LESSON F5



High Angle of Attack:

Stalls and Spins

F-16 Departures





More High AoA Videos

- X-31
- X-29
- F-35
- F-35 Tail Slide
- F-22

- Thunderbird Pass

Why High α?

- Controllability of the aircraft changes at high angles of attack
  - Uncommanded motions
  - Inability to command motions
  - Buffet
- Recovery techniques
- High angle-of-attack flight phases
  - Aerial Combat
  - Weapons Delivery
  - Landings
  - Takeoffs



Test Objective 5

- **Evaluate Stall Characteristics**
  - **MOP 5-1 :** *Stall Speed*

Description	Speed at which a stall occurs.
Test Methodology	*Stall Eval FTT (Appendix C)*
Success Criteria	Three stalls with and without rudder.
Evaluation Criteria	The following criteria will be used to evaluate stall speed. NOTE: Correct results to 7,000' PA, 2,550 lbs GW, and standard day.

Criteria (KIAS stall speed)	**Rating**
> 55	Unsatisfactory
$50 - 55$	Marginal
< 50	Satisfactory

  - **MOP 5-2 :** *Stall Handling Qualities*

Description	Measure of pilot workload and ability to safely recover from a stall (performance).
Test Methodology	Refer to MOP 5-1 for stall setup. Stall recovery will be performed by release of yoke pressure only -- aileron and rudder may be used to right wings
Success Criteria	Three stalls with and without rudder.
Evaluation Criteria	The following MIL-STD-1797 paragraph(s) will be used for evaluation: 5.2.5.2 Stall approach 5.2.5.2.1 Stall warning 5.2.5.2.2 Uncommanded oscillations prior to stall 5.2.5.2.3 Cockpit controls prior to stall 5.2.5.3 Stall characteristics 5.2.5.4 Stall prevention and recovery 5.2.5.4.1 Stall recovery

OUTLINE

- Safety
- Stalls
  - Definitions
  - Phases
  - Flight Test Techniques
  - MIL-HDBK requirements
- Spins
  - Phases
  - Autorotation
  - Characterizing Spins
  - Recoveries
- Other types of High α Flight



Safety

- High α testing is inherently hazardous
  - High α testing in Aero 456 will is limited to well known benign stalls



Safety Mitigations

- Some high α modes are stable (spins, deep stalls) and may be unrecoverable with normal controls

- Initial high α testing will usually include: Build-up approach
  - Telemetry
  - Safety Chase - Training
  - Minimum Crew
  - Recovery device
    - HARP, Nitrogen Thrusters



NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: ECN-22193 Date: 1982

AFTI/F-16 Spin chute close-up

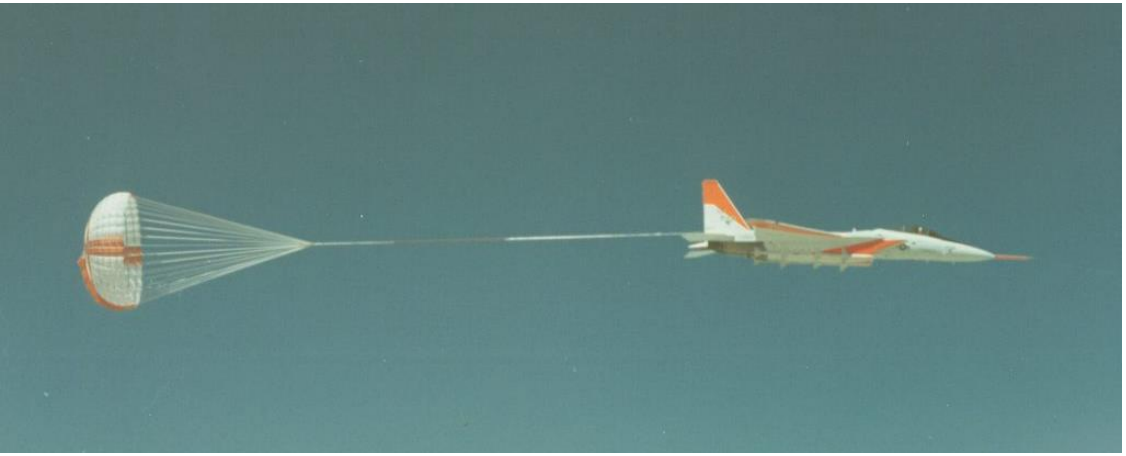
Safety Mitigations

- High α recovery device must be extremely reliable
  - Unusual attitudes, g-loadings, and motions
  - Break AoA, recovery cone





