Multi-Engine Lesson 2

ONE ENGINE INOPERATIVE (OEI) OPERATIONS

Tiziano Bernard, CFI

Mission Objectives

- Review all V-speeds pertaining to multi-engine aircraft.
- Understand the **physics** of a multi-engine aircraft operating under a single engine (one engine inoperative – OEI).
- Understand the concept and factors affecting:
    - the **critical engine**;
    - Minimum controllable airspeed (**Vmc**).
- Learn and memorize **engine out procedures**.

OEI SCIENCE

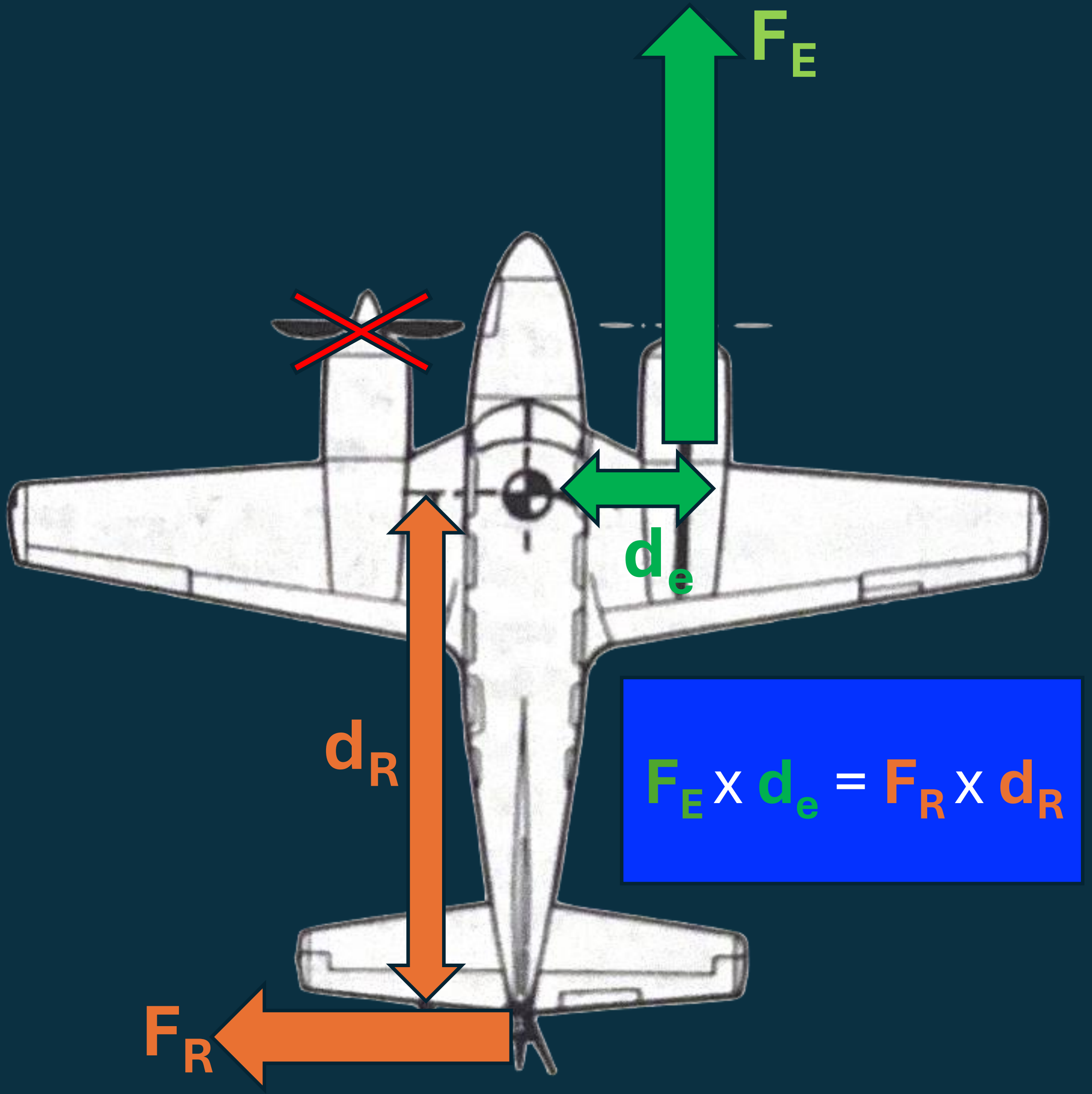
"Twice the engine will kill you twice as fast..." – Most MEIs

Basic Physics

- The loss of an engine results in a "force asymmetry".
  - One engine causes thrust, the other does not…
  - Pilot requires control surface inputs to stabilize the aircraft…
- Equilibrium is no longer present.
- Sudden OEI during maneuvering can have dangerous consequences.
- During straight and level flight, OEI results in un-commanded motions.

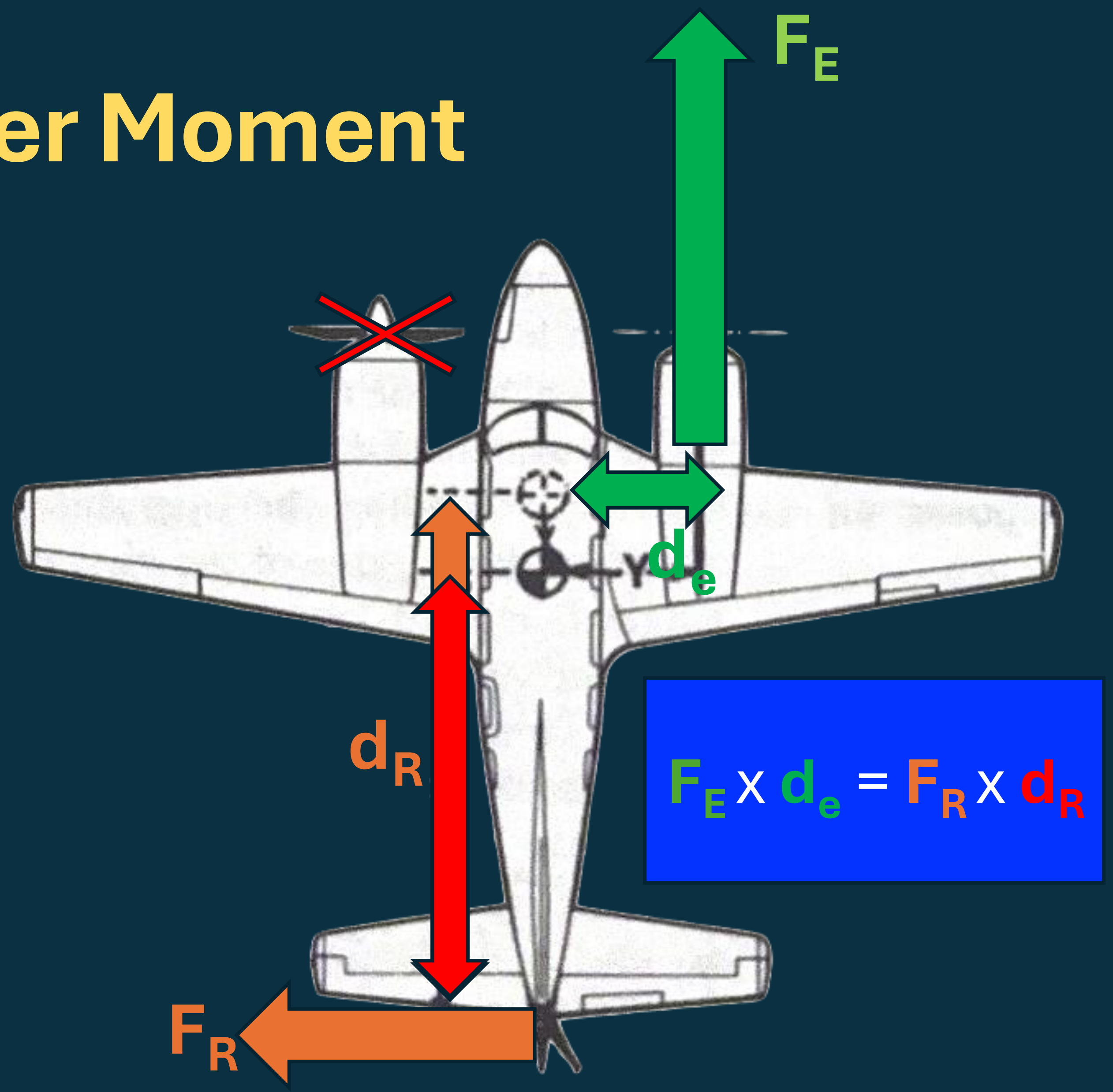
Forces and Moments

- Losing one engine will cause an asymmetry that has to be corrected using the rudder.
- The **two moments** must balance each other out.
- The force created by the rudder is "lift" and can be increased by speed.
- Minimum speed plays a critical role.



Effects of CG on Rudder Moment

- Moving the aircraft CG aft will reduce the moment achievable by the rudder.
- Less rudder effectiveness, we need more speed.
- Minimum safe speed must therefore be increased!
- FWD CG = good
- AFT CG = bad

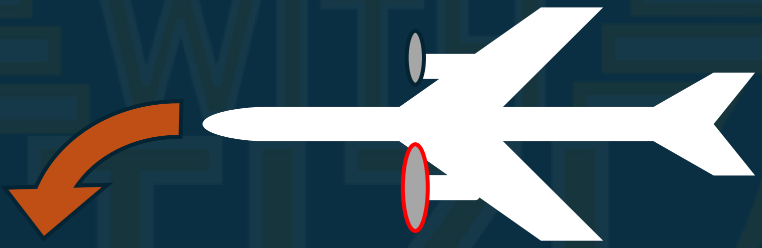


OEI Effects on the Aircraft (1/2)

- The aircraft will essentially react in three distinct ways about each axis:

1. Lateral: **AIRCRAFT WILL PITCH DOWN**
2. Longitudinal: **AIRCRAFT WILL ROLL INTO INOP ENGINE**
3. Vertical: **AIRCRAFT WILL YAW INTO INOP ENGINE**

OEI Effects on the Aircraft (2/2)

