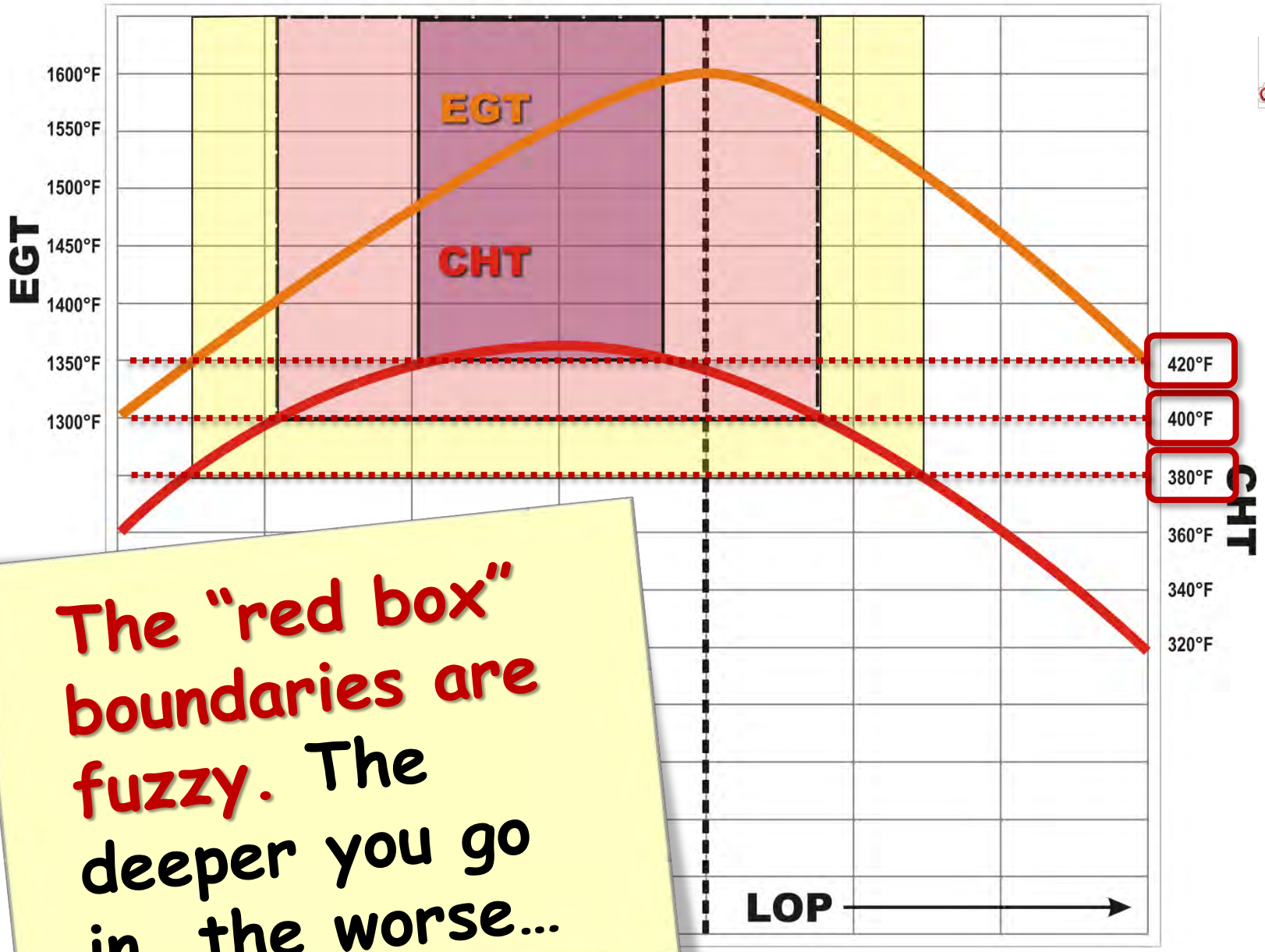


NOTE: 420ºF for Lycoming or 400ºF for Continental is appropriate for most legacy aircraft when OAT is ISA or higher

If OAT is colder than ISA and/or if the aircraft has an extraordinarily efficient cooling system (e.g., Cirrus, Corvallis, Diamond) then max CHT should be a bit lower.

Keep CHTs below your max target CHT (420°F/400°F/380°F) and you'll stay out of the red box

