Secondary Flight Controls

Session Time: One, 50-minute session

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

The intended purpose and use of an aircraft drives aircraft design considerations and construction techniques, materials, and components. (EU1)

The principles of aerodynamics all an aircraft to fly, yet those same principles limit its ultimate performance and capabilities. (EU2)

A deep understanding of how an aircraft operates enables a pilot to fly the aircraft to its maximum capabilities in both normal and abnormal situations. (EU5)

ESSENTIAL QUESTIONS

1. Why would a pilot want to change the aerodynamics of a wing in flight?

LEARNING GOALS

Students Will Know

- The types and placement of secondary flight controls
- The primary functions of secondary flight controls
- How to differentiate among flap styles

Students Will Be Able To

- *Identify* examples of secondary flight controls installed in various aircraft. (DOK-L1)
- *Explain* the characteristics of different types of flap systems. (DOK-L2)
- *Explain* the function of secondary flight controls (DOK-L2)
- *Predict* the effects of secondary flight control failures. (DOK-L2)

ASSESSMENT EVIDENCE

Warm-up
Students watch a video of an impressive performance by a STOL (Short Take Off and Landing) aircraft. Students will predict why this airplane can perform is such a manner based on what they've learned about lift and drag.

Formative Assessment
Students will identify the different flap types and describe the aerodynamic principles behind how they affect flight behavior.

Summative Assessment

Students will explain the normal function of each secondary flight control and then describe the consequences to an airplane's performance when that control system is not functional.

LESSON PREPARATION

MATERIALS/RESOURCES

- Secondary Flight Controls Presentation
- Secondary Flight Controls Student Activity 1
- Secondary Flight Controls Student Activity 2 **(Optional)**
- Secondary Flight Controls Student Activity 3
- Secondary Flight Controls Teacher Notes 1
- Secondary Flight Controls Teacher Notes 2 **(Optional)**
- Secondary Flight Controls Teacher Notes 3

Explore the Effects of Secondary Flight Controls (Optional)

- iPads with "Wind Tunnel" application downloaded ($4.99)
  https://itunes.apple.com/us/app/wind-tunnel-for-ipad/id450980034?mt=8

Recommended Student Reading

- **Pilot's Handbook of Aeronautical Knowledge**
  Chapter Six, Flight Controls
  https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/08_phak_ch6.pdf

LESSON SUMMARY

The lesson will begin by introducing students to the importance of the secondary flight controls. An example of an aircraft where they play a key role is a STOL (Short Take Off and Landing) aircraft. These airplanes are essential in places like Alaska where long runways aren't always possible. To achieve their impressively short takeoff and landing rolls, they use flaps, a type of secondary flight control.

Students will then learn about the first of four types of secondary flight controls: flaps. After learning about flaps, students are assessed on their understanding of different flap types and their effects.

The remainder of the lesson covers leading edge devices (slots, slats, and leading edge flaps), the trim system, and spoilers. A second optional activity allows students to experiment with adding flaps, slats, and spoilers to an airfoil in a wind tunnel simulator.

FInally, students have the opportunity to demonstrate what they've learned by answering private pilot knowledge test questions. The summative assessment asks students to describe how the failure of various secondary flight controls will affect aircraft performance.

BACKGROUND

Secondary flight controls may not be as essential as primary flight controls, but they significantly add to an aircraft's overall safety and flyability. Every pilot must understand their functions and benefits and be skilled in operating them in coordination with the primary flight controls. Secondary flight controls rely on the same aerodynamic principles that students have been analyzing throughout this course.

There are four main types of secondary flight controls: flaps, leading edge devices, the trim system, and spoilers.

Flaps are typically found on the trailing edge of the wing. (We will cover leading edge flaps in the leading edge devices section.) They increase the camber of the wing and, in the case of Fowler flaps, the surface area. Deploying flaps increases both lift and drag, and changes the critical angle of attack for the wing, allowing for a lower stall speed.

Leading edge devices are found on the leading (front) edge of the wing. Like flaps, they may increase camber and/or surface area, increase lift and drag, and allow higher angles of attack and slower airspeeds.