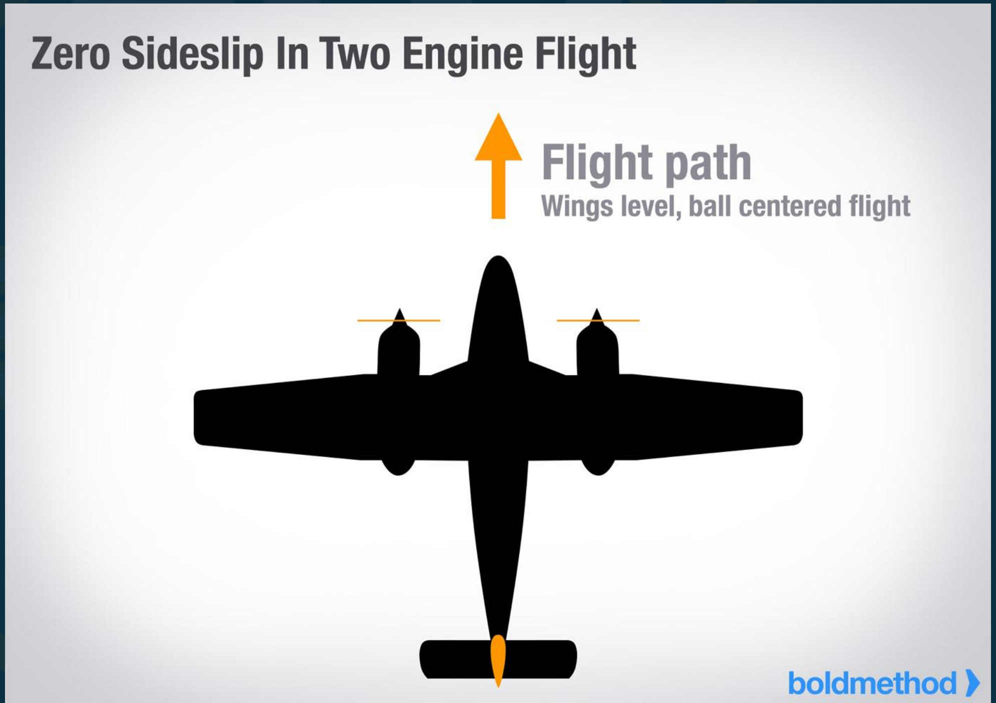


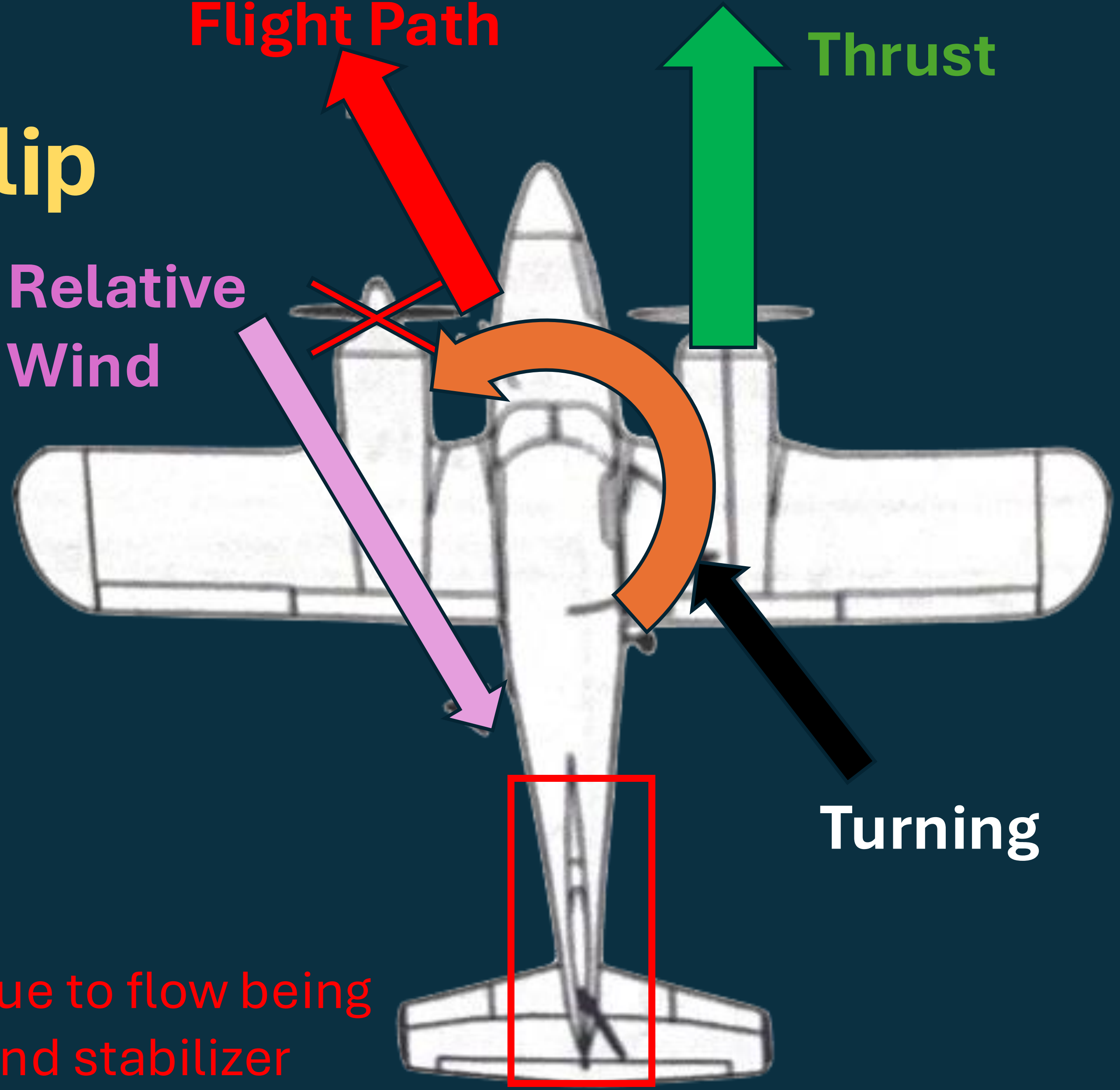
- Loss of Thrust and Lift
- Pitch down motion

- Operating engine lifts the wing
- Induced Roll

- OEI no yawing moment
- Induced Yaw

OEI = Induced Sideslip





Reduced Rudder Effectiveness due to flow being shadowed by new relative wind and stabilizer

Correction of OEI Aerodynamics (1/2)

- OEI conditions are corrected by:

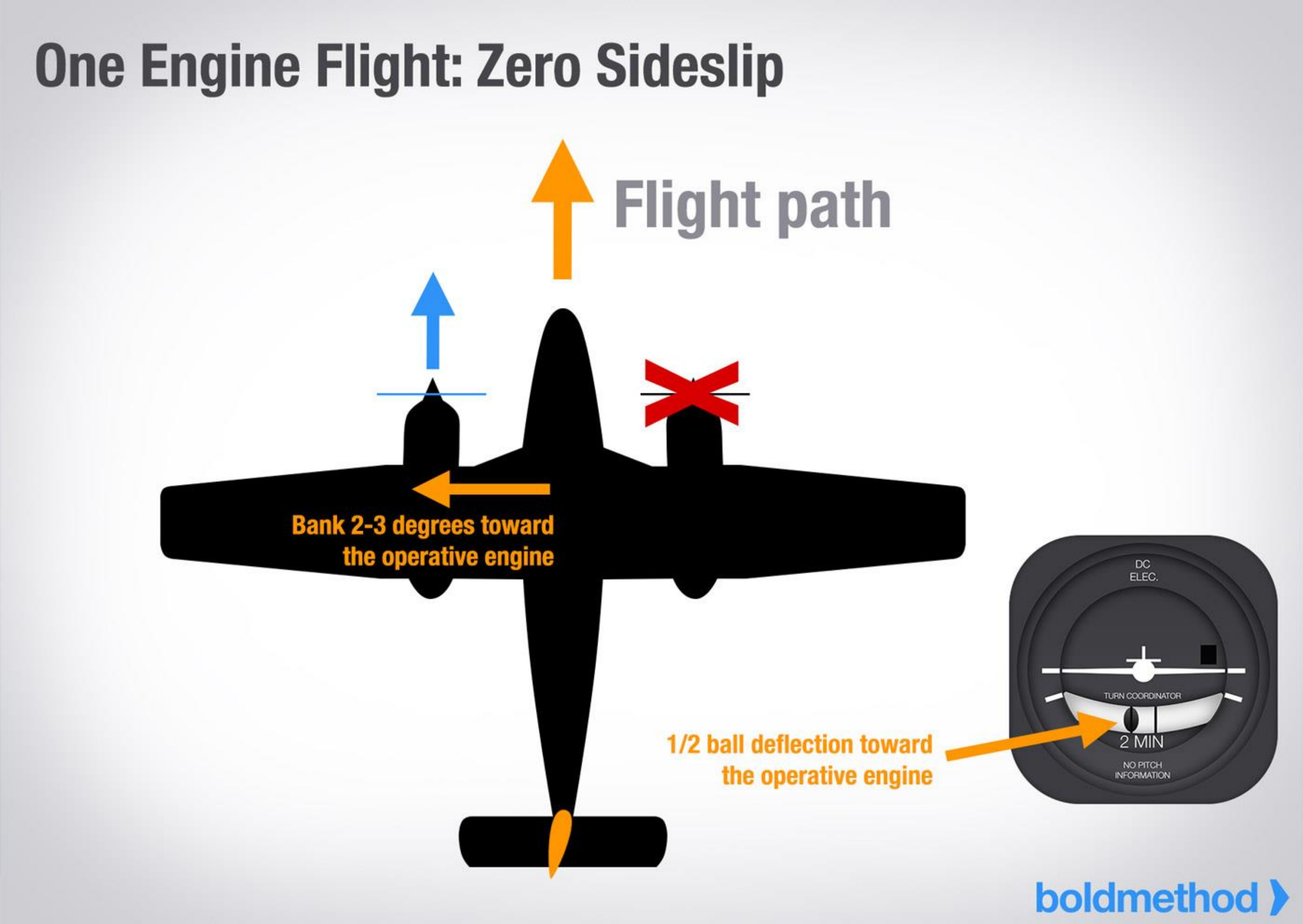
ESTABLISHING ZERO SIDESLIP

- Zero sideslip = coordinated flight on given heading.
- Obtained by using:

1. rudder on side of OEI (counteract the yaw)
2. banking 5 deg into the OEI (counteract the roll)

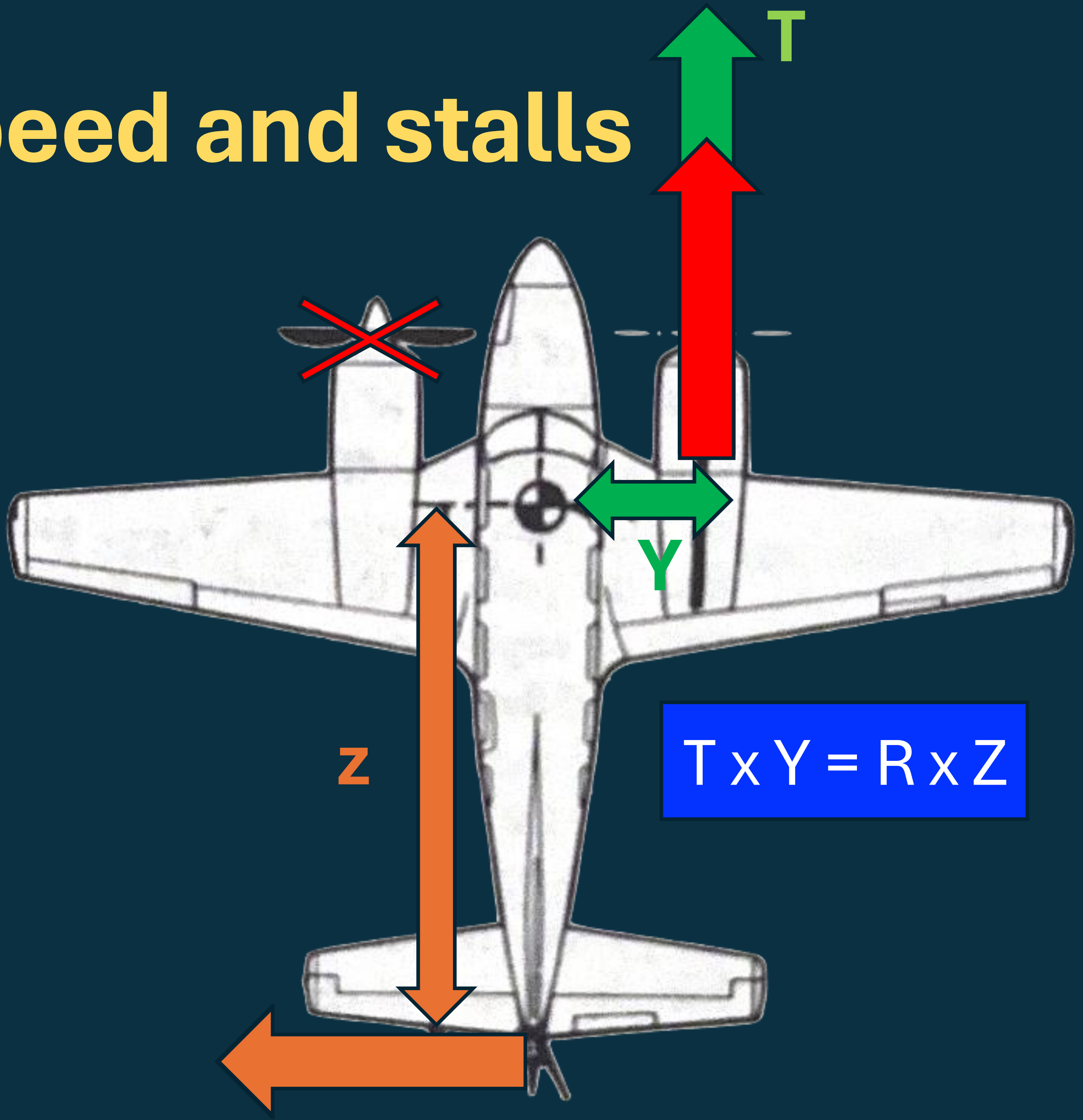
TO MAINTAIN DIRECTION OF FLIGHT

Correction of OEI Aerodynamics (2/2)



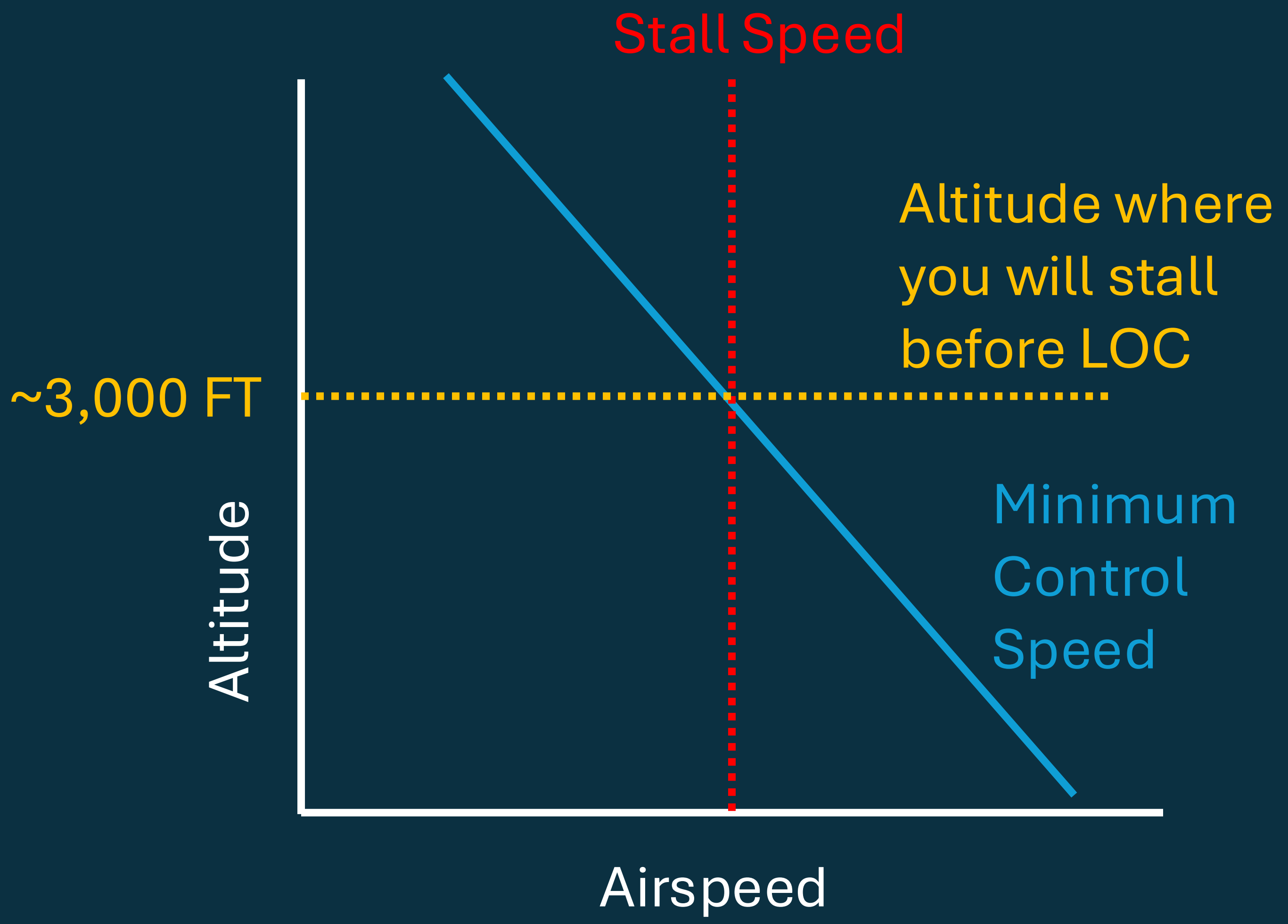
Warning on altitude, speed and stalls

- Minimum controllable speed decreases with altitude
- Thrust is reduced at altitude;
- Need less rudder moment to counteract that thrust!
- Therefore, if I don't change rudder deflection, I need less speed (dynamic pressure)!