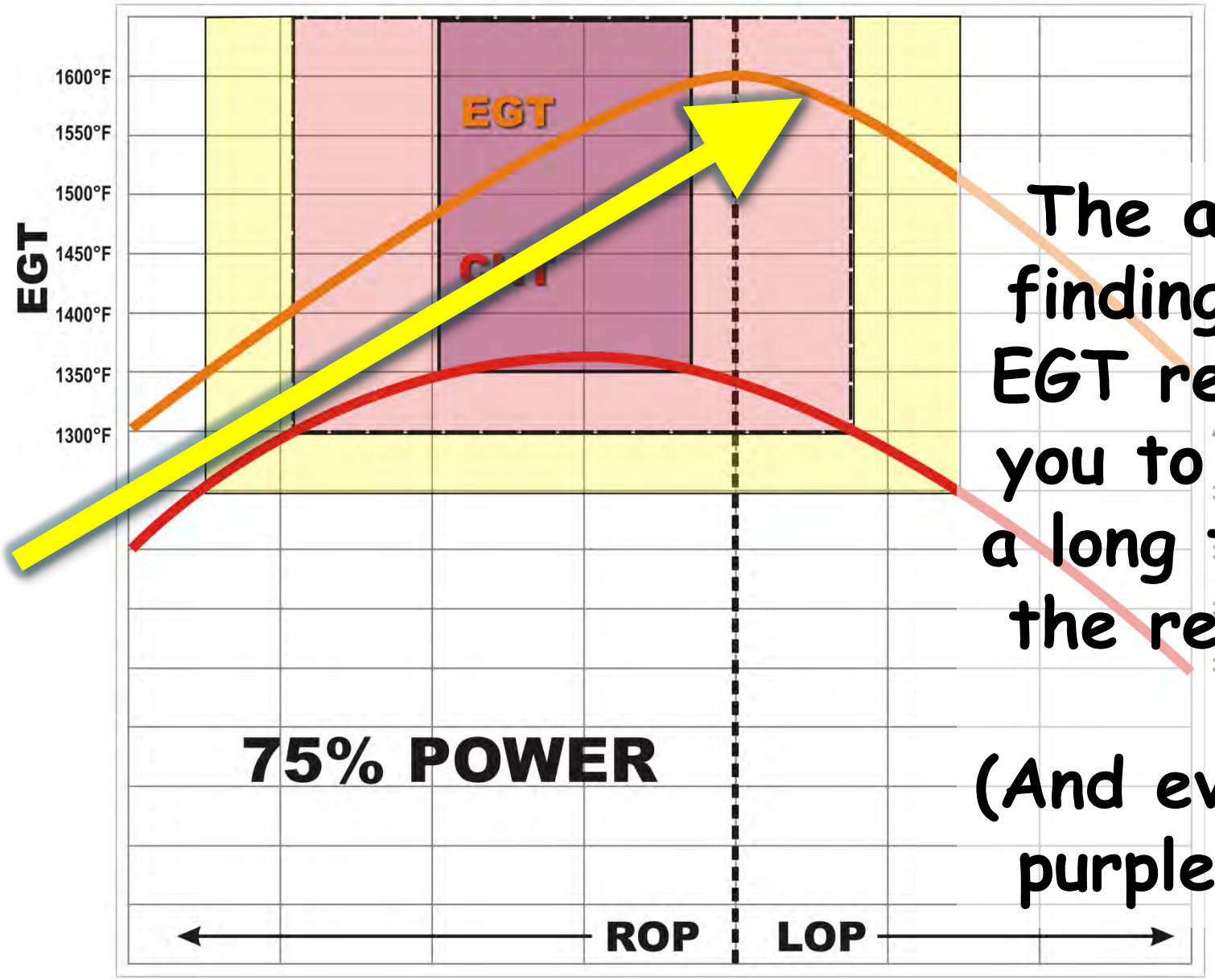
Target max CHT should be adjusted down for cold OAT and/or efficient cooling systems



The "red box" boundaries are fuzzy. The deeper you go in, the worse…

DON'T USE EGT AS A LEANING REFERENCE!

Especially don't use the "lean-find" feature of your engine monitor!



The act of finding peak EGT requires you to spend a long time in the red box

(And even the purple one!)

How do we know this is bad?

Rash of cracked nose core insulators in Champion fine-wire spark plugs in aircraft that used the lean-find feature

When transitioning the red box from ROP to LOP (or vice versa), DO IT QUICKLY and don't dwell there.

"Big Mixture Pull"

BMP can be done by reference to fuel flow or to perceptible power loss

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Fr 1000 #7	Where Fuel Meets Air
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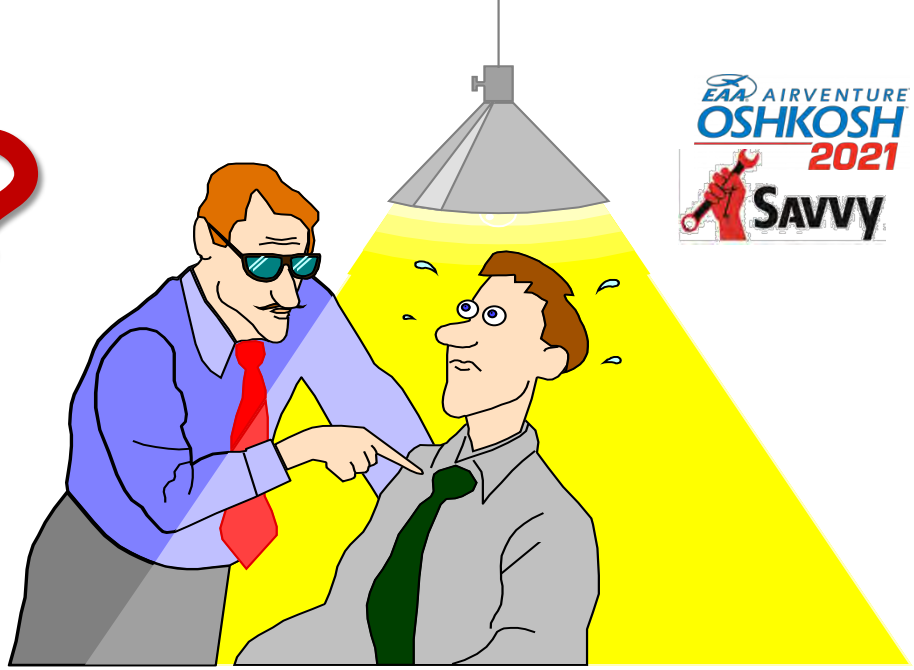

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