The trim system allows the pilot to keep the airplane balanced, or "trimmed," for the desired attitude in flight. By adjusting a trim tab specific to each one of the primary controls--elevator, rudder, and ailerons--the pilot can alleviate the pressure needed to hold each control surface in the desired position. This allows the pilot to avoid the physical strain and mental distraction of applying constant pressure on the primary controls. This is especially useful in the event that a multi-engine aircraft loses an engine, as rudder trim alleviates the need for the pilot to put exhaustive, constant force on the rudder.

Spoilers are a device to "dump lift" and increase drag. They are often used to rapidly slow down a fast, powerful airplane, either during descent or on the runway after landing.

MISCONCEPTIONS

A key point for understanding secondary flight controls is to appreciate that different flight scenarios require different aerodynamics. Even though drag sounds like a negative force, sometimes drag can be a helpful feature (e.g., when spoilers help slow a heavy aircraft when aborting takeoff or upon landing).

DIFFERENTIATION

To support student comprehension in the **EXPLAIN** section, conduct the discussion as a Think-Pair-Share rather than as a large group activity. Have students work with a partner to discuss when an aircraft may need to reduce lift and increase drag before sharing their thoughts with the larger group. This strategy ensures that all students contribute to the discussion, generate ideas, and verbally analyze information.

LEARNING PLAN

ENGAGE

Teacher Material: Secondary Flight Controls Presentation

Slides 1-3: Introduce the topic and learning objectives of the lesson.

Slide 4: Conduct the **Warm-Up**.

Warm-Up

This warm-up engages students with a short video showing an interesting type of aircraft designed to take off and land using very short runways. Over the course of this lesson, students will learn how secondary flight controls make this possible.

First, define the acronym STOL = short takeoff and landing. Then remind students about the lift formula: $L = (C_L \rho V^2 S) / 2$ and the drag formula: $D = (C_D \rho V^2 S) / 2$

Then, show students the video and elicit predictions from students in response to the questions below. They can explain their predictions based on what they know about lift and drag.

- "Super STOL Aircraft" (Length: 0:42]
  http://video.link/w/tPoe

[DOK-L2;*Predict*]

Questions

Why do you think this airplane can take off and land in such a short distance? (Hint: Watch the flaps located on the trailing edge of the wings.)
It uses the flaps to increase lift and drag, allowing it to fly slower without stalling.

Where might this be important?
Short takeoffs and landings are important on aircraft carriers; on islands, where there might not be room for long runways; or in remote portions of Alaska, where runways are often improvised or surrounded by mountains.

EXPLORE

Teacher Materials: Secondary Flight Controls Presentation, Secondary Flight Controls Teacher Notes 1
Student Material: Secondary Flight Controls Student Activity 1

Slide 5: Briefly review the primary flight controls. Ask students to recall the three different kinds of primary flight controls, what they are used for and where they are located.

- Ailerons - control roll, located on the wings
- Elevator - controls pitch, located on the horizontal stabilizer
- Rudder - controls yaw, located on the vertical stabilizer

Remind students that all the primary controls are required to maintain coordinated flight.

Slide 6: Introduce students to secondary flight controls. Tell students that they improve performance by relieving excessive aerodynamic and control forces. The following slides will cover each secondary flight control in more detail:

- Wing flaps
- Leading edge devices
- Trim system
- Spoilers

Secondary flight controls are not present on all airplanes, but students will need to know what they do and how to use them, especially as they learn to fly larger, and more complex, aircraft.

Slide 7: Flaps are the most common secondary flight control, found on almost every airplane. A flap is a moveable surface attached to the trailing edge of a wing. Sometimes, flaps are also located on the leading edge; this type of flap will be discussed as a leading edge device.

A flap is considered a high-lift device. Deploying flaps increases the wings camber which increases lift. As students learned in the last unit, drag is a byproduct of lift. Therefore, deploying flaps also increases drag. The pilot can extend flaps to increase lift when needed (during takeoff or landing) or retract them into the wing when not needed (such as during cruise flight). Flaps are deployed at different angles during different phases of flight.

