How To Fly The Space Shuttle

Excerpt from

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Edward.Rafacz@safepic.com

Chapter 1

The Primary Flight Display: Foundation of Spacecraft Navigation

Introduction

Spaceflight captures the imagination of many, but navigating a spaceship is an intricate dance between engineering and human intuition. This chapter serves as your entry point into the fascinating world of spacecraft instrumentation. We'll explore the cockpit of the Space Shuttle as a foundational example, bridging its mechanical displays to the cutting-edge interfaces of modern spacecraft like SpaceX's Dragon, NASA's Orion, and vehicles supporting the Artemis program.

The Primary Flight Display

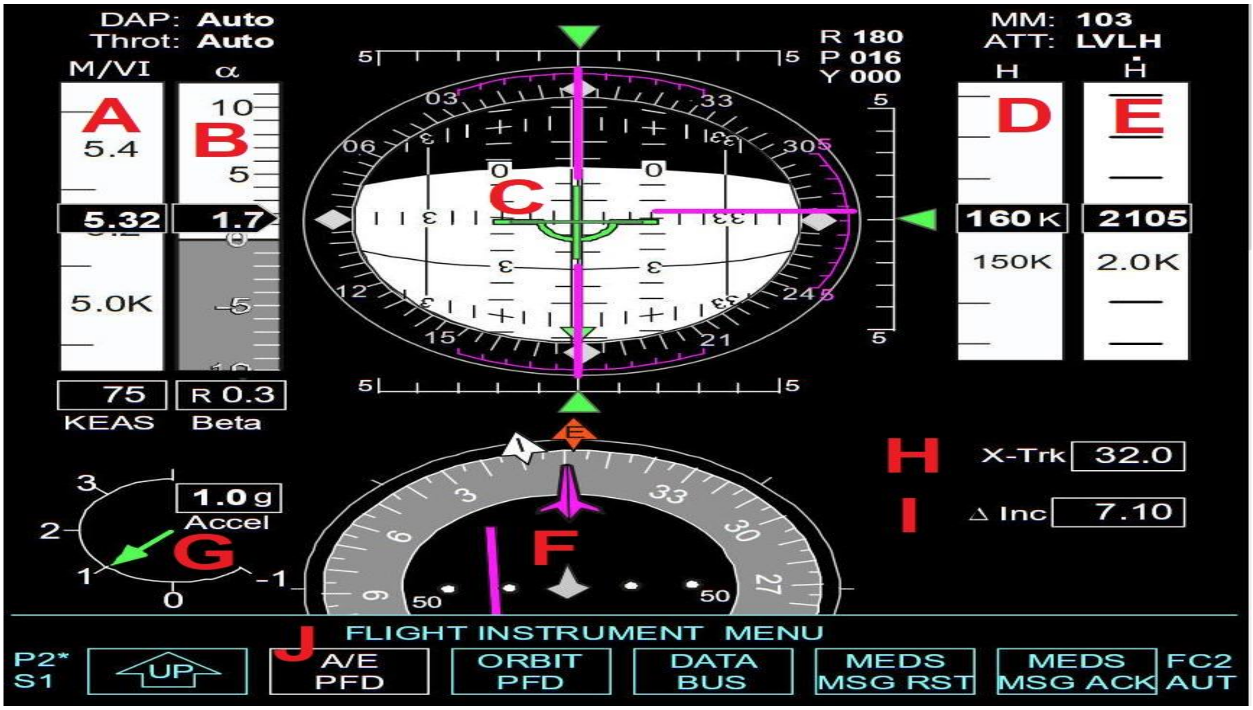
In original aircraft, the Primary Instruments allowed the pilot to fly in all kinds of atmospheric phenomena from clear daytime skies to cloudy nighttime conditions. These instruments carried over to the Space Program as Astronauts, who started their training as pilots, demanded these basic instruments. This was due to the fact that in an instant, the Primary Flight Instruments could tell pilots the orientation of their craft in one glance.