Chute Types



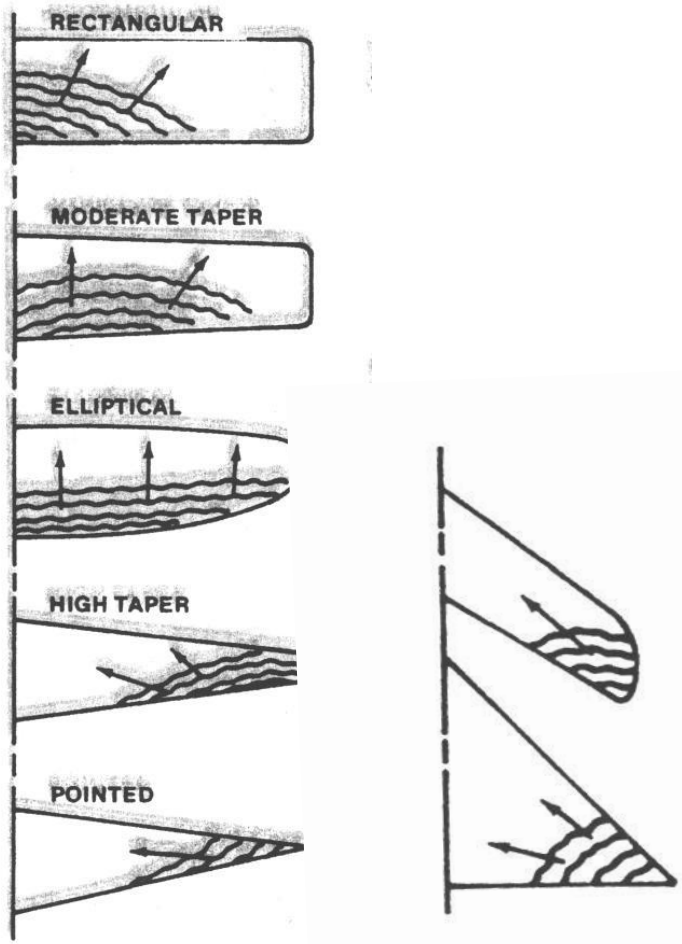








Wing Stall Patterns





3- D Wing Shape
Aircraft Stall Characteristics



Elliptical Plan Form



Supermarine Spitfire
Elliptical Wing



Elliptical Wing!?!?!