Refer to the wing illustrations on the slide when describing common flap deployment during a flight.

A. During takeoff and initial climb, flaps may be extended (typically 10-15 degrees) to generate more lift and increase the climb gradient (amount of altitude gained over a particular distance).

B. When climb gradient is no longer a significant consideration after clearing an obstacle or during cruise flight, flaps are retracted for the most efficient and streamlined aircraft profile.

C. During final approach and landing, the flaps are extended to change the wing's camber, which generates both lift and drag, enabling descent at a steeper angle and lower airspeed. In the lesser degrees of flap deployment (typically from 0 to about 25), lift increases significantly more than drag. In the greater degrees of flap deployment (typically from 25 to about 50), drag increases significantly more than lift.

Slide 8: Because flaps increase lift and drag, they are most often deployed to some degree during takeoff and landing. The main benefits of using flaps for takeoff and landing include:

Reduced Stall Speed - Extending flaps reduces an aircraft's stall speed because the wing creates more lift with the flaps down. This means an aircraft can fly at a slower speed on landing without the risk of stalling. By extending the flaps a little bit during takeoff, and airplane benefits from the increase in lift (due to camber), but it doesn't pay the high form drag penalty caused by fully extended flaps.

Shorter runways - Airplanes can lift off and land at lower speeds, so they need less runway to speed up or slow down. Without the increase in lift that flaps provide on takeoff, most large aircraft would simply not be able to go fast enough, or have enough runway, to get off the ground.

Increasing Drag - Extending flaps increases drag as well, which, for the most part, is a good thing. As students learned in the last unit, when an aircraft produces more lift, it also produces more drag (in the form of both induced drag and parasite drag).

Using flaps on landing gives pilots two distinct advantages. First, the airplane has a slower stall speed, which means the airplane can land slower. Second, the airplane produces more drag, which allows it to fly a steeper descent angle to the runway. Thinking back to the STOL airplane in the warm-up video, flaps were key to allowing that pilot to land both slow and steep.

An additional benefit of using flaps during takeoff and landing include extending the life of an airplane's landing gear. During landing, rapid acceleration of the wheels upon touchdown and application of the brakes at high speed stresses and wears down aircraft components. Therefore, landing at a lower speed saves wear and tear and increases longevity of the landing gear components.

Slide 9: Use the table to explain the four main types of flaps.

Plain Flap

- This is the most mechanically simple of the four types.
- It is a hinged portion of the wing's trailing edge.
- It increases the wing's camber, which increases drag as well as the coefficient of lift.
- It does not increase the wing's surface area.

Split Flap

- It is a hinged portion deflected from underneath the wing's trailing edge.
- It produces slightly more lift than plain flaps as well as more drag due to the turbulent air pattern it produces.
- Like a plain flap, it increases the wing's camber, but not its surface area.

Although they are cheaper to manufacture, both plain and split flaps produce high drag with minimal additional lift.

Slotted Flap

- This is found on both small and large aircraft. There are many different types of slotted flaps. Some large aircraft have multiple slots in the flaps.

- When deployed, there is a slot between the flap well in the wing and the leading edge of the flap. This slot forms a duct of air between these surfaces. This gap forces the high pressure air from below the wing over the upper surface of the flap, which helps keep the airflow continuous.
- Because of the delay in airflow separation, it also increases the maximum coefficient of lift more than plain or split flaps.
- Like plain and split flaps, it only changes the wing's camber, not the surface area.

Fowler Flap

- This is a type of slotted flap.
- Instead of being hinged like the other types, it moves backward on a track that extends beyond the trailing edge of the wing, which increases the surface area *and* camber.
- Among flap types, it has the highest lift to drag ratio in its lesser degrees of extension, giving it the greatest aerodynamic advantage.
- It is the most expensive to manufacture and is most commonly seen on passenger airliners.

Teaching Tips

Show students an example of each flap type on a real aircraft:

- Plain - Piper Aztec
- Split - North American T-6 Trainer
- Slotted - Carbon Cub
- Fowler - Boeing 747-400

Slide 10: Complete the **Formative Assessment**.

