Effects of CG on Aircraft Flight Characteristics

Introduction

- Definition of the CG
- How is the CG of an aircraft calculated?
- The effects on flight characteristics
- The importance and risk mitigation in flight tests
- Midwest Flight 5481 case study

Definition and Calculation

- **What is center of gravity (CG)?**

  It is the point about which an aircraft would balance if it were possible to suspend it at that point (FAA).

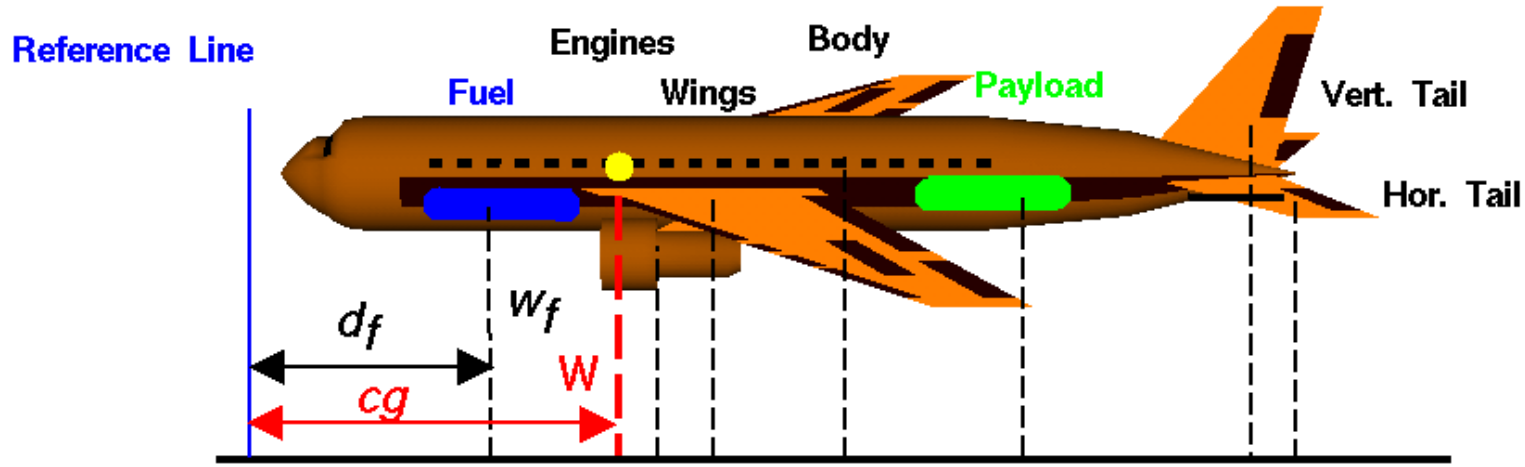
- **Why is it important?**

  - An airplane in flight can be manuevered by the pilot using the aerodynamic control surfaces, the elevator, rudder or ailerons.
  - The force changes on those surface produce rotation around the CG.

Center of Gravity – cg

Aircraft Application

Glenn Research Center



Each component has some weight w_i
located some distance d_i from reference line.

Distance *cg* times the weight W equals the sum of the component distance times weight.

$$cg\ W = d_f w_f + d_e w_e + d_w w_w + d_p w_p + \ldots$$

$$cg\ W = \sum_i^n (wd)_i$$

The Effects on Flight Characteristics

- **Effects of Forward CG:**

- Higher V_{stall} due to the following formula:

$$V_{stall} = \sqrt{\frac{2W}{\rho S C_{Lmax}}}$$

- Since W gets higher due to the increasing downforce on the elevator, V_{stall} increases.

- The efficiency is lower due to the increasing need for lift and resulting increase in the induced drag (Also due to the higher trim drag).

$$C_{D_i} = \frac{C_L^2}{\pi\, e\, AR}$$

The Effects on Flight Characteristics

- **Effects of Forward CG:**

- A higher elevator authority due to the increasing moment arm.
- The stall recovery is easier since the nose has a natural tendency to pitch down and there is a higher elevator authority.
- Increase in the required downforce on the elevator demands a greater elevator deflection and higher control forces, so the aircraft becomes more stable but responds more slowly to pitch commands.