Highly Tapered Wing



Wing Twist

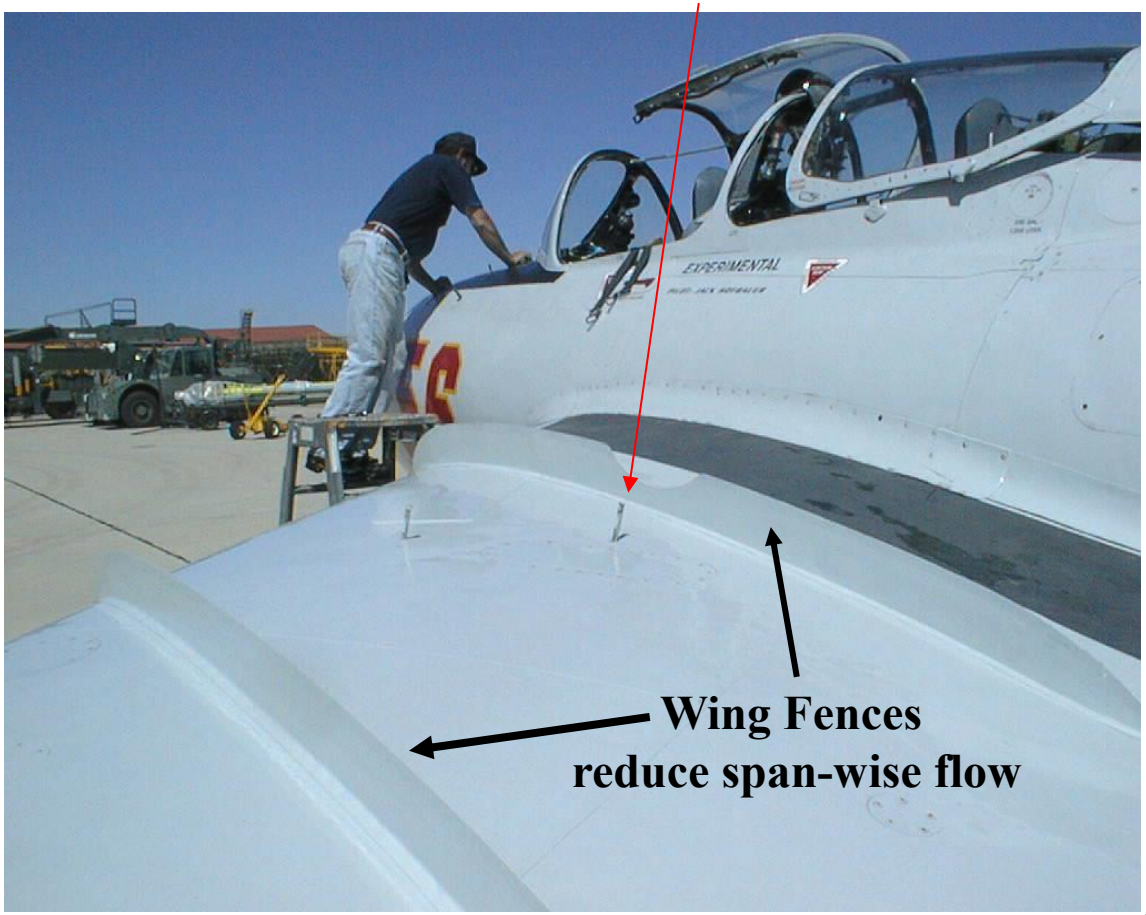

Lower Angle of Attack at Wing Tip
Better Stall Characteristics!
YB A
SM832

Mechanical Wing Fences

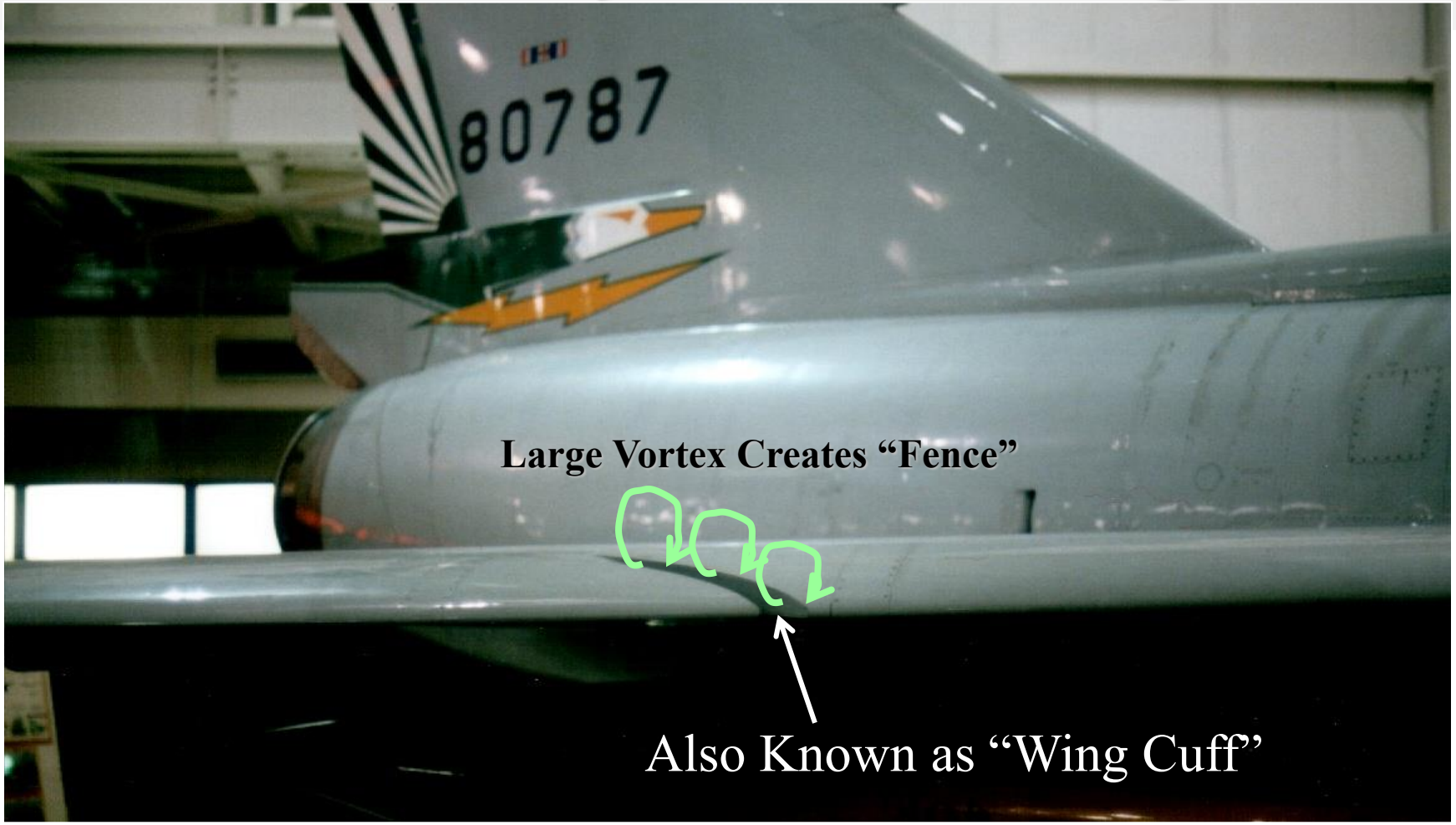




MIG-15



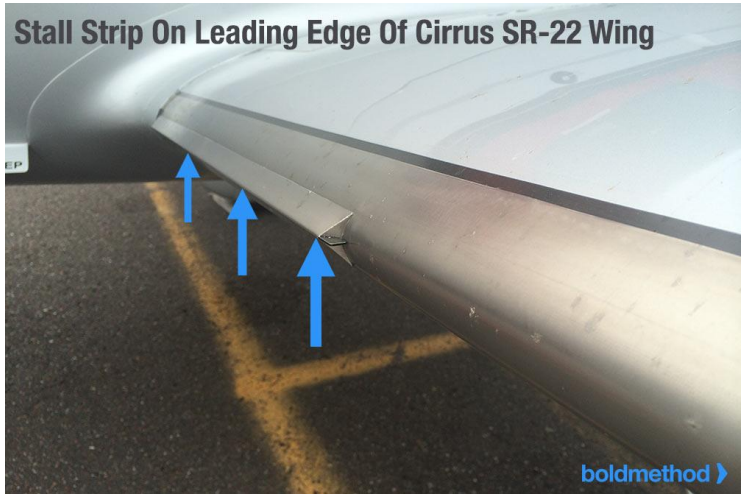
Aerodynamic Wing Fences



Stall Strips









Vortex Generators









Weird Shapes









TG-7A Motor Glider

- **Very Little Natural Stall Warning**
- **Unreliable Stall Warning Horn Triggered by Thermals and Turbulence!**
- **Stall Warning Horn Deactivated by Pilots**
- **Severe Roll Off at Stall**
- **Several Fatal Accidents**



Stalls Defined

- **MIL-S-83691A defines stall as when one of the following occurs:**

1. **Definite g-break** (T-41)

2. **Rapid, uncommanded angular motion develops** (Piper Tomahawk)

3. **The aft stick stop reached and pitch cannot be increased** (Long-Ez)

4. **Sustained heavy buffet** (T-38)



Stall FTT

- Stabilize and trim at approximately 1.3 V_{stall}
- Using pitch, slowly bleed off airspeed
  - Typically 1-2 knots/second
- At 5-10 knot intervals, check controllability
  - Test each axis
  - Use small inputs - don't prematurely cause departure
  - Note any degradation in aircraft response
- Note stall warning (horn or buffet)
  and corresponding airspeeds
- Record stall airspeed
- Apply controls as required for stall phase tested
- Recover, noting altitude lost in recovery