Speed reduction to stall speed

- As the required speed to maintain control decreases, you get closer to stall!
- There exists an altitude at which the airplane will stall before it loses control.
- Minimum control speed matches stall speed.



THE CRITICAL ENGINE

"Obviously, THAT ONE had to fail" – pilots adding up their luck

What is the Critical Engine?

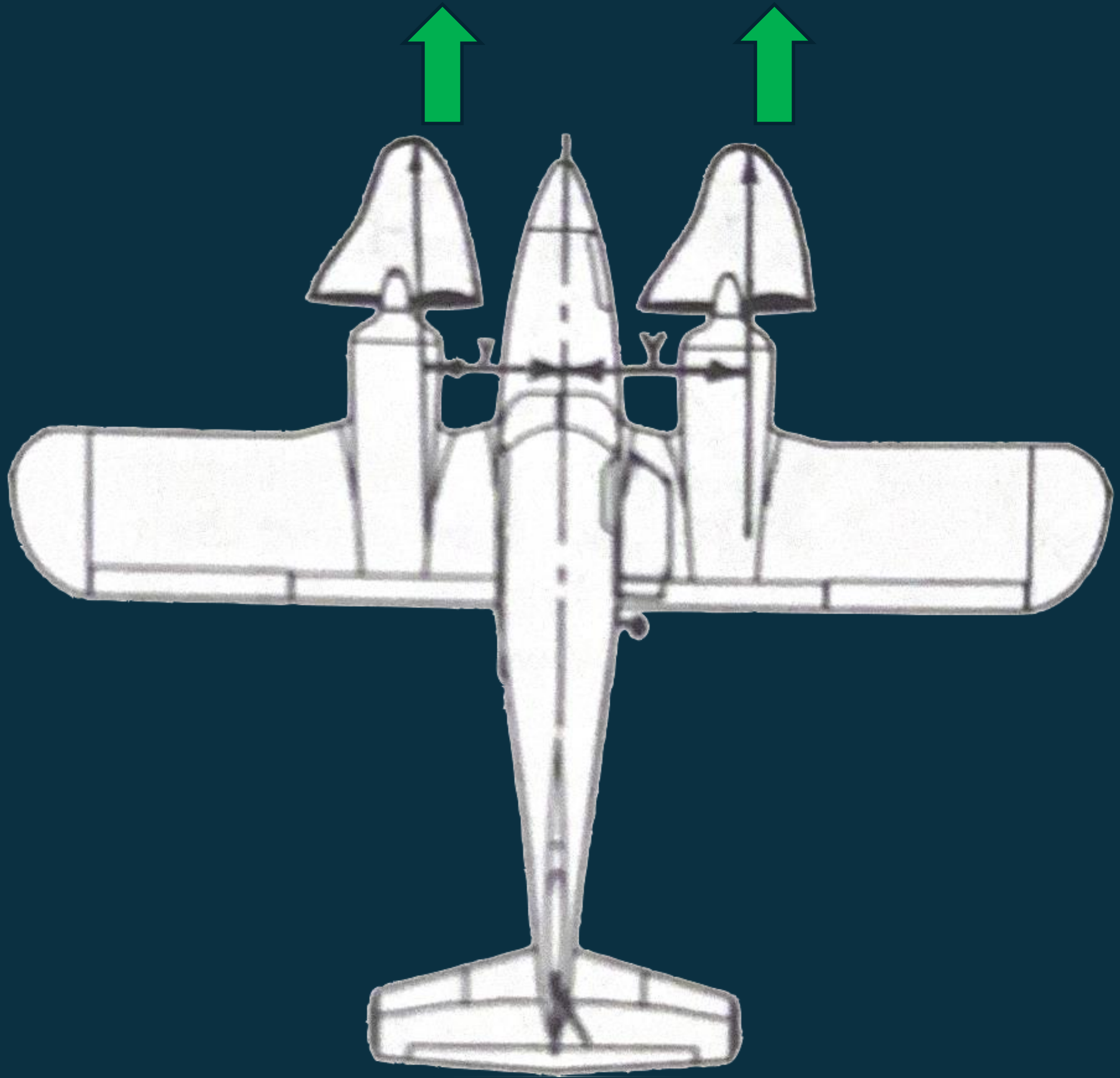
- Losing an engine causes adverse effects.
- Is one worse than the other? Yup.
- The engine that, if failed, would cause the **most adverse effects** on aircraft performance and handling characteristics.
- Applicable aerodynamically to **propeller-driven** airplanes only.
- Not to be confused with the critical engine in larger turbine aircraft, which is often defined in terms of **systems** consequences.
    - Large aircraft use engine “air” to power/run systems. But don’t worry too much on that for now. Wait until your type rating to start crying.
- Critical engine is defined by propeller aerodynamics.
    - Counter-rotating props prevent a “critical engine”.

Factors affecting the Critical Engine (PAST)

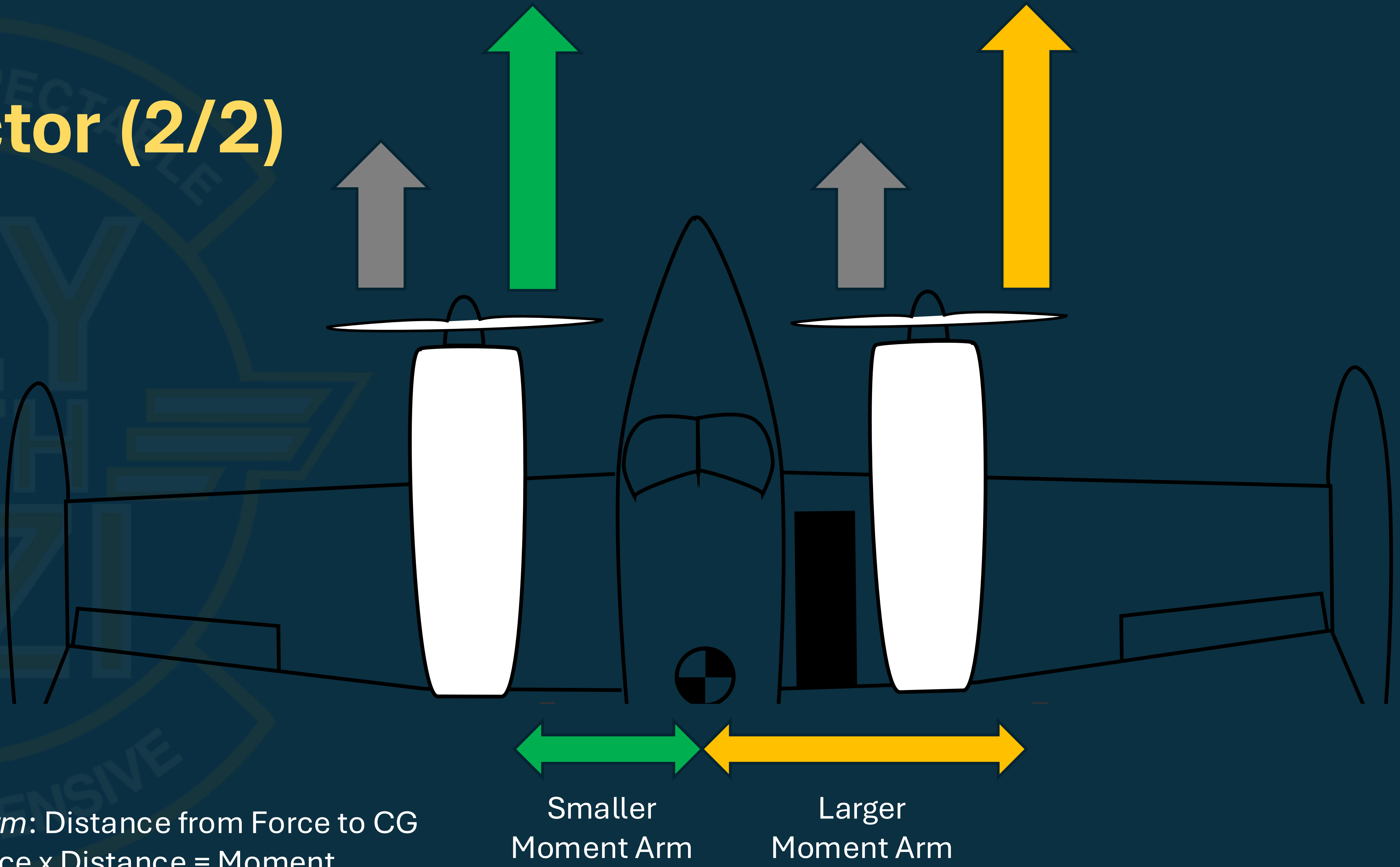
- **P**-Factor
- **A**ccelerated Slipstream
- **S**piraling Slipstream
- **T**orque

P-Factor (1/2)

- Recall that P-factor is the phenomenon where, at positive angles of attack, the **descending blade of the prop** produces a higher thrust (aerodynamically) than the ascending blade.
- As such, the propeller itself produces asymmetric thrust.

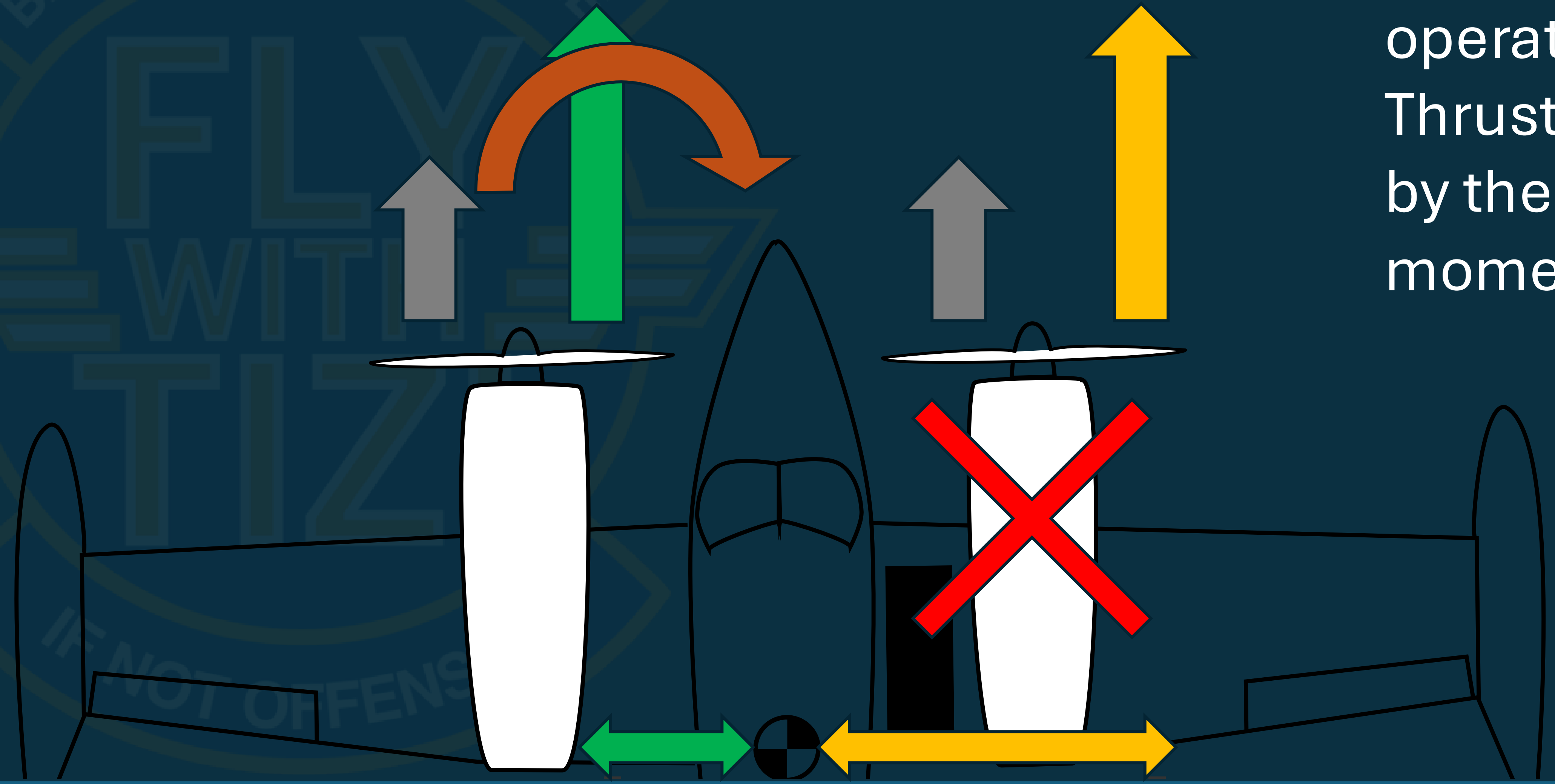


P-Factor (2/2)