Primary Flight Displays (PFD) are part of a display unit that replaces most conventional flight instruments. Flight Management Computers acquire and process all input from airplane sensors and computers to generate display images. The PFDs present *a dynamic color display of parameters necessary for flight path control*. There are three PFDs one each for the Commander and Pilot in the front of the Shuttle, and one in the rear for docking.

Why Start with the Shuttle?

The Space Shuttle may feel like a relic of the past, but its cockpit provides a clear and structured introduction to the fundamentals of flight instrumentation. It also was a spacecraft that was converted from the old mechanical Flight Instruments to a Primary Flight Display on a screen. By understanding its systems, we can build a framework to interpret more advanced and streamlined interfaces found in current and future spacecraft.

Core Flight Instruments



Let's begin with an overview of the Shuttle's primary flight instruments, which are surprisingly similar in function to those in modern spacecraft:

Tapes: Velocity and Angle of Attack

1. **Velocity Indicator (M/VI) (A on Image)**: This tape measures speed, typically displayed in Mach, (percentage of the Speed of Sound), or knots equivalent airspeed, (KEAS). Velocity plays a critical role in maintaining control and achieving the desired trajectory.

   The M/VI scale displays one of the following: Mach number, relative velocity, or inertial velocity. Mach number is the ratio of vehicle airspeed to the speed of sound. The relative velocity is in feet per second in relation to the launch site.

   Inertial velocity is in feet per second and does not consider the rotational speed of the surface. The actual parameter displayed is always Mach number; the tape is simply rescaled above Mach 4 to read relative velocity which are in the atmosphere, or inertial velocity which are out of the atmosphere. The scale ranges from zero to 27, with a scale change at Mach 4.

2. **Angle of Attack Indicator (B on Image)**: This instrument reveals the angle between the spacecraft's direction of travel and the airflow around it. Modern aircraft and spacecraft rely on this metric to optimize performance and avoid aerodynamic stalls.

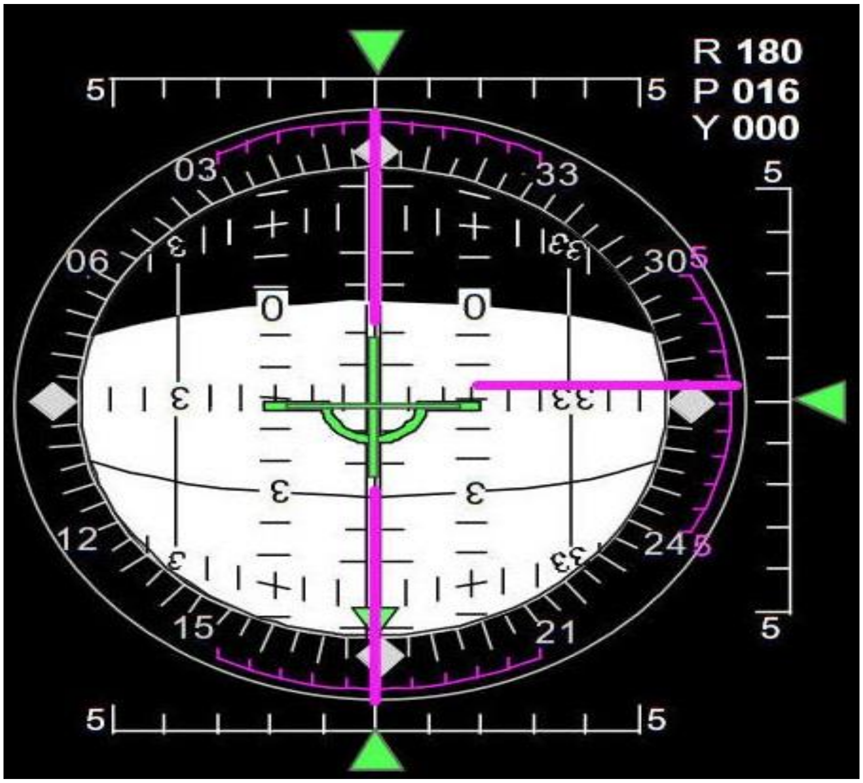
   

   It measures the angle between the vehicle plus X axis and the wind-relative velocity vector (negative wind vector). *ALPHA* is displayed by a combination moving scale and moving pointer.