Formative Assessment

In this activity, students will examine a series of diagrams and identify the name for the type of flap shown. Then, students will describe how the design of each type affects the aerodynamics and behavior of the airplane.

Provide each student with **Secondary Flight Controls Student Activity 1** and have the student identify the name of the flap and describe its effects.

Answers to this assessment are found in **Secondary Flight Controls Teacher Notes 1**.

[DOK-L1; *identify*; DOK-L2; *describe*]

EXPLAIN

Teacher Material: Secondary Flight Controls Presentation

Slide 11: Introduce students to the next type of secondary flight controls: leading edge devices. Like flaps, these devices help the aircraft fly at lower speeds. Unlike most flaps, they are attached to the leading edge of the wing, rather than the trailing edge.

Leading edge devices change the wing's camber and/or surface area. The exception to this is fixed slots which don't move and therefore don't change the camber or surface area of the wing. (These will be discussed in greater detail on the next slide.)

When a leading edge device is lowered, it increases the wing's camber and when it is extended forward, it increases the wing's surface area.

Remind students that whenever more lift is generated, more drag accompanies it, so leading edge devices will always produce more lift *and* drag.

Leading edge devices have a gap or slot that directs air over the top of the airfoil to delay airflow separation. By keeping the airflow continuous against the wing's upper surface at high angles of attack, the leading edge device produces more lift, lowers stall speed and changes the critical angle of attack. Without a slot, the airflow over the upper surface would separate sooner.

Slide 12: Use the table to explain the most common types of leading edge devices.

Fixed Slot

- This has a gap behind the wing's leading edge.
- By directing the airflow to the upper wing surface, it delays airflow separation at higher angles of attack.
- It is "fixed" because it cannot close or move.
- It does not change the wing's camber or surface area.

Slat

- A slat is a moveable slot, meaning the leading edge segment moves from being flush against the wing's leading edge to being extended forward. At low angles of attack, the high pressure of air on the wing's leading edge forces the slot closed. At higher angles of attack, the high pressure area moves backward on the lower surface of the wing, and the slats move forward, opening their slots.
- When the slats are open, the air below the wing is directed over the upper surface, delaying airflow separation in the same way that fixed slots do.
- On many aircraft, air pressure will automatically move the slats, but some slats can be manually deployed by the pilot regardless of the angle of attack.

Leading Edge Flap

- This is similar to a slat in the way it extends and retracts.
- It has a similar design to trailing edge flaps. It is attached with a hinge to the bottom of the leading edge.
- When deployed, it increases wing's camber, which increases both lift and drag. In the initial degrees of deployment, it increases lift significantly more than drag. In the greater degrees of deployment, it increases drag significantly more than lift.
- These are often included in aircraft with trailing edge flaps to counteract the nose-down pitch tendency that they produce at higher degrees of extension.
- Typically in larger commercial aircraft, leading edge flaps automatically begin to deploy when the flaps pass through a set degree, often between 20 and 25 degrees.

Slide 13: Introduce students to the next secondary flight control: trim systems. Explain that "trimming" an aircraft during flight means adjusting control surfaces to maintain the desired flight attitude. Without trim, the pilot would strain to maintain pressure on the yoke and/or rudder pedals to maintain the desired flight path. Trim systems, when used properly, help alleviate this pressure.

Trim systems can reduce pilot workload and fatigue by alleviating pressure on the primary controls. They also help maintain desired airspeed and flight attitude.

Point out that the pilot must re-trim the airplane to hold the desired flight attitude after any change in airspeed, angle of attack, or configuration (e.g. deploying flaps).

Use the diagram to point out the trim tabs on an airplane's ailerons, rudder, and elevators.

Trim systems can work in different ways but they all achieve the same goal: allowing the pilot to fly a given attitude "hands off" without constant pressure on the yoke or rudder pedals.

Slide 14: As mentioned previously, trim tabs may be placed on the rudder, ailerons or elevator. They allow the pilot to make subtle adjustments to the control surfaces. The image shows the elevator trim tab on a Cessna 172.