Stall Data Reduction

- **Stall speed must be corrected to standard weight**

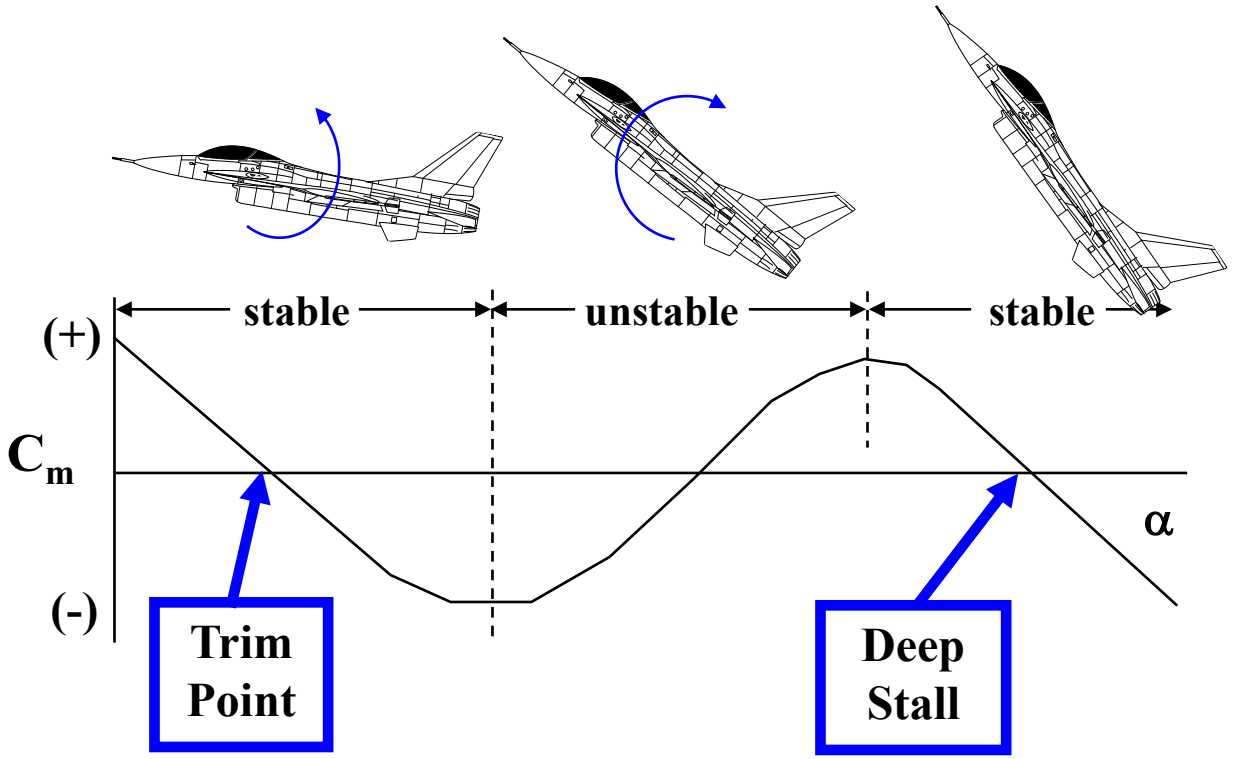
$$V_{iw} = V_e \sqrt{\frac{W_s}{W_t}}$$

Departures Defined

- Event in the Post-Stall Regime that precipitates entry into one of the following;
  - Post Stall Gyration - Uncommanded motion about one or more axes
  - Deep Stall - Out of controlled flight sustained at AOA beyond stall with negligible rotational velocities
  - Spin - Sustained yaw and roll at AOA beyond stall

Deep Stall

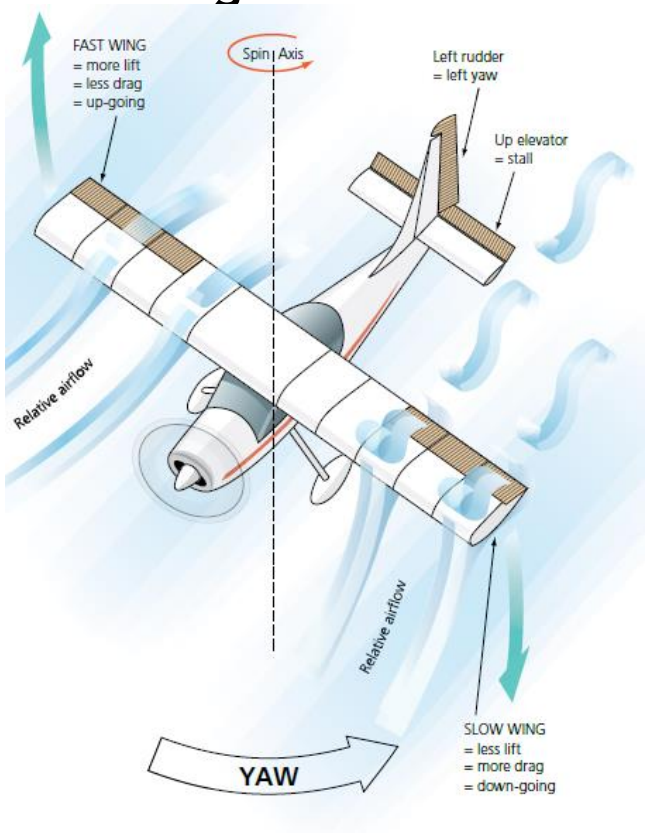
- AoA stabilizes beyond stall AoA
  - F-16 around +/- 60° angle of attack
  - Requires Manual Pitch Override (MPO) to recover
    - MPO bypasses flight control computers and gives pilot direct control of the stabilators



What is a Spin?