   For angles with lower values, the scale remains stationary, and the pointer moves to the correct reading. For smaller angles, the pointer stops and the scale moves so that the correct reading is adjacent to the pointer.

   The *ALPHA* tape negative scale numbers (below zero) have no minus signs. The actual tape has black markings on a white background on the negative side, and white markings on a black background on the positive side.

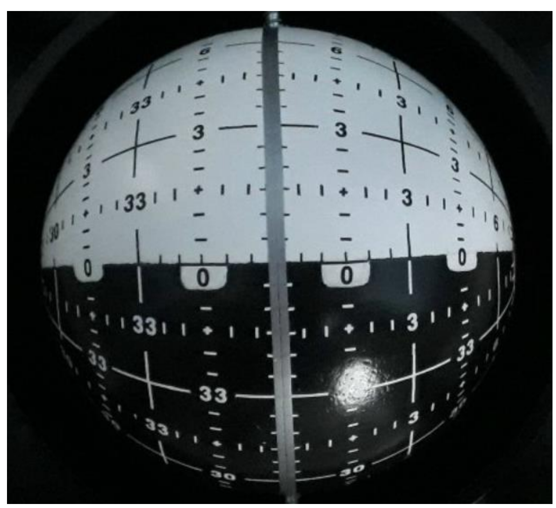
Attitude Directional Indicator (ADI) (C on Image)



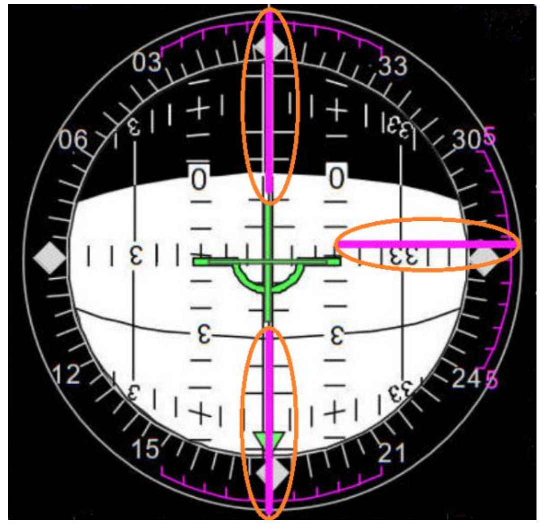
Located prominently in the cockpit, the ADI depicts the spacecraft's orientation in three-dimensional space. It combines:

- **Roll**: Measured in degrees, indicating rotation around the longitudinal axis.
- **Pitch**: Reflects the nose-up or nose-down angle relative to the horizon.
- **Yaw**: Tracks the side-to-side rotation, essential for precise directional control.

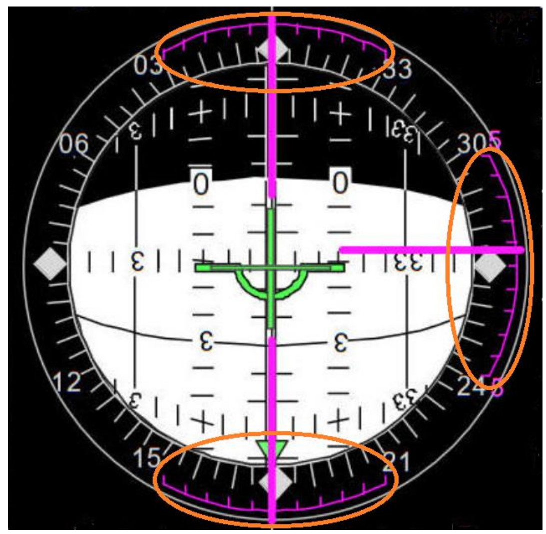
Understanding the ADI is vital for mastering spacecraft orientation during launch, orbit, and reentry. The basis of the ADI is the Attitude Ball. This critical tool provides astronauts with the orientation of their spacecraft relative to a chosen reference, such as Earth, the Moon, or a docking station like the International Space Station. While it may look similar to the attitude indicators used in airplanes, the Attitude Ball introduces complexities unique to space navigation.