The Effects on Flight Characteristics

- **Effects of Aft CG:**

- Lower V_{stall} due to having a lower downforce.
- More efficient due to needing a lower lift and having a lower induced drag.
- A lower elevator authority due to a shorter moment arm.
- The stall recovery is harder since there is a tendency to perform a backflip and it has a low elevator authority.
- Since the required downforce is lower, the aircraft is more responsive to the inputs and more agile while it is less stable.
- Irreversible control systems are used to prevent backflip tendencies and mitigate the risk associated with instability.

Risk Mitigation in Flight Tests

- **Case Study: Stall Demo of a L-29 Aircraft**

- Risk assesment:

	Catastrophic	Major	Moderate	Minor	Negligible
Frequent					
Probable					
Occasional	X				
Remote					
Improbable		X			

*Risk = Severity x Probability

(ITPS)

Risk Mitigation in Flight Tests

- **Hazard Description:**

1. Post stall gyration and fail to recover.

- **Causes:**

1. Aircraft out of desired conditions (CG).
2. Incorrect recovery technique after stall.

- **Effects:**

1. Aircraft impacting on the ground
2. Loss of aircraft and death of aircrew.

(ITPS)

Risk Mitigation in Flight Tests

- **Minimizing Procedures:**

1. Stall testing at minimum 5oooft AGL.
2. Tests will be done at idle power, wings level.
3. Forward CG points will precede aft CG.
4. Lateral fuel will be balanced.
5. Spin recovery procedures will be reviewed.

- **Corrective Actions:**

1. Bailout if aircraft is not controlled at 1,5oo ft AGL.

(ITPS)