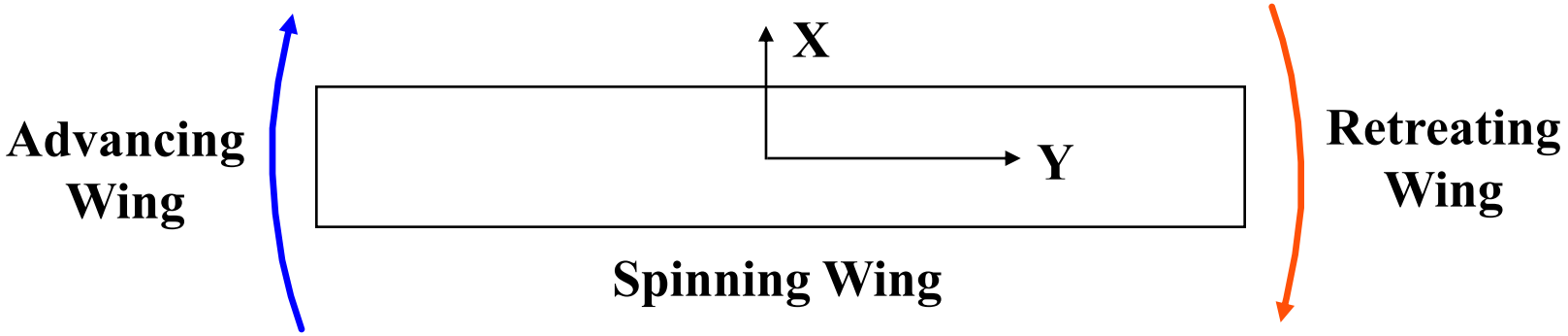
- A SPIN occurs when the aircraft is Stalled and has a yaw rate
  - Therefore it is impossible to spin below the stall angle of attack
  - Typically a ~1g maneuver
  - V_∞ is typically straight up
  - Sideslip is typically zero
  - Roll rate accompanies yaw rate

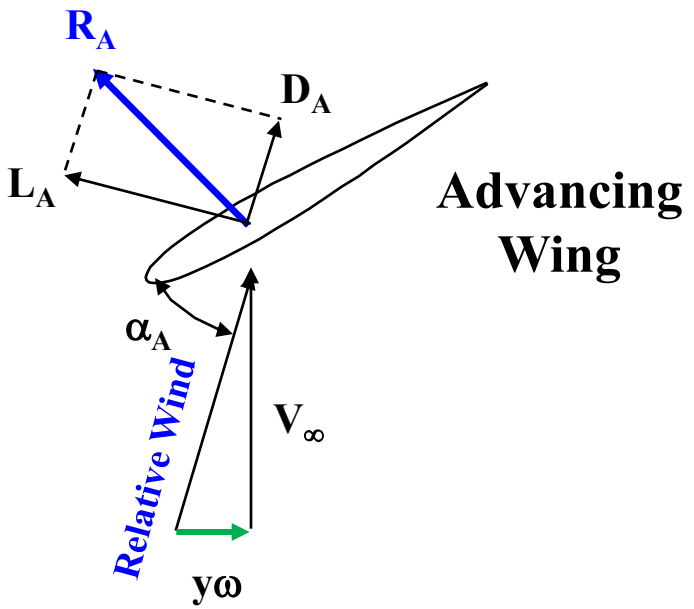
- Spiral dives occur below the stall AoA
  - High load factor
  - Bank angle large enough that resulting vertical lift is smaller than weight