The pilot can adjust the trim tabs mechanically with a trim wheel, often located below the center of the instrument panel, or electronically with a trim switch on the yoke. More advanced aircraft take this a step further with the option of automatic trim.

Slide 15: To help students understand how trim tabs work and why they must be adjusted during flight, consider the following example. When a pilot increases airspeed, lift also increases. This tends to pitch the nose of the airplane upward. In order to return to the desired flight attitude, the pilot needs to exert forward pressure on the yoke (moving the elevator) to bring the nose back down. If the pilot takes no further action, he'll need to maintain the forward pressure to keep the airplane in the desired attitude. But if he adjusts the elevator trim tab upward, he can relieve the pressure, allowing the airplane to maintain the desired attitude without continuous pilot input.

Keep in mind that any time airspeed, weight, center of gravity, or configuration change, the pilot will need to adjust the trim as well.

Slide 16: Spoilers or speed breaks are perhaps the most counterintuitive of the secondary flight controls. They do, in fact, "spoil" the good aerodynamics of the airfoil, creating a lot of drag and reducing lift. These qualities are useful in certain situations. Ask students to consider when an aircraft might need to reduce lift and increase drag.

Questions

When would a pilot need to use spoilers?

Because spoilers increase drag and decrease lift, the pilot would deploy them to slow the aircraft down greatly, most likely during descent. Steep descents are required for some approaches that come over mountains, and deploying spoilers, although they would induce turbulence, would allow a pilot to "dump the nose" and descend rapidly while maintaining the same airspeed. Dropping the landing gear would achieve a similar effect, but to a lesser extent. Upon landing, or to abort a takeoff, spoilers induce significant drag, helping the aircraft stop in a much shorter distance and reducing wear and tear (particularly heat) on the brakes and tires.

Slide 17: On descent, deploying the spoilers allows the airplane to descend rapidly without accelerating. After landing, they help keep the airplane firmly on the ground, reducing rollout and stopping distance. Spoilers can also be isolated and deployed individually to reduce turn radius by adding drag to the turning side. On a passenger jet, you will see spoilers on top of the wings raised upon touchdown, ensuring that the aircraft is firmly grounded by significantly reducing the lift component. Show students videos of a passenger jet deploying spoilers midflight and after touchdown.

- "Medical Emergency - Midflight Spoiler Deployment" (Length 00:20)
  http://video.link/w/urFe
- "Slow Motion Spoiler Deployment" (Length 00:26)
  http://video.link/w/7ZDe

EXTEND

Teacher Materials: Secondary Flight Controls Presentation, Secondary Flight Controls Teacher Notes 2 **(Optional)**
Student Material: Secondary Flight Controls Student Activity 2 **(Optional)**

Slide 18: If time allows, this activity will explore the effects of various secondary flight controls—flaps, slats, and spoilers—on airflow around the airfoil.

In this activity, students will use the Wind Tunnel simulation app to add simulated control devices to an airfoil, and examine the effects on lift and drag. They can experiment with different placement, size, and connections of flaps, and instantly see the resulting airflow patterns as well as lift, drag, and L/D ratio.

Distribute a copy of **Secondary Flight Controls Student Activity 2** to each student. Instruct them to work in groups or individually, depending on the number of devices. Step-by-step instructions and answers are provided in **Secondary Flight Controls Teacher Notes 2**.

EVALUATE

Teacher Materials: Secondary Flight Controls Presentation, Secondary Flight Controls Teacher Notes 3
Student Material: Secondary Flight Controls Student Activity 3

Slides 19-24: Quiz the students on questions related to secondary flight controls for the Private Pilot Knowledge Test.

Slide 25: Conduct the **Summative Assessment**.

Summative Assessment

The summative assessment asks students to describe the effects on an airplane of losing the benefits of each type of secondary flight control: flaps, leading edge devices, trim system, and spoilers.

Distribute a copy of **Secondary Flight Controls Student Activity 3** to each student.

For each airplane, students should first briefly explain the normal function of the particular secondary control system. Then, students should describe the change in airplane behavior when that system is not functioning correctly.

Answers to this assessment are found in **Secondary Flight Controls Teacher Notes 3**.