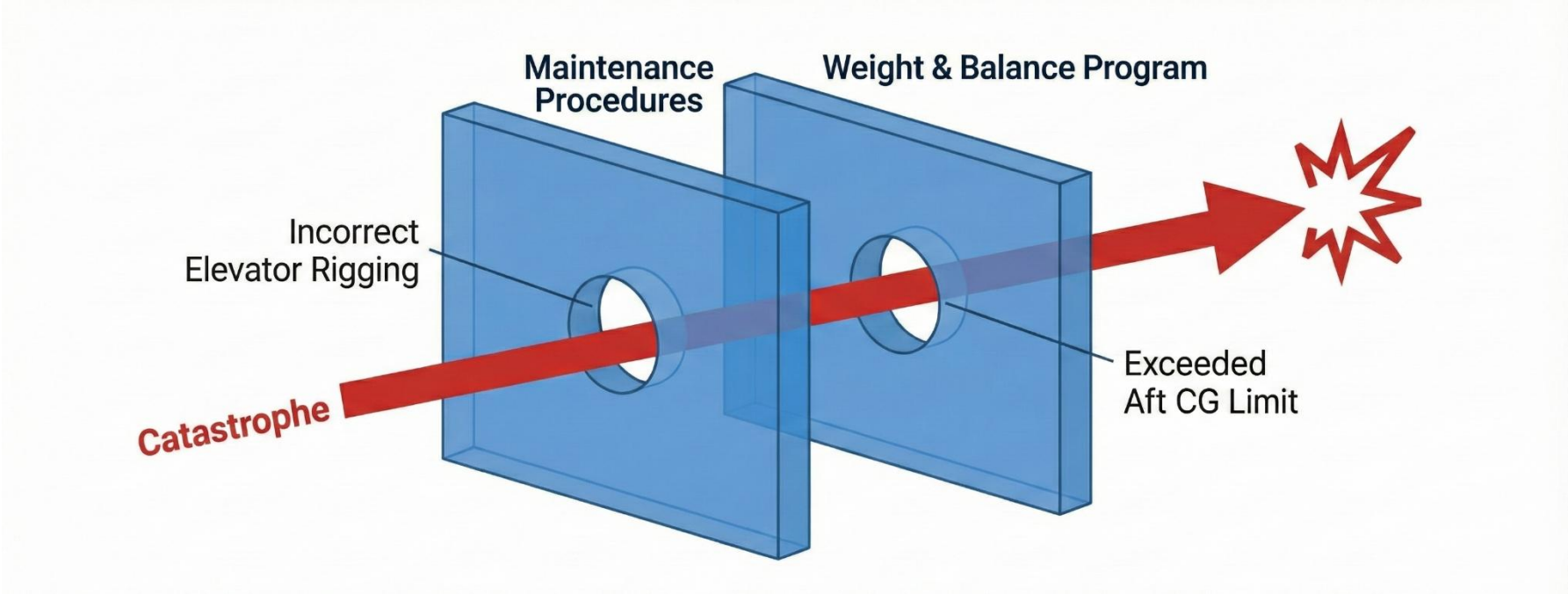
Case Study: Midwest Flight 5481

- **Key Facts:**

- **Flight :** Air Midwest 5481 operating under the provisions of 14 Code of Federal Regulations Part 121 on an instrument flight rules flight plan.
- **Aircraft** : Beechcraft 1900D, N233YV
- **Date :** January 8, 2003
- **Departure:** Charlotte-Douglas International Airport
- **Event:** Loss of pitch control immediatly after takeoff.
- **Outcome:** 21 fatatlites (2 crew, 19 passengers). The aircraft was destroyed.

(NTSB)

Case Study: Midwest Flight 5481



The accident was the result of two critical, unrelated errors that aligned perfectly. A maintenance error created a hidden limitation in the aircraft's control system. An operational error placed the aircraft in a condition where that exact limitation became fatal.