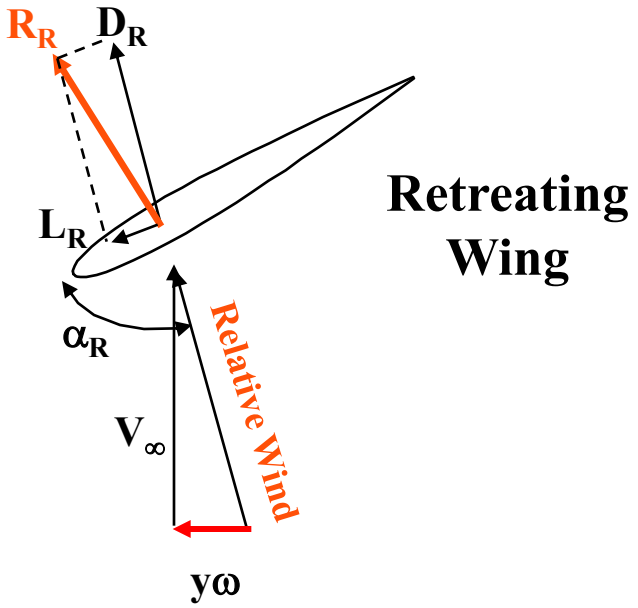


V_∞

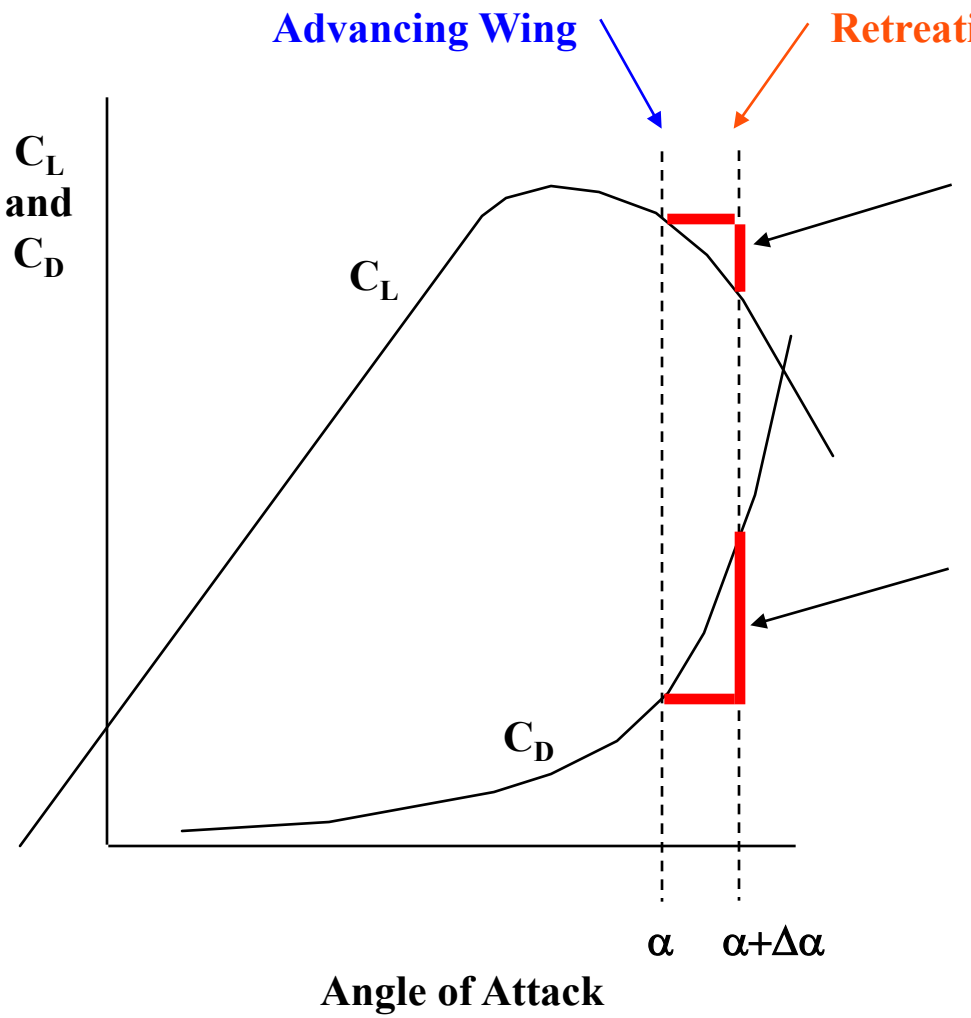
Spin Autorotation







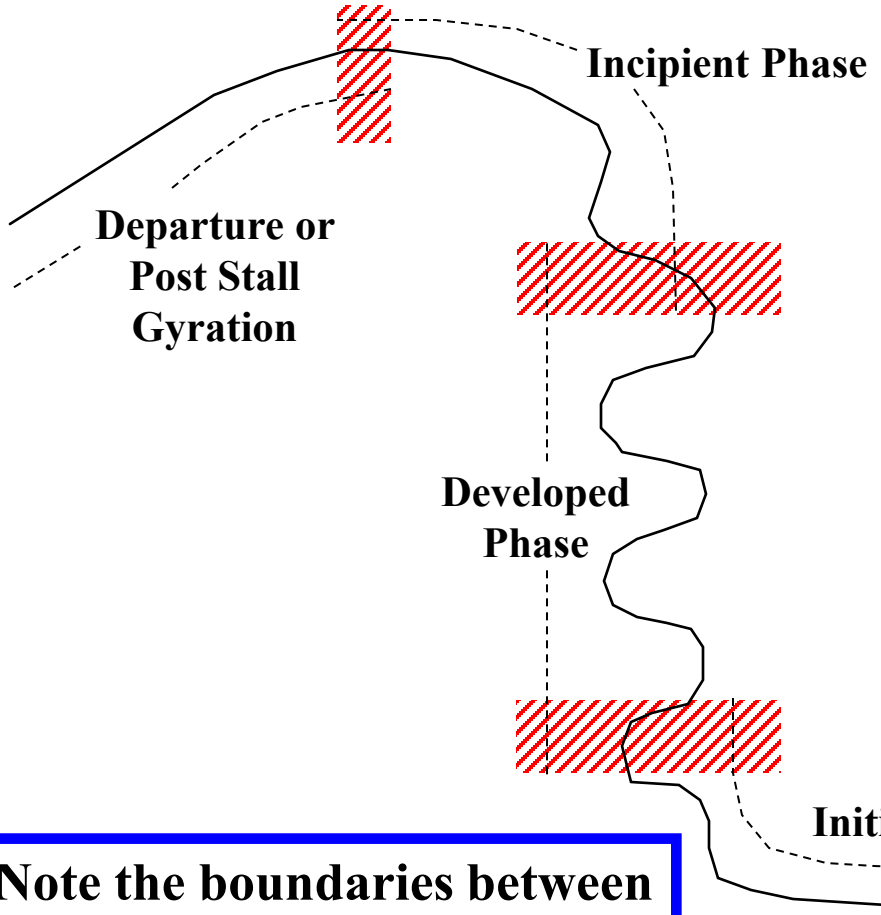
Spin Autorotation



An increase in angle of attack decreases lift, dropping the wing and feeding the rolling moment

An increase in angle of attack increases drag, retreating the wing and feeding the yawing moment