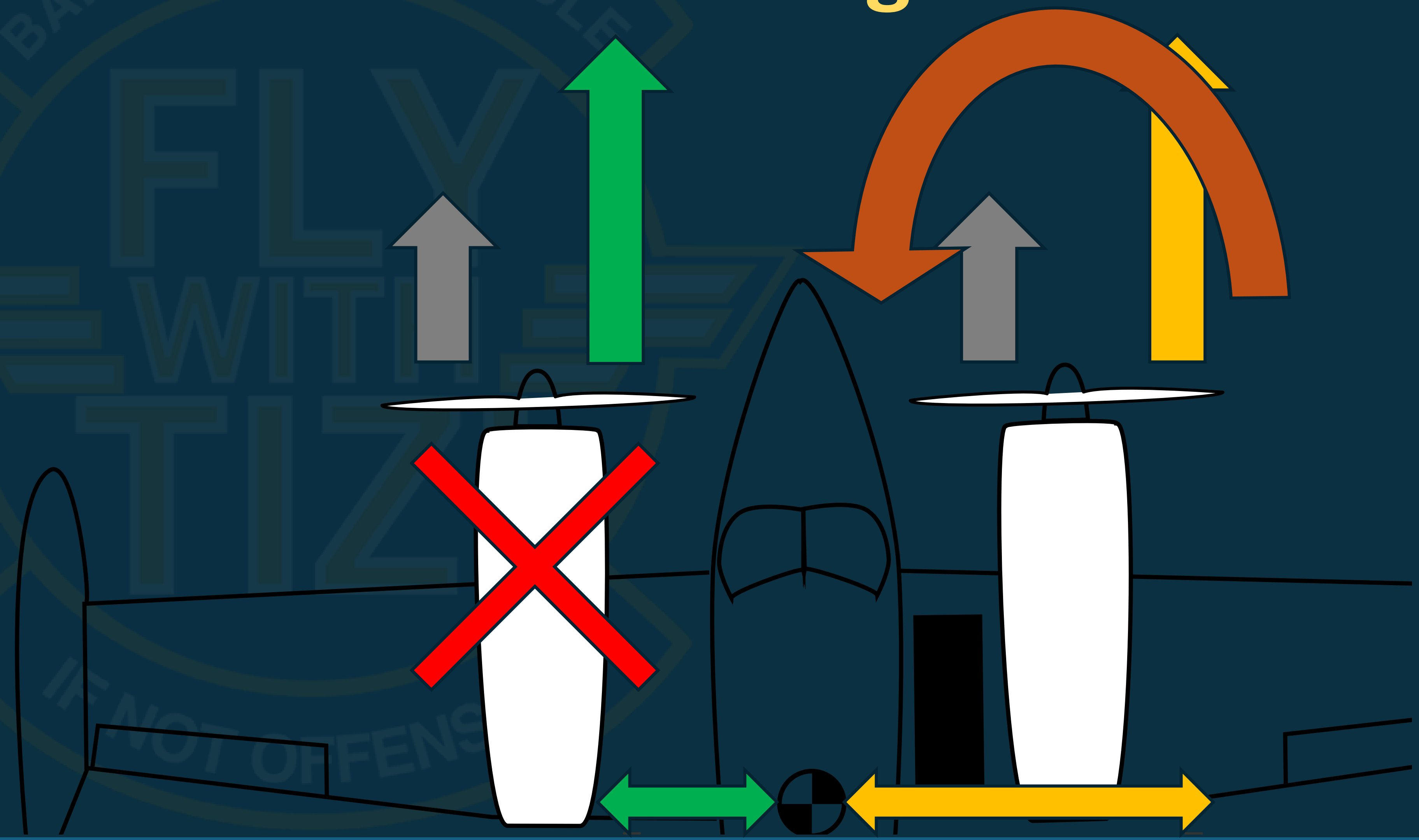
Moment arm: Distance from Force to CG
Recall: Force x Distance = Moment

P-Factor: If Right Engine Fails...



The resultant moment from the operative engine is Thrust multiplied by the “smaller” moment arm.

P-Factor: If Left Engine Fails...



The resultant moment from the operative engine is Thrust multiplied by the "larger" moment arm. So the moment is greater compared to the right engine inop case.

P-Factor: Critical Engine Determination

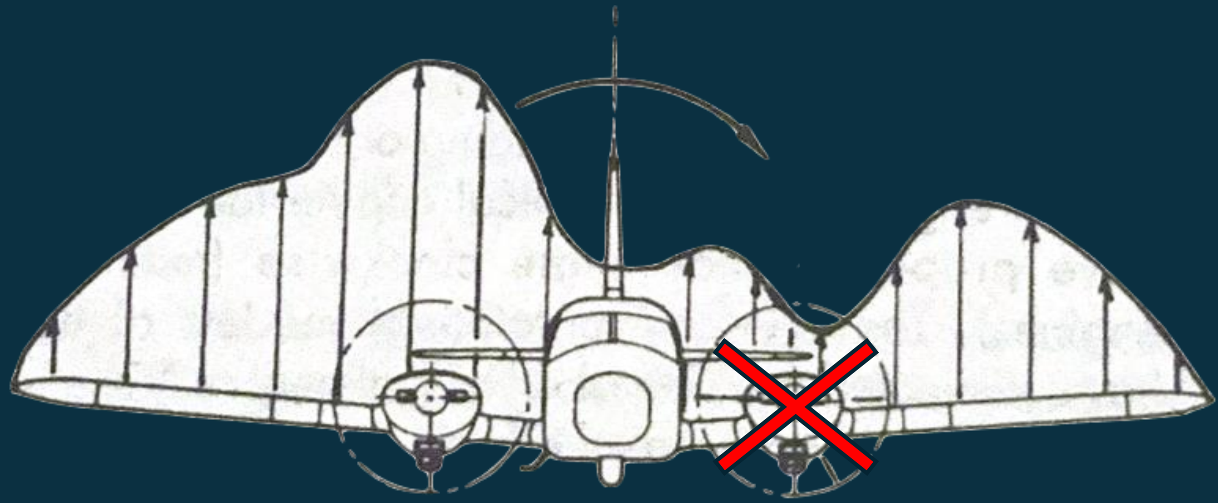
- If the right engine fails, there will be an induced yaw to the right.
- If the left engine fails, there will be an induced yaw to the left. **But because the moment arm is larger between the right engine descending propeller and the center of gravity, the yawing moment will be larger!**

CRITICAL ENGINE

LEFT

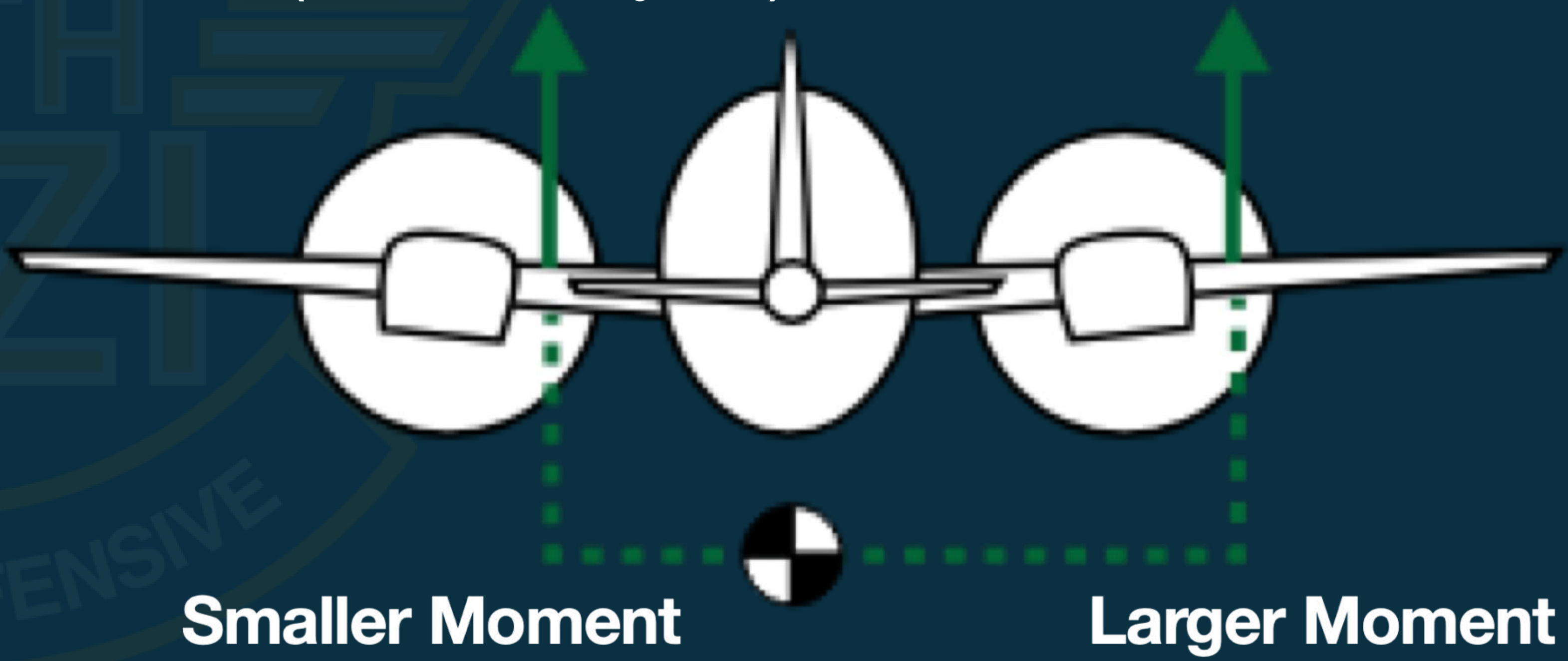
Accelerated Slipstream (1/2)

- We learned how P-factor affects thrust. This thrust has a consequence on the lift generated behind the propeller!
- More thrust = **more slipstream** on the side of the descending blade.
- More slipstream = **more lift**!

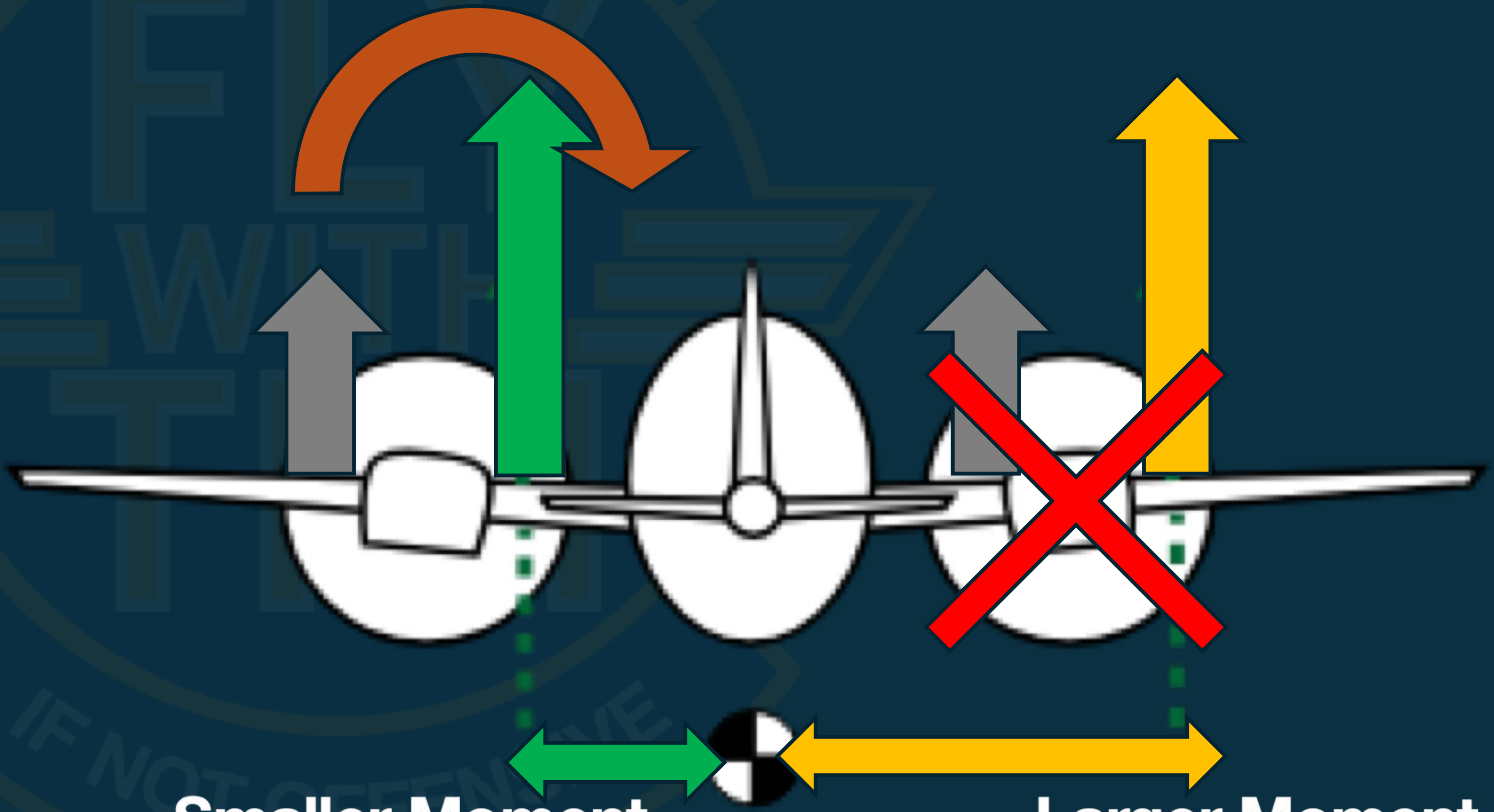


Accelerated Slipstream (2/2)

- The same argument for P-factor applies. The only difference that instead of looking at “yaw” (induced by thrust), we are looking at “roll” (induced by lift).