Case Study: Midwest Flight 5481

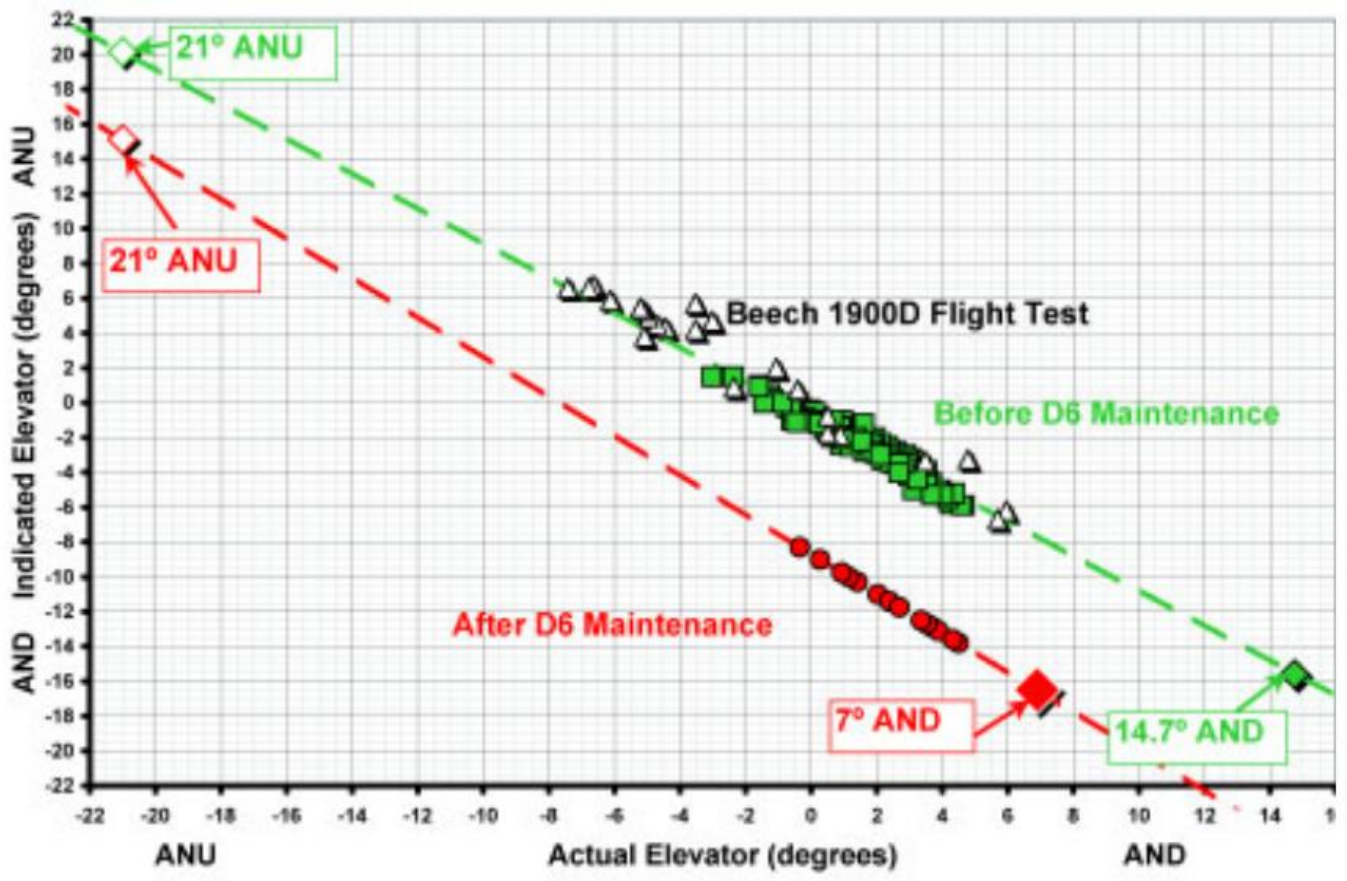


Figure 9. Elevator travel available before and after the detail six maintenance check.

(NTSB)

Case Study: Midwest Flight 5481

- The operator used **outdated** FAA standart average weights.
- This flight occurred in winter, with passengers wearing **heavy clothing** and carrying unusually heavy personal bags.
- The spare wheel in the aft baggage area was **not included** on the load sheet.
- The baggage compartment on the Beech 1900D is located **near the tail**.
- Passengers were expected to be distributed longitudinally, but most sat in the **rear rows**.