To correct the path of the spacecraft, the Astronauts use the Error Needles. Error needles, such as the Pitch Error Needle, Yaw Error Needle, and Roll Error Needle, are like compasses for spaceflight. Each one has a unique job: to show astronauts exactly how much they need to adjust their spacecraft to maintain control. These needles are displayed on the Primary Flight Display, a special screen packed with information that pilots use to guide their vehicles safely.

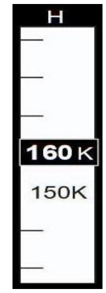


The amount of change of pitch, roll, and yaw sometimes needs to be calculated down to degrees per second for some maneuvers. This could be to match the rate of a satellite’s orientation. To accomplish this operation, the Astronaut uses the Rate Indicators.



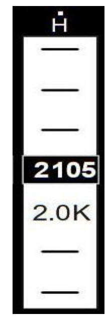
Height and Vertical Velocity Indicators

1. **Height (H) (D on Image)**: Displays altitude in kilometers above Earth's surface, a critical metric for orbital navigation. The scale, a moving tape read against a fixed lubber line, displays the altitude of the vehicle above the runway (barometric altitude). The scale range is –1,100 feet to +165 nautical miles, with scale change at –100, 0, 500 feet, and +100,000 meters. The scale is in feet from –1,100 to +4000 kilometers. It is in nautical miles from +40 to +165. Feet and nautical miles overlap from +40 to +61 nautical miles.



2. **Altitude Rate (H Dot) (E on Image)**: Measures the rate of ascent or descent, helping astronauts gauge their approach or departure vertical velocity. The Altitude RATE scale displays vehicle altitude rate, which is read at the intersection of the moving tape and the fixed lubber line.

   The scale range is –2,940 to +2,940 feet per second with scale changes at –740 feet per second and +740 feet per second. The negative and positive regions are color-reversed: negative numbers are white on a black background and positive numbers are black on white.



3. **Altitude Acceleration (H Double Dot)**: The derivative of vertical velocity, indicating changes in acceleration, critical during docking or deorbit burns. The ALTITUDE ACCELERATION indicator, which displays altitude acceleration of the vehicle, is read at the intersection of the moving pointer and the fixed scale.

   The scale range is –13.3 to 13.3 feet per second squared, and the scaling is 6.67 feet per second squared per inch. Software limits acceleration values to ±12.75 feet per second squared.

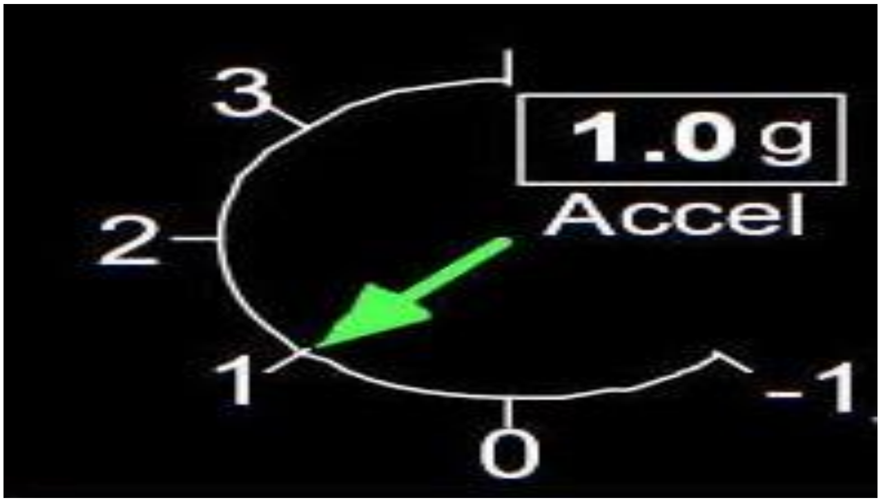
Horizontal Situation Indicator (HSI) (F on Image)

This advanced tool integrates navigation data to present a real-time overview of the spacecraft’s trajectory, lateral alignment, and cross-track deviation. It is essential for maintaining course accuracy.