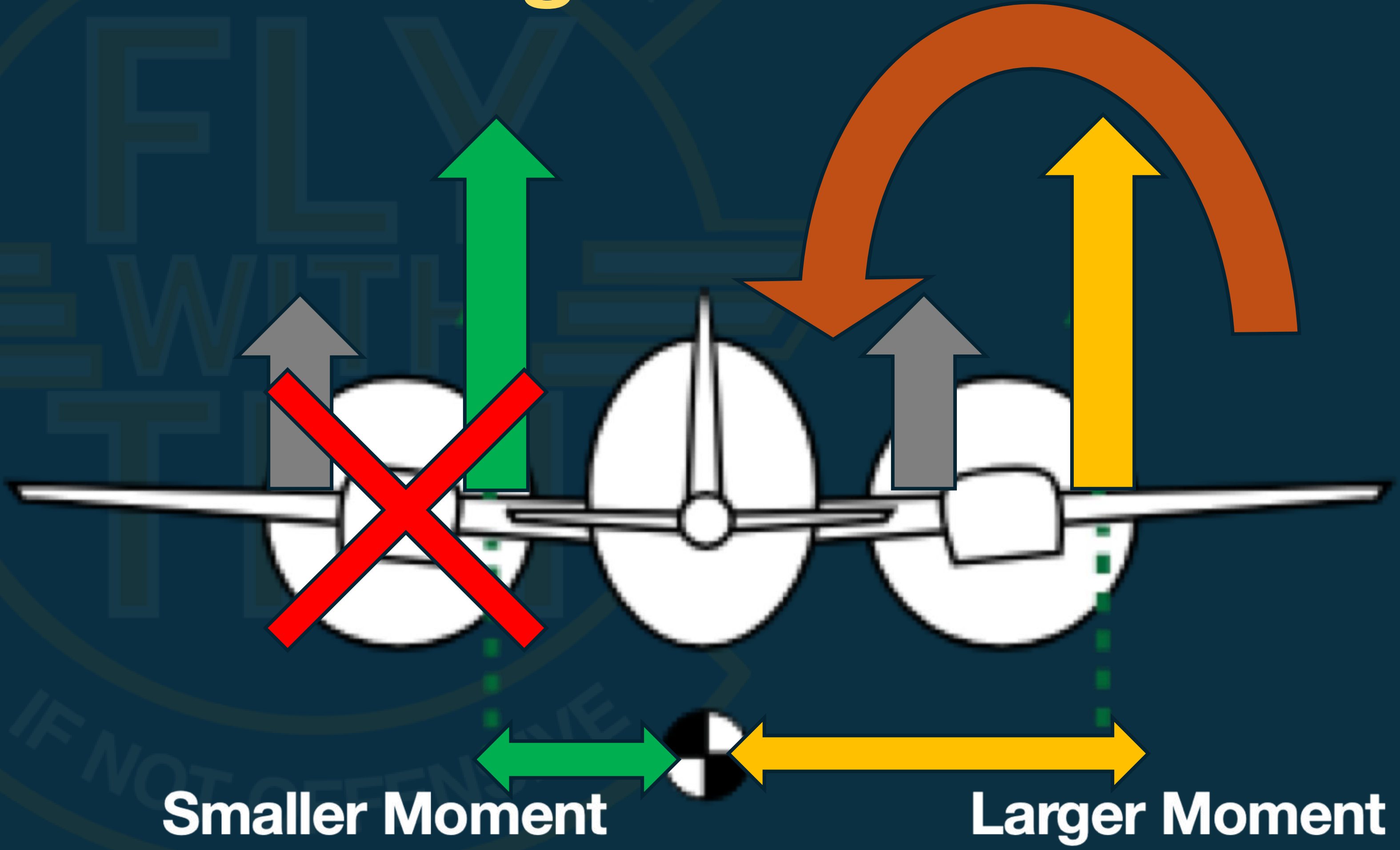


Accelerated Slipstream: If Right Engine Fails?



The resultant moment from the operative engine is Lift multiplied by the “smaller” moment arm.

Accelerated Slipstream: If Left Engine Fails?



The resultant moment from the operative engine is Lift multiplied by the "larger" moment arm. So the moment is greater compared to the right engine inop case.

Accelerated Slipstream: Critical Engine Determination

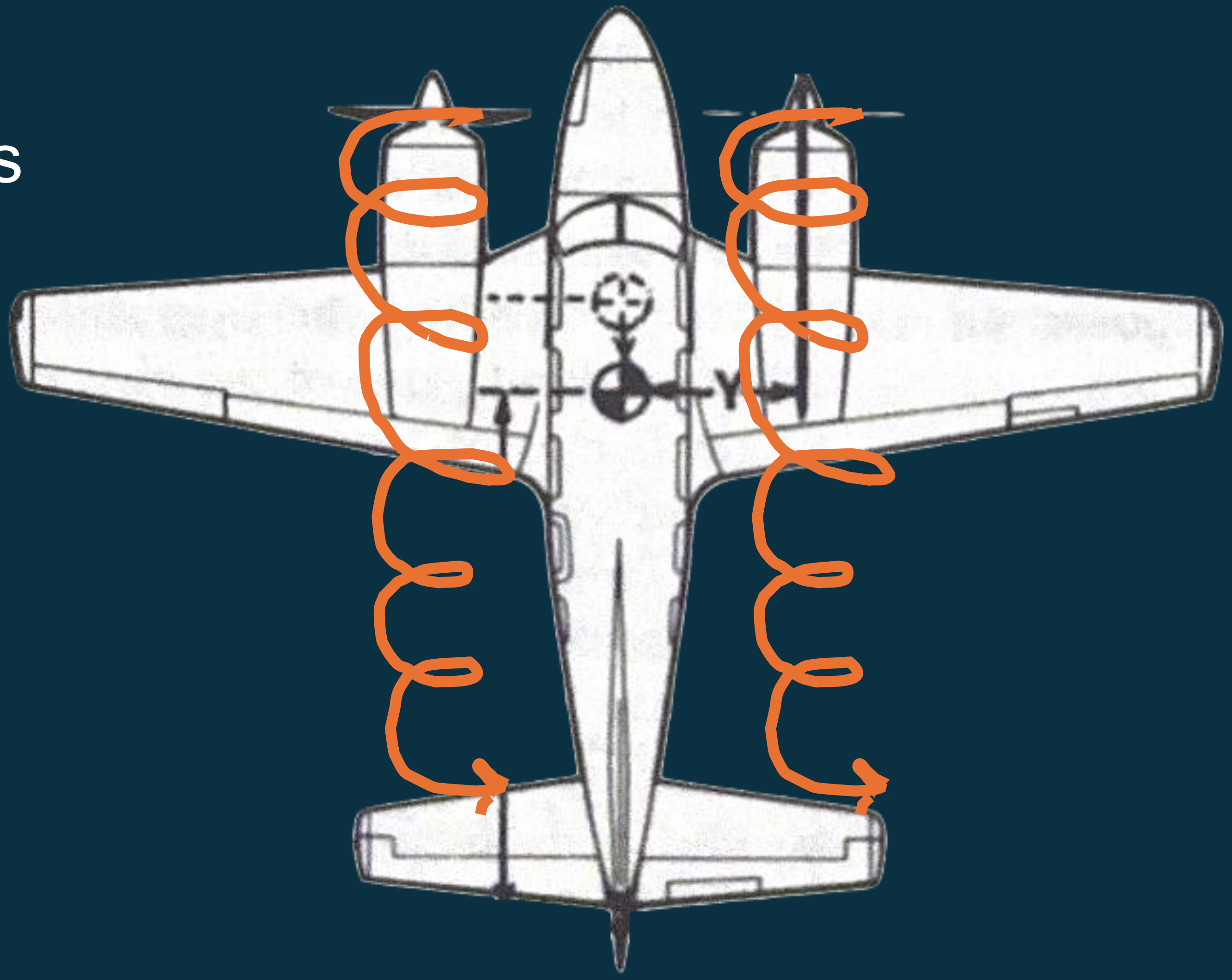
- If the right engine fails, there will be an induced roll to the right.
- If the left engine fails, there will be an induced roll to the left. **But because the moment arm is larger between the right engine descending propeller (where lift is higher) and the center of gravity, the rolling moment will be larger!**

CRITICAL ENGINE

LEFT

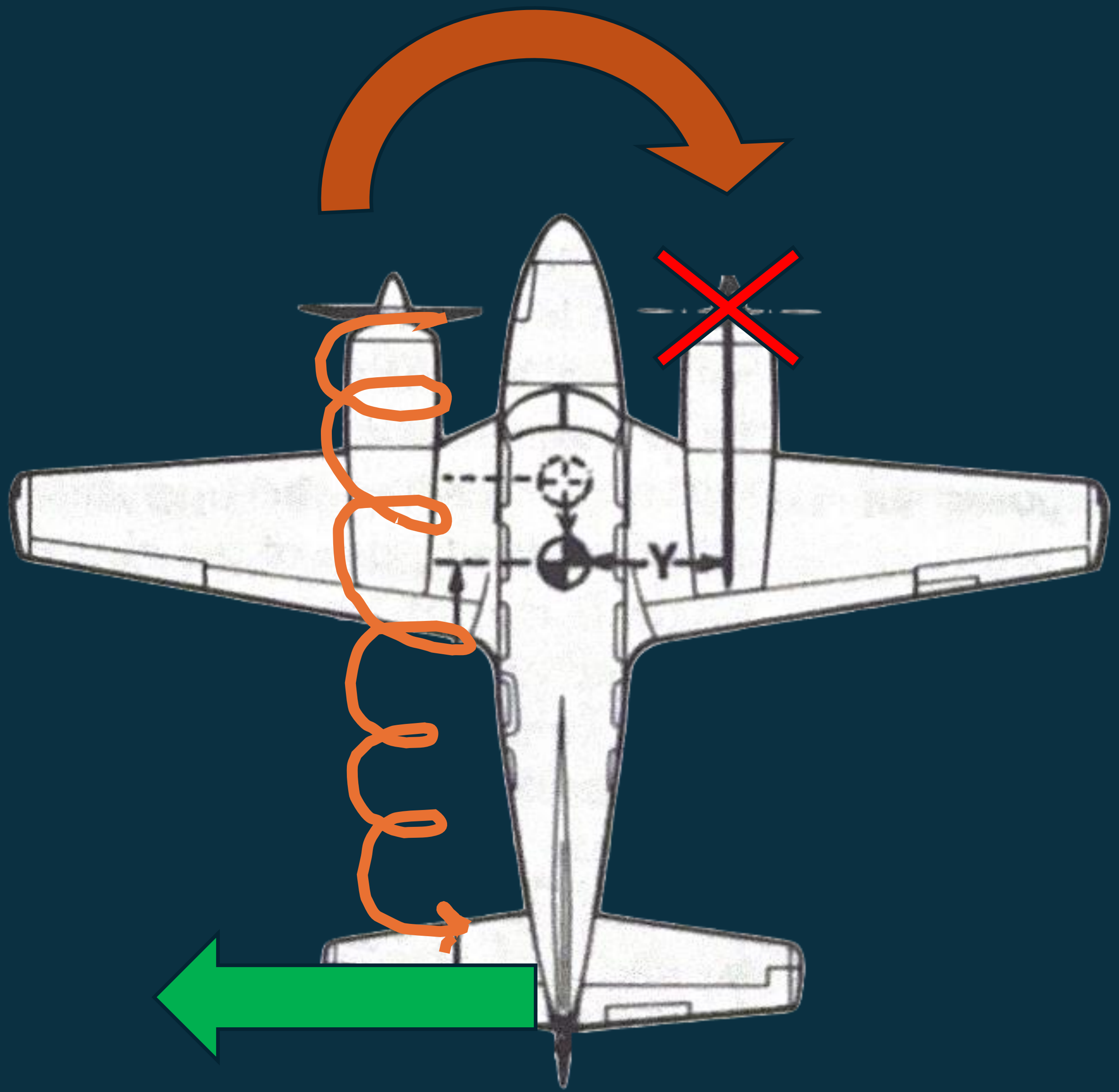
Spiraling Slipstream

- An operative engine produces a spiraling slipstream.
- An inoperative engine does not produce a spiraling slipstream.
- The slipstream moves aft during flight with prop wash.
- Slipstream affects the rudder.



Spiraling Slipstream: If Right Engine Fails?

- The spiraling slipstream from the left engine projects onto the rudder providing rudder effectiveness.
- The yawing helps counteract the yawing tendency from the inop engine.



Spiraling Slipstream: If Left Engine Fails?

- The spiraling slipstream from the right engine does not project onto the rudder.
- The engine's yaw motion is not counteracted by the rudder since the slipstream does not hit it.

Spiraling Slipstream: Critical Engine Determination

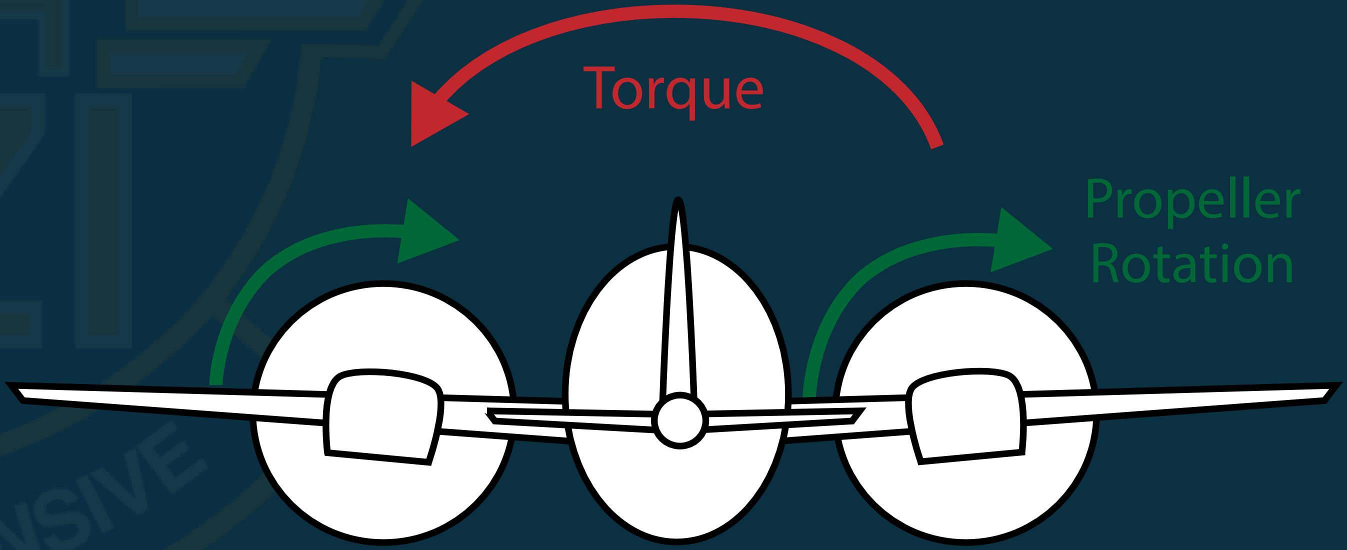
- If the right engine fails, the left slipstream will hit the rudder and help counteract the yawing tendency.
- If the **left engine fails**, slipstream will not hit the rudder and not help counteract the yawing tendency.