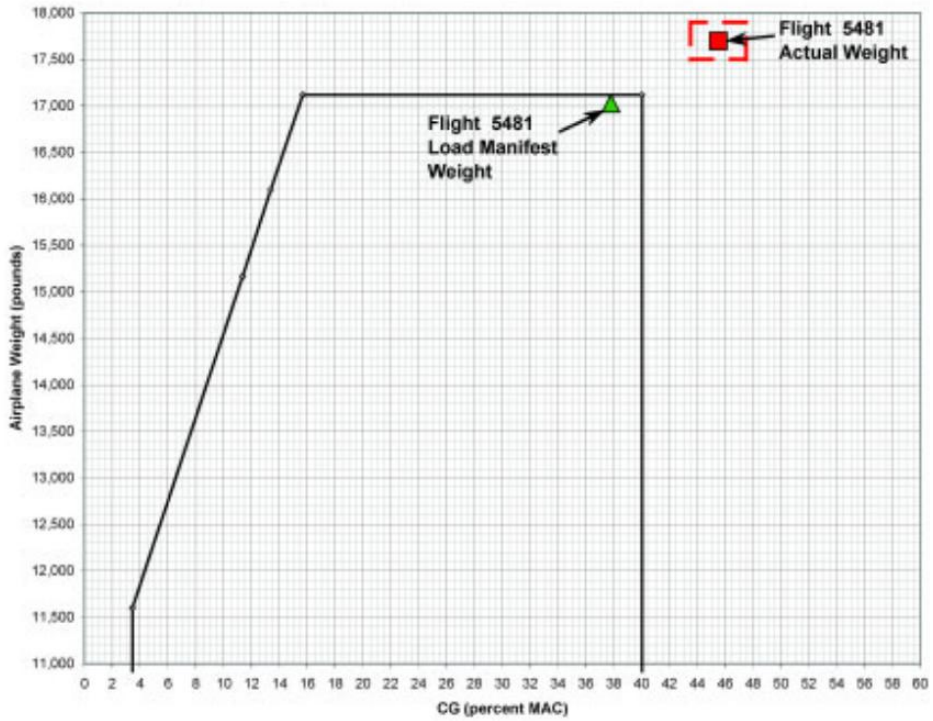


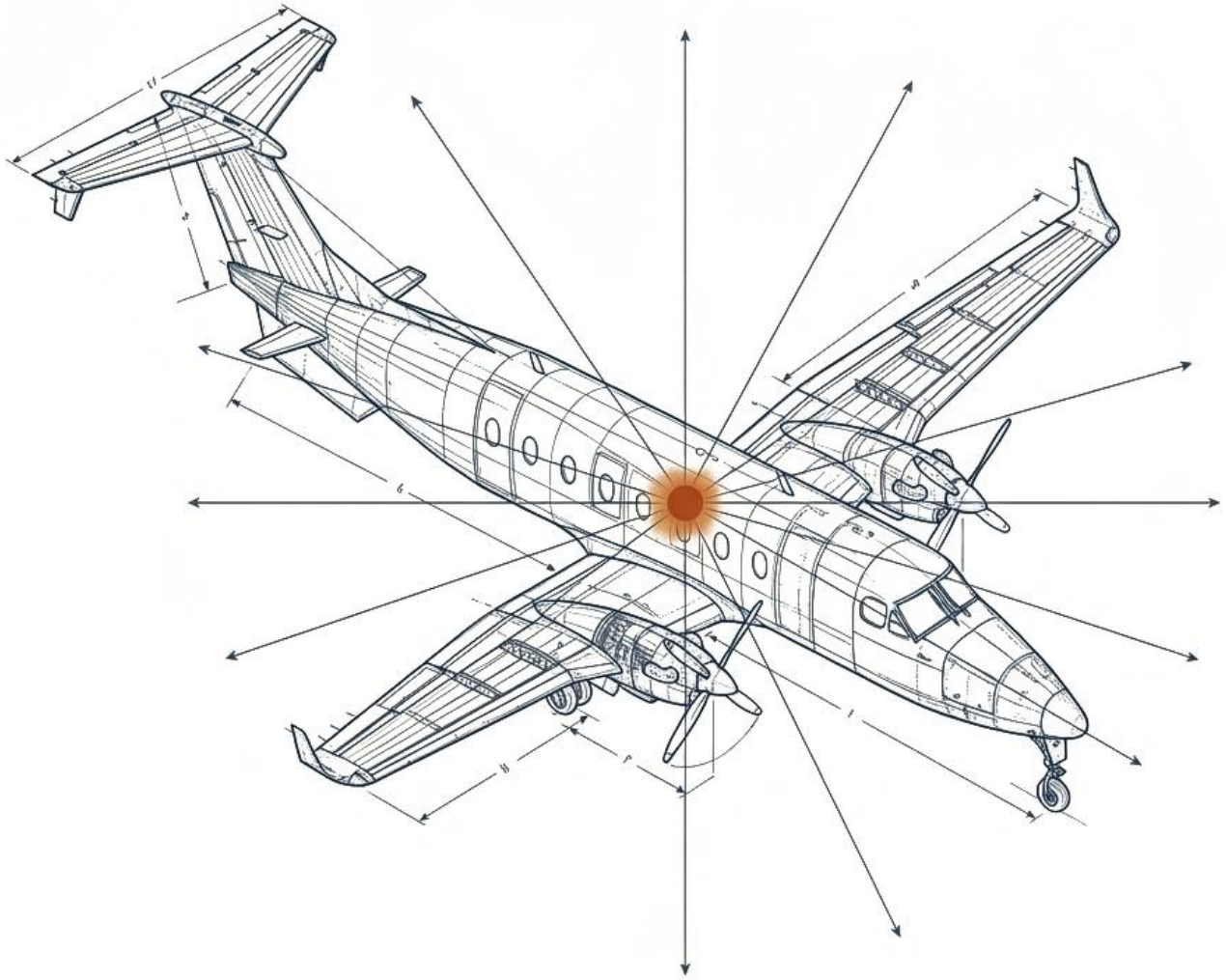
Figure 7. Weight and center of gravity information for flight 5481.

(NTSB)

Case Study: Midwest Flight 5481

- In simulation, the aircraft required approximately **9° of nose-down** elevator to counteract its aft CG condition.
- Due to the rigging error, the elevator could only generate about **7° of effective nose-down** travel, making the aircraft unrecoverable.

(NTSB)



Thank you.

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