The HSI is more than just a simple gauge; it’s a pilot’s window into the spacecraft’s orientation and navigation. It provides a real-time, pictorial representation of the vehicle’s position relative to key waypoints, guidance paths, and navigation aids. Whether you’re aligning for launch, executing a return-to-launch-site abort, or preparing for reentry and landing, the HSI gives you critical information about direction, distance, and course deviation. With this instrument, astronauts can assess their trajectory at a glance, compare independent navigation sources, and ensure the spacecraft is on the right path—even when flying manually.

Understanding the HSI isn’t just about learning what the numbers and symbols mean; it’s about using them to make split-second decisions that determine the success of a mission.

G-Meter (G on Image)



The G-Meter measures gravitational forces acting on the crew and spacecraft. Values range from zero (weightlessness) to multiple Gs during acceleration. Understanding these forces is essential for both crew safety and vehicle integrity.

Cross-Track and Inclination

1. **Cross-Track Error (H on Image)**: Shows deviation from the intended flight path.
2. **Inclination (I on Image)**: Indicates the angle of the spacecraft's orbital plane relative to Earth's equator, critical for mission planning and execution.

Flight Instrument Menu (J on Image)

The Flight Instrument Menu displays several modes for the Astronauts. These modes include the A/E PFD,

The Ascent/Entry PFD (A/E PFD)

The A/E PFD displays flight instruments, which include angle of attack, vehicle velocity, knots equivalent airspeed, acceleration, altitude, radar altitude. vertical velocity, and vertical acceleration on a flight phase-tailored basis for ascent, aborts, and entry.

The A/E PFD has a status indicator field across the top for major mode, abort, and DAP status. The orbit PFD is simply an ADI with no status indicators across the top.

Data Bus Network

The Data Bus network display displays the transfer of serial digital commands and data between the GPCs and vehicle systems. The network has seven groups that perform specific functions.

Multifunction Electronic Display System (MEDS)

MEDS allows onboard monitoring of orbiter systems, computer software processing, and manual control for flight crew data and software manipulation.

MEDS has four types of hardware: four IDPs, 11 multifunction display units (MDUs), 4 analog-to-digital converters (ADCs), and 3 keyboard units, which together communicate with the GPCs over the DK data buses.

Transitioning to Modern Interfaces

The Space Shuttle's instrumentation may appear cluttered compared to modern spacecraft, but its principles remain intact. Newer vehicles, like SpaceX's Dragon and NASA's Orion, employ digital primary flight displays (PFDs), offering streamlined visualizations of the same essential metrics. These advanced systems include ascent and entry PFDs, orbit-specific displays, and integrated data buses for real-time analysis.

Looking Ahead

In this chapter, we've laid the groundwork by exploring core instruments. In the next chapters, we'll delve deeper into specific tools like the ADI and HSI, unpacking their modern adaptations and applications. For those eager to dive into the technical nuances, links to additional resources and interactive simulations are provided to enrich your understanding.

Mastery of these instruments is the first step toward commanding a spacecraft with confidence and precision. Let's embark on this journey together, decoding the art and science of space navigation.

Question: Answer the question to Earn a bonus for completing the PFD training, the video description of how the PDF operates!

What does the PFD do?

1. The PDFs controls the display controlling the temperature of the Shuttle
2. The PDFs monitors Astronauts on Space Walks
3. The PFDs present *a dynamic color display of parameters necessary for flight path control.*
4. The PDFs produces a tone warning Astronauts of danger
5. All of the above

Send email to Edward.Rafacz@safepic.com to receive the next chapter when it is finished or if you have any questions.