CRITICAL ENGINE

LEFT

Torque

- Propeller turning causes torque.
- The torque causes a roll tendency in the opposite direction of propeller rotation.



Torque: If Right Engine Fails?

- Airplane wants to roll right.
- Propeller rotation causes a torque in the opposite direction.
- That causes a roll to the left.
- The torque helps to counteract the inop engine rolling tendency.

Torque: If Left Engine Fails?

- Airplane wants to roll left.
- Propeller rotation causes a torque in the opposite direction.
- That causes a roll to the left.
- The torque enhances the left rolling tendency, making it worse.

Torque: Critical Engine Determination

- If the right engine fails, there torque will counteract the rolling tendency.
- If the **left engine fails**, the torque will not counteract the rolling tendency. It will in fact enhance it.

CRITICAL ENGINE

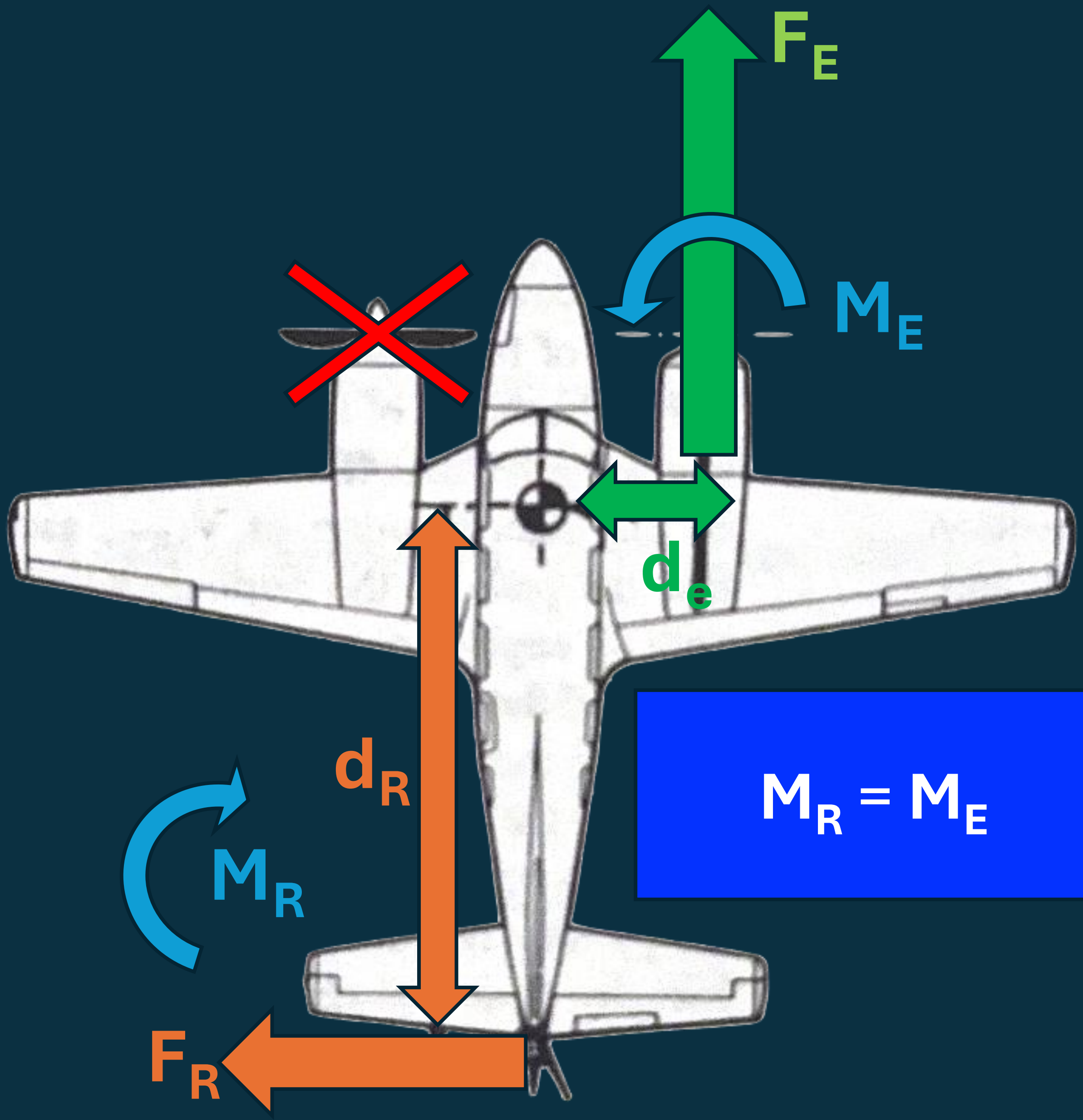
LEFT

Minimum Control Speed, V_{MC}

“Airspeed is life”– Tizi

What is the V_{MC}?

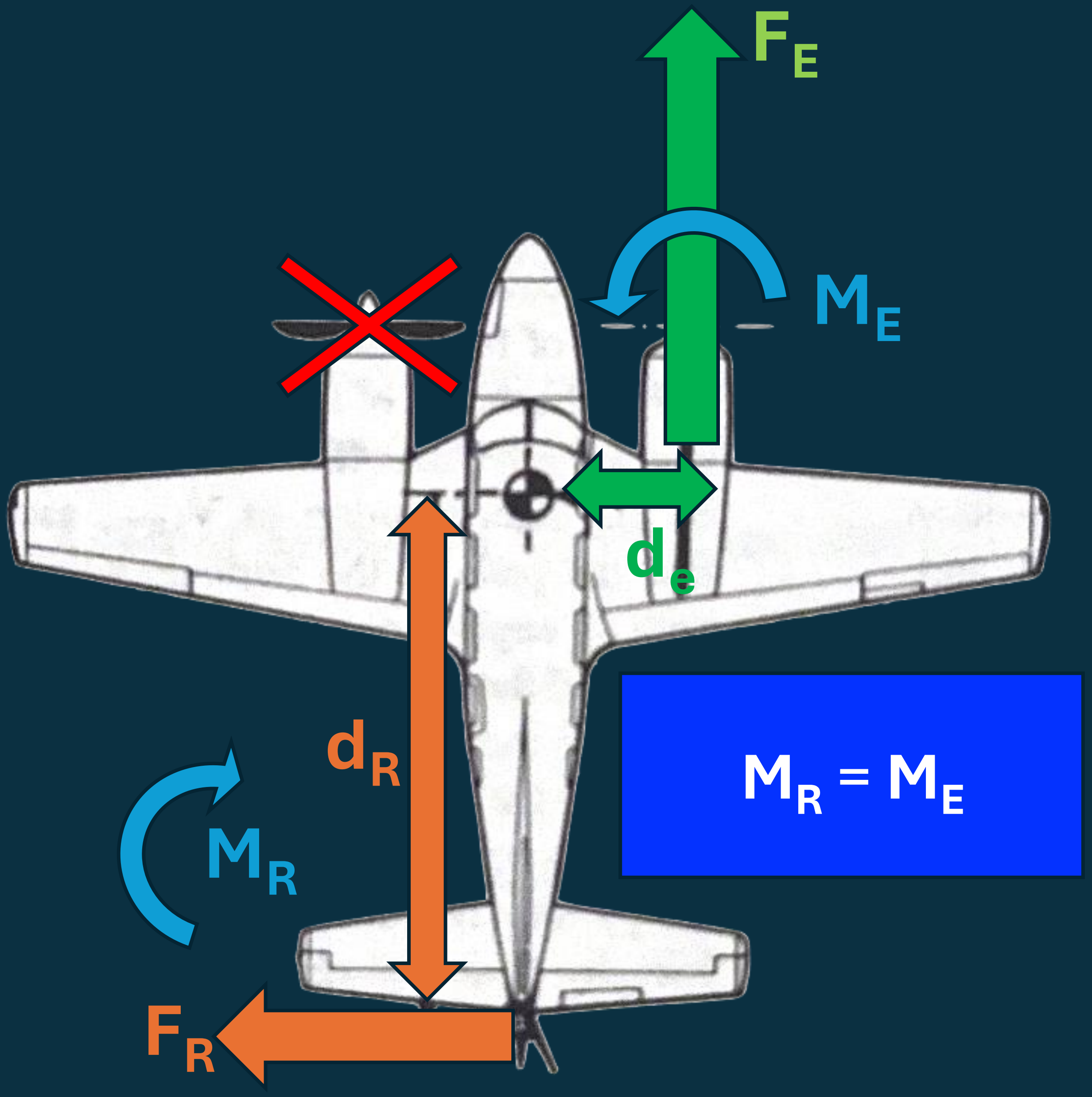
- V_{MC} is the minimum controllable airspeed at which directional control can be maintained with the critical engine inoperative.
- As I lose airspeed, the rudder becomes less effective.
- I need to counteract the effect of F_E
- Speed at which rudder authority is not enough to counteract the aerodynamic forces due to OEI.



$M_R = M_E$

Changes in V_{MC}?

- **Lower V_{MC}** = good.
  - More airspeeds to fly and farther away from LOC.
- **Higher V_{MC}** = bad.
  - Less airspeeds to fly and closer to LOC.
- Whatever helps F_E
  - Increases V_{MC} - need more rudder!
- Whatever helps F_R
  - Decreases V_{MC} - need less rudder!

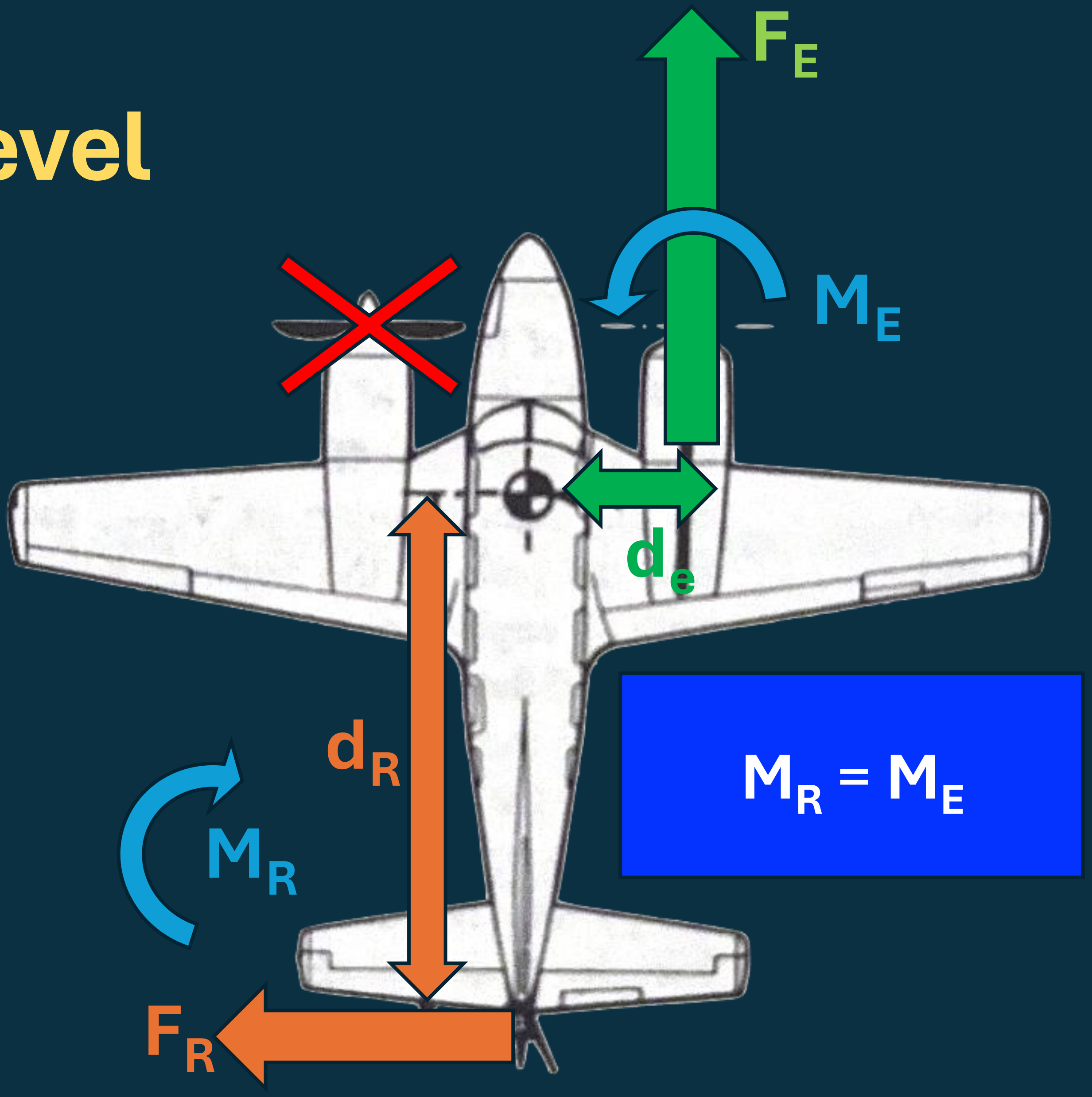


Factors affecting V_{MC} (SMACFUM)

- **S**tandard Day at Sea Level
- **M**ost unfavorable Weight
- **A**ft CG
- **C**ritical Engine Windmilling
- **F**laps Up
- **U**p to 5° Bank
- **M**ax Power