[DOK-L3; *analyze*]

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Responses show evidence of each of the following:
    - Knowledge of the normal function of the secondary flight control
    - Details about the physics behind the design of each type
    - Effects on airflow, lift, and drag
    - Consequences of the nonfunctional secondary flight control

Points **Performance Levels**

9-10 Accurately and clearly describes the normal function and change in airplane behavior for all four types of secondary flight controls; demonstrates a clear understanding of the effects on an airplane of losing each type of secondary flight control

7-8 Correctly describes the normal function and change in airplane behavior for at least three of the four types of secondary flight controls; describes the effects on an airplane of losing each type of secondary flight control, with minor gaps in understanding

5-6 Partially describes the normal function and change in airplane behavior for some, or all four types of secondary flight controls; incompletely describes the effects on an airplane of losing each type of secondary flight control, with major gaps in understanding

0-4 Shows little or no evidence of understanding about the normal function and change in airplane behavior for secondary flight controls; shows little or no evidence of understanding about the effects on an airplane of losing each type of secondary flight control

GOING FURTHER

If time allows, consider using a flight simulator to illustrate the concepts from the lesson. In the simulator, students should try to control the aircraft using flaps, slats, trim tabs, and spoilers. Try different types of aircraft to see the varying effect of the controls on each.

- While cruising in straight and level flight, incrementally deploy flaps without any other inputs. Will the aircraft pitch up or down, and why? Does it behave as predicted? What happened to altitude and airspeed?
- On the runway, take off with no flaps deployed. What do the students predict in regard to lift off speed and take off roll, and why? How do the results from a large aircraft vary from a small one?
- Produce the same scenario, but this time with the flaps in the first detent (should be between 10-15 degrees). What do the students predict in regard to lift off speed and take off roll, and how will it differ from the no-flap takeoff? How do the results from a large aircraft vary from a small one?
- Using a large/heavy aircraft (one with spoilers or speed brakes available), start a takeoff roll down the runway. As the aircraft reaches 100 knots, pull the throttles to idle and hit the brakes. Note the stopping distance. Repeat the experiment, and this time deploy the spoilers while hitting the brakes. How much sooner did the aircraft come to a stop?
- While cruising at 20,000 ft in straight and level flight in a large aircraft, fully deploy the spoilers. Note the rapidly decreasing airspeed. Drop the nose and maintain airspeed as you descend. Have the students take note that the descent gradient is significant, even though the descent is controlled and airspeed remains constant.
- While cruising in straight and level flight with a multi-engine aircraft, pull one of the throttles to idle to simulate an engine failure. Try to maintain straight and level flight. How difficult is it, and why? Students should understand that thrust is now asymmetric, and the only way to compensate, other than reducing power on the opposing engine(s), is to apply rudder and perhaps some aileron. Now trim off the control forces with rudder trim. How much easier is it to control now? What actually changed in regard to the aircraft configuration/airfoil shape?

STANDARDS ALIGNMENT

NGSS STANDARDS

Three-dimensional Learning

- **HS-ETS1-2** - Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering
    - Science and Engineering Practices
        - Asking Questions and Defining Problems
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - ETS1.A: Defining and Delimiting Engineering Problems
    - Crosscutting Concepts
        - None
- **HS-ETS1-3** - Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
    - Science and Engineering Practices
        - Constructing Explanations and Designing Solutions
    - Disciplinary Core Ideas
        - ETS1.B: Developing Possible Solutions
    - Crosscutting Concepts
        - None

COMMON CORE STATE STANDARDS

- **RST.9-10.2** - Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- **RST.9-10.4** - Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.
- **WHST.9-10.6** - Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically.
- **WHST.9-10.8** - Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- **WHST.9-10.9** - Draw evidence from informational texts to support analysis, reflection, and research.

REFERENCES

http://www.boldmethod.com/learn-to-fly/aircraft-systems/how-the-four-types-of-aircraft-flaps-work/
http://www.boldmethod.com/learn-to-fly/aircraft-systems/here-is-how-leading-edge-slats-work-to-get-you-off-the-ground/
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