Standard Day at Sea Level

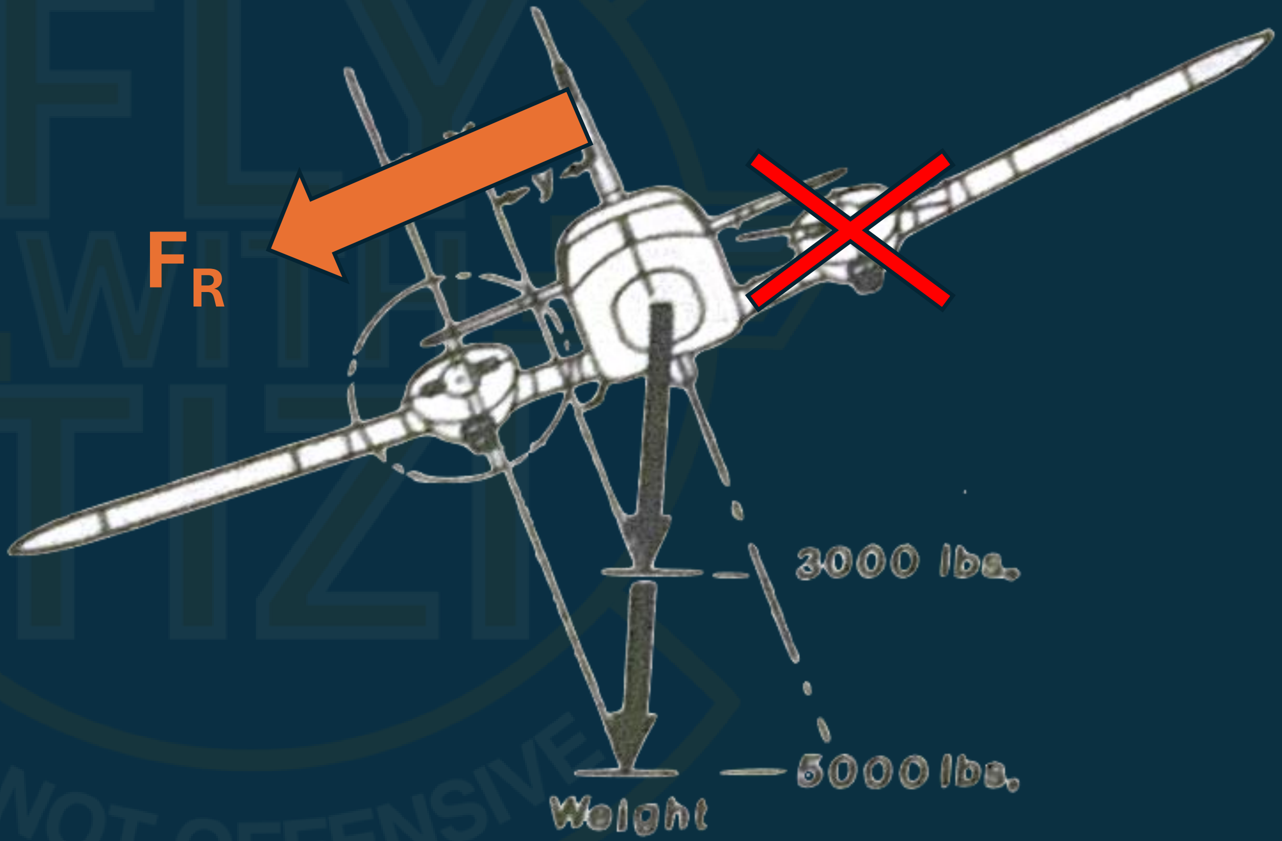
- The higher the air density, the higher the engine performance.
- The lower the density altitude, the higher the engine performance.
- Higher air density causes a higher F_E.
- Higher F_E causes V_{MC} to increase.

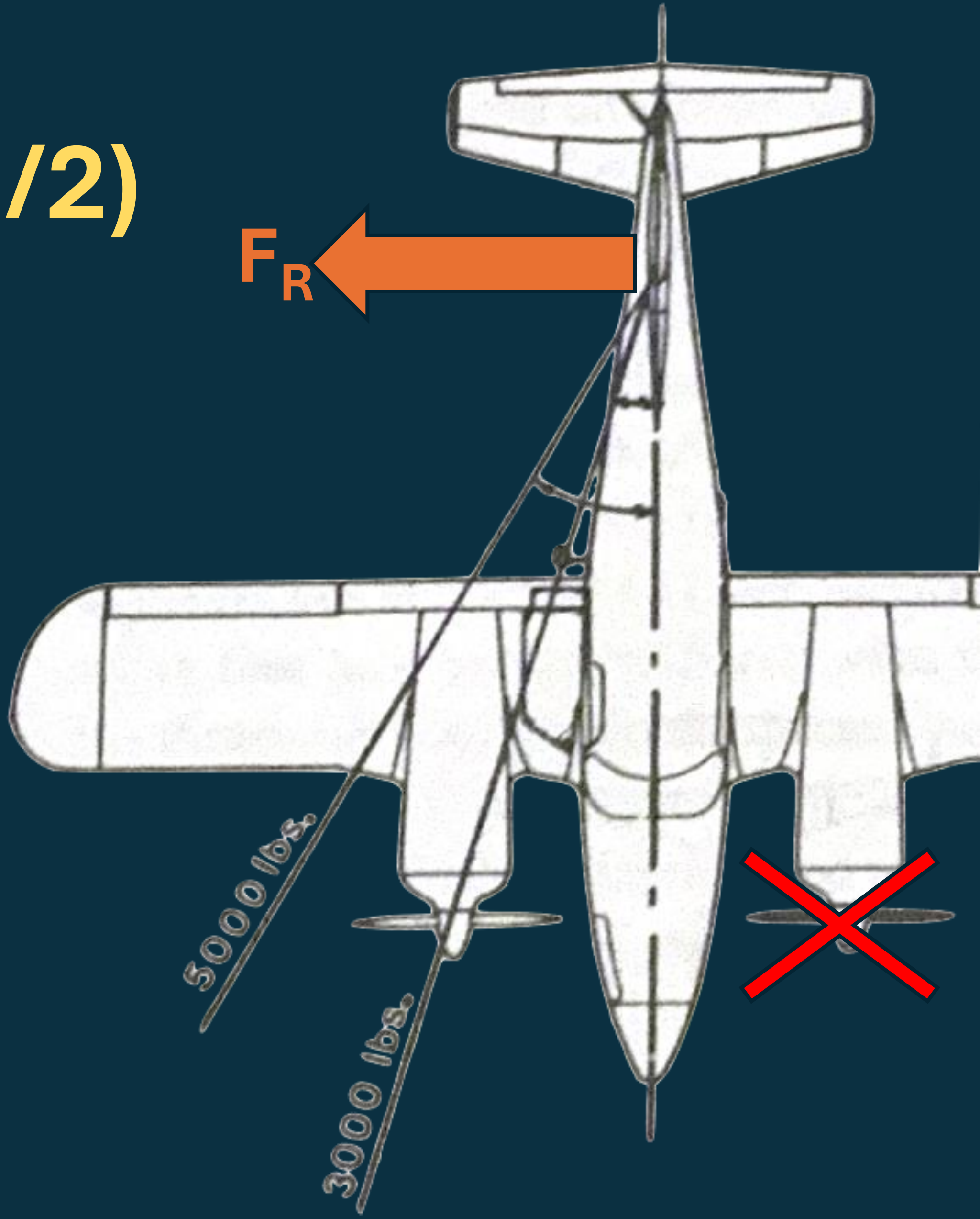


Most unfavorable weight (1/2)

- Weight plays a role in the lateral control of the aircraft.
- Part of recovery procedures include raising the dead engine's wing.
- The roll will project the weight vector towards the operating engine, enhancing the moment arm for rudder effectiveness.
- The greater the weight, the higher F_R.
  - Decreases V_{MC} - need less speed!
- Thel lower the weight, the lower F_R.
  - Increases V_{MC} - need more speed!

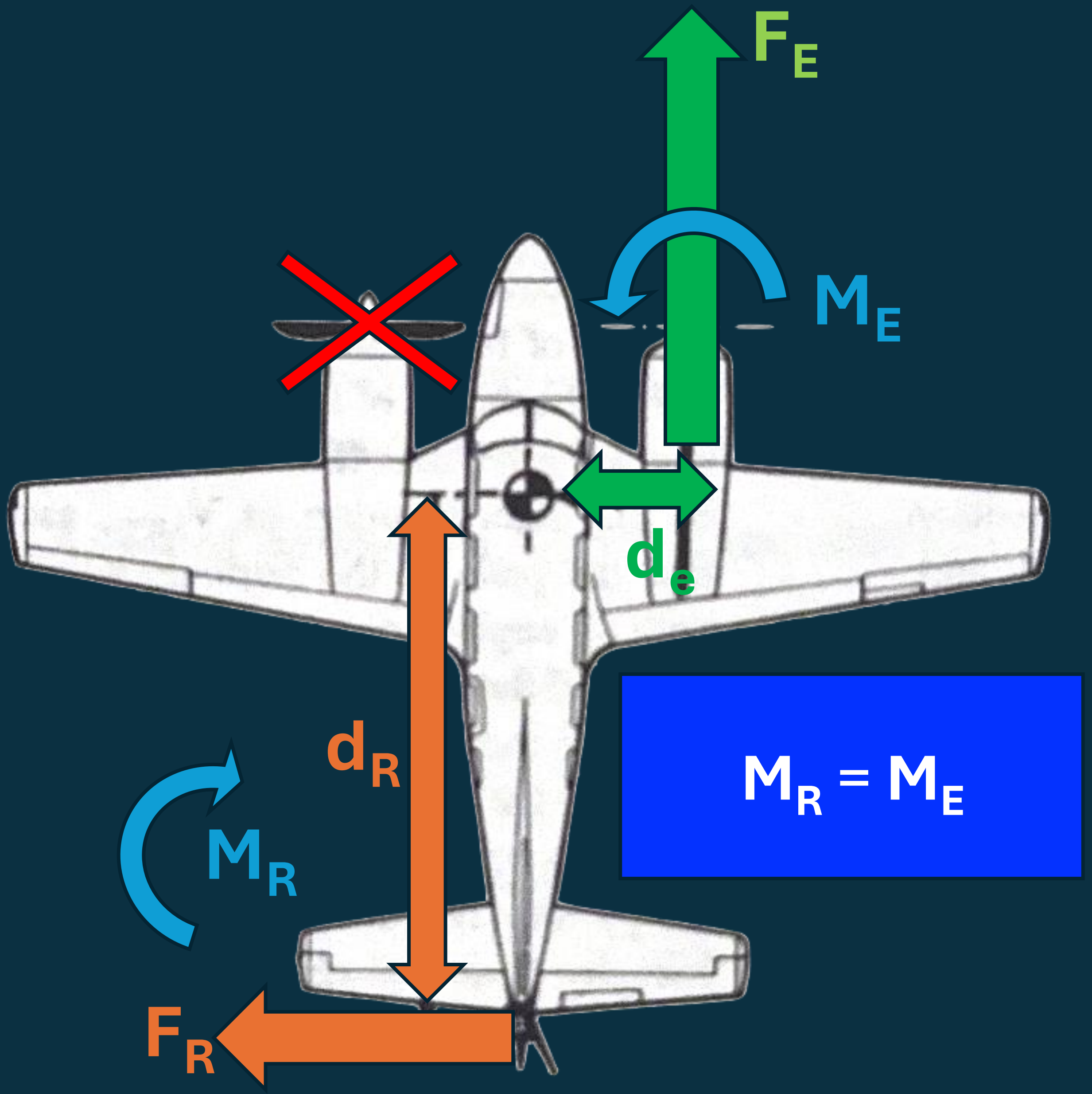
Most unfavorable weight (2/2)





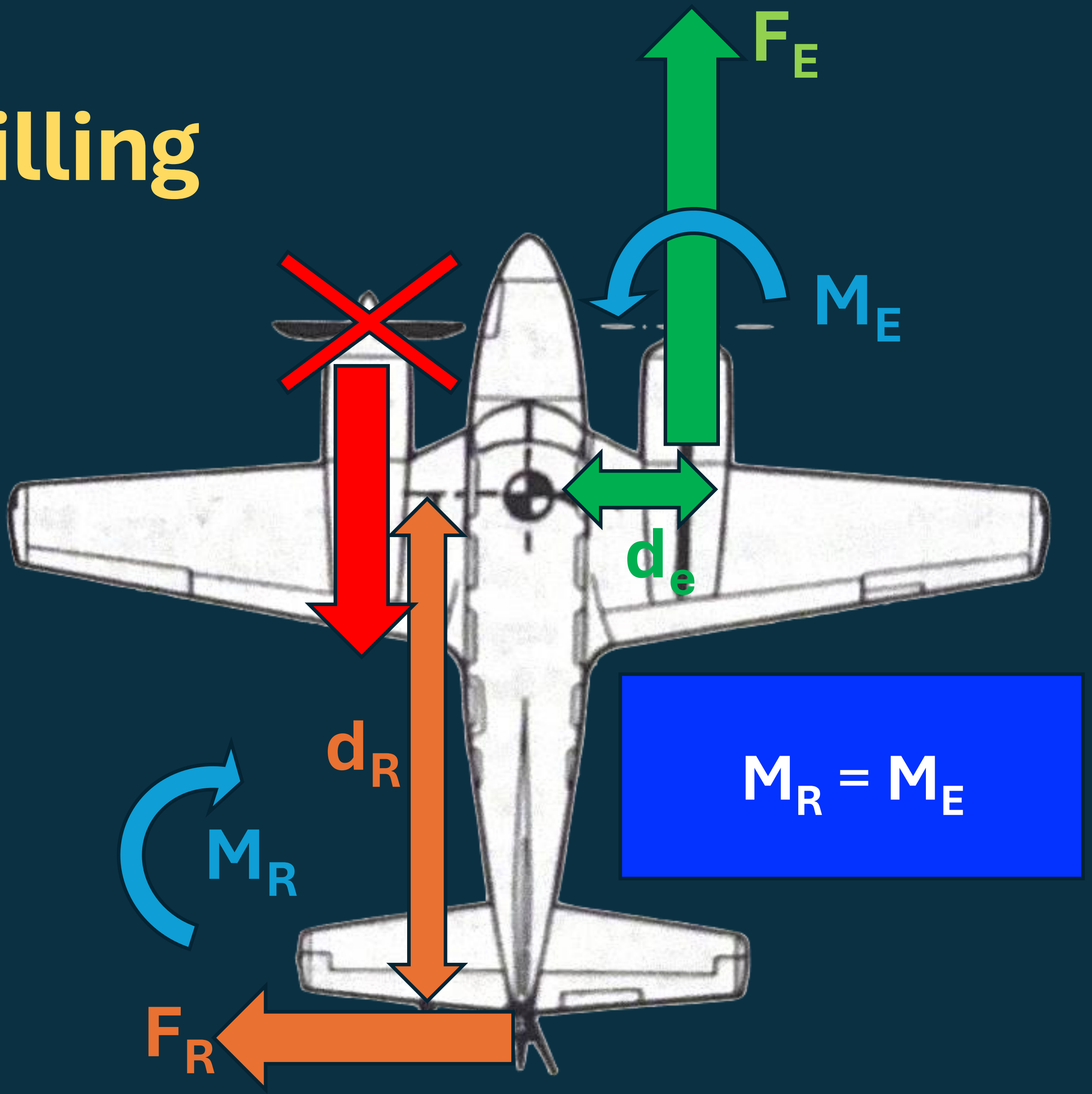
Aft CG

- Moving the aircraft CG aft will reduce the moment achievable by the rudder.
- Less rudder effectiveness, we need more speed.
- V_{MC} therefore increases.
- FWD CG = good, more F_R.
- AFT CG = bad, less F_R.



Critical Engine Windmilling

- Feathering the inop engine propeller minimizes drag.
- Windmilling is "unfeathering", which increases drag.
- Increased drag couples the moment from F_E.
- That requires more F_R and more speed, increasing V_{MC}.

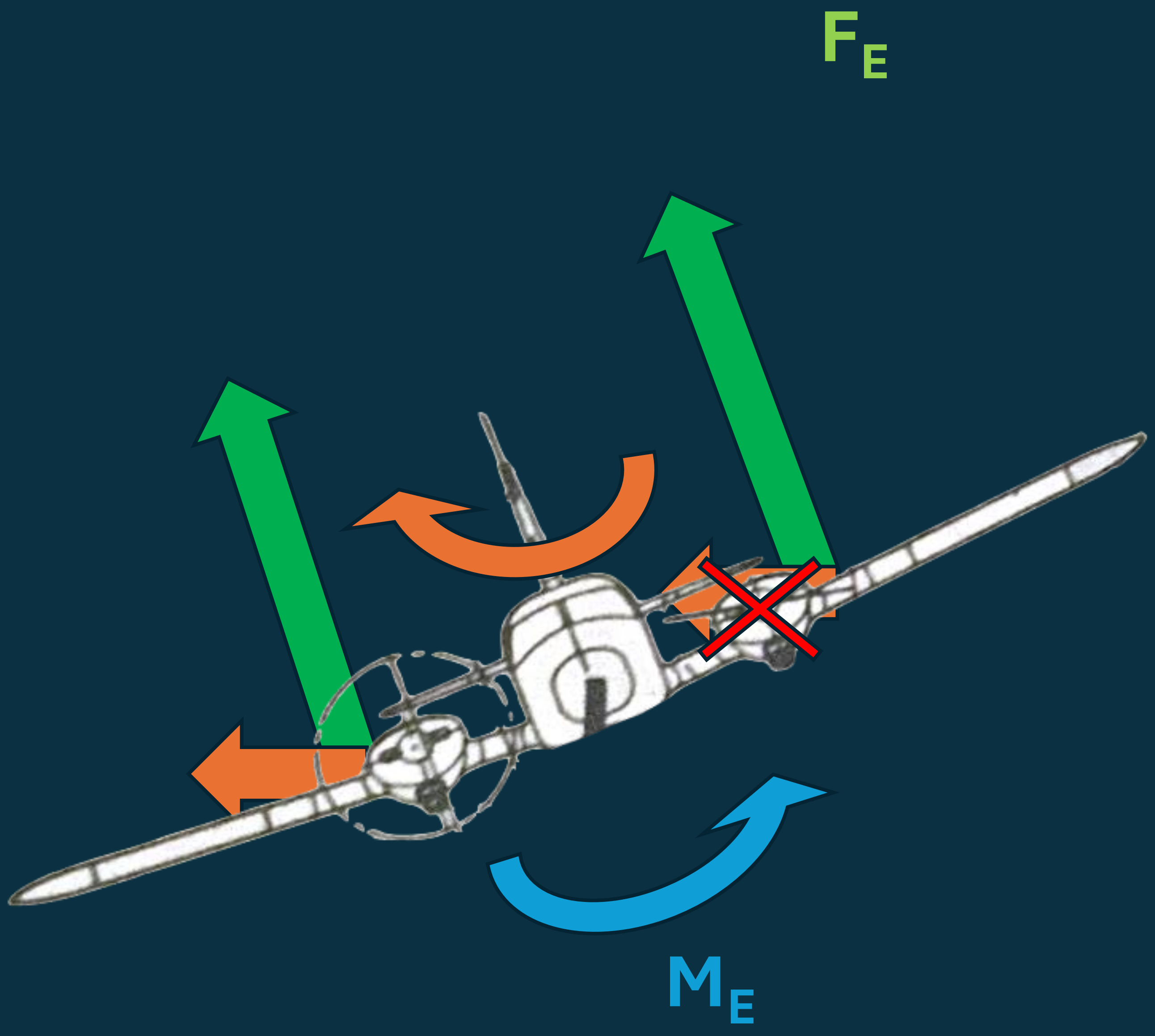


Flaps Up, Gear Up

- Both flaps and gear deployed will cause drag, which is a stabilizing element during OEI.
- The gear will cause a “keel effect”, which helps the airplane stay on course.
  - Like a psudo-wing.
  - Drag caused by propeller slipstream.
- Flaps up and gear up negatively affect this stabilizing element, increasing V_{MC}.

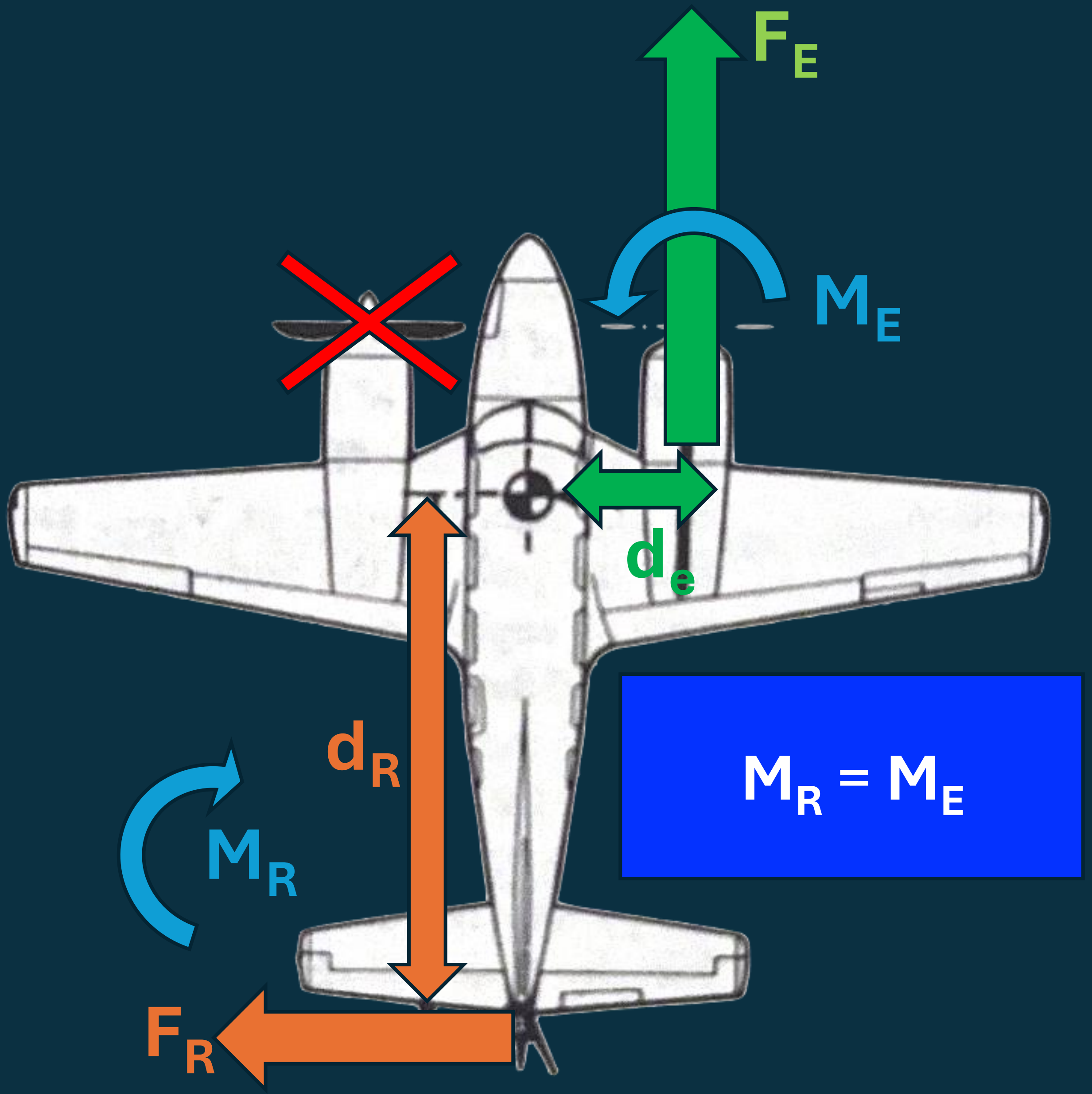
Up to 5° Bank

- The operating engine causes a **yaw moment**.
- By raising the OEI wing, we re-distribute some of the lift to a horizontal component which acts in the **opposite direction of that yaw moment**.
- Increasing the bank angle will decrease V_{MC}.



Maximum Power

- Just like density altitude, the more power means more F_R required.
- If I run out of F_R, I need more speed, increasing V_{MC}.



ENGINE OUT PROCEDURES

"Identify, Verify, Screaaaaam" – Most Multiengine students

Memory Procedure (5 steps)

1. Maintain Directional Control
2. All engine controls full forward
3. Flaps Up / Gear Up
4. Identify – Verify – Secure
5. Cheklist

NOTE: All of these happen very quickly one after the other.

Maintain Directional Control

- Apply rudder as necessary to maintain directional control
- Pitch speed for Blue Line: V_{YSE}.
  - V_{YSE} is best single engine climb rate with max power and minimum drag
  - V_{XSE} is only used to clear obstructions during OEI and may be very close to V_{MC}, so a lot of danger.
- Coordinate the aircraft by
  - Raising the dead – raise the dead engine wing ~5 degrees
  - Splitting the ball – adjust rudder to split the ball

All Engine Controls Full Forward

- Give yourself maximum RPM and manifold pressure by
  - Increasing mixture to full rich
  - Increasing prop control to max RPM
  - Increase throttle to max manifold pressure
- If you're on takeoff, these will already be configured. All you need to do is verify.
- If you're already in a given engine configuration, remember to start from the right and move to the left as to follow proper engine RPM/power setting changing procedures (i.e. increase prop before throttle).

Flaps Up, Gear Up

- Minimize drag by making sure that the flaps and the gear are in the up position.
- In cruise, this will already be the case, so just verify.
- On takeoff, these will most probably need to be adjusted.
- To avoid a rapid loss of lift with still a lot of drag, some prefer to
  - Retract flaps partially
  - Raise the gear
  - Finish retracting the flaps
- Always refer to POH for guidance.

Identify – Verify - Secure

- The previous steps should happen by instinct. That is, you apply rudder to counteract dead engine by seeing what the airplane does. Then you proceed to
- Identify the dead engine. Dead foot (not using rudder) is the dead engine.
- Verify that is indeed the dead engine by throttling back. That should not affect the lateral-directional controllability of the airplane.
- Secure the dead engine by
  - feathering (propeller full aft)
  - Closing the mixture to cutoff fuel supply

Checklist

- If this happens for real, you will be more than startled.
- Verify all your procedures by referencing the checklist.
- FOLLOW THE CHECKIST!!

Operational Considerations (1/3)

- Losing an engine is a major problem.
- Below 3,000 ft it should be considered an emergency.
  - Declare immediately, prepare to land, follow the checklist.
- Above 3,000 ft, it's considered an urgency.
  - Troubleshoot, be ready to declare an emergency.
- For training, there exists a minimum safe single engine speed, V_{SSE} below which one should not try to shut down an engine.
  - For PA30, V_{SSE} >85 kts (but please stay above blue line).

Operational Considerations (2/3)

- Single engine service ceiling: Density ALT at which you are not capable of maintain 50 FPM climb with OEI
- Single engine absolute ceiling: Density ALT at which you achieve 0 FPM climb with OEI fully feathered and other engine at max power.
- OEI = loss of 50% of thrust
  - **Loss of 80—90% of climb performance**!
- Accelerate Stop: distance required to accelerate to V_R, lose an engine, and abort to complete stop on the runway (~3,000 ft, see POH)
- Accelerate Go: distance required to accelerate to V_R, lose an engine, and continue to takeoff and reach 50 ft.

Operational Considerations (3/3)

- Landing single engine is not fun.
- Avoid too much drag, so limit flaps to partial configurations only.
  - Full flaps on short final only, if required
- As you change speed, directional control will change
  - Modulate rudder input as needed
- Please avoid OEI go-arounds
  - You should have declared an emergency at that point, so the field should be all yours
- Remember that V_{MC} increases as altitude decreases, so watch your red line on landing.

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