Spin Phases

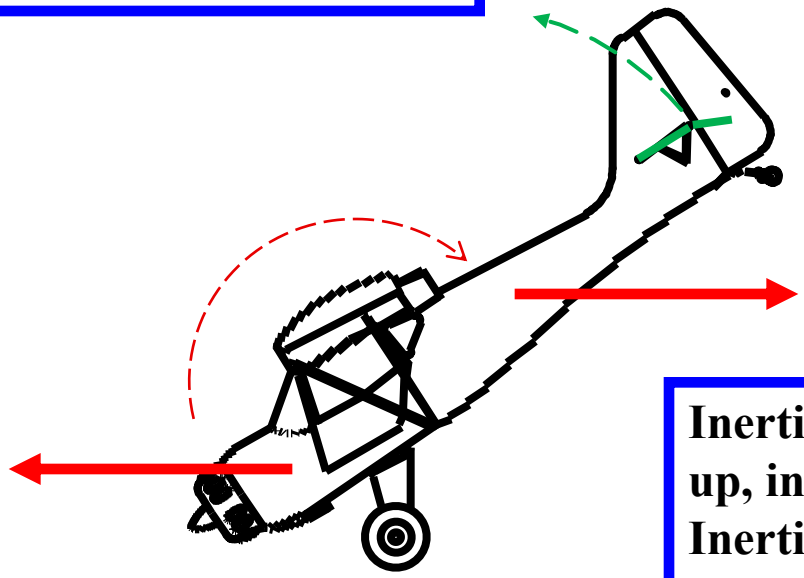




Note the boundaries between phases are not always distinct or well defined

Spin Pitching Moments

Aerodynamic forces try to pitch the nose down, decreasing the angle of attack



Inertial forces try to pitch the nose up, increasing the angle of attack. Inertial forces also cause the wing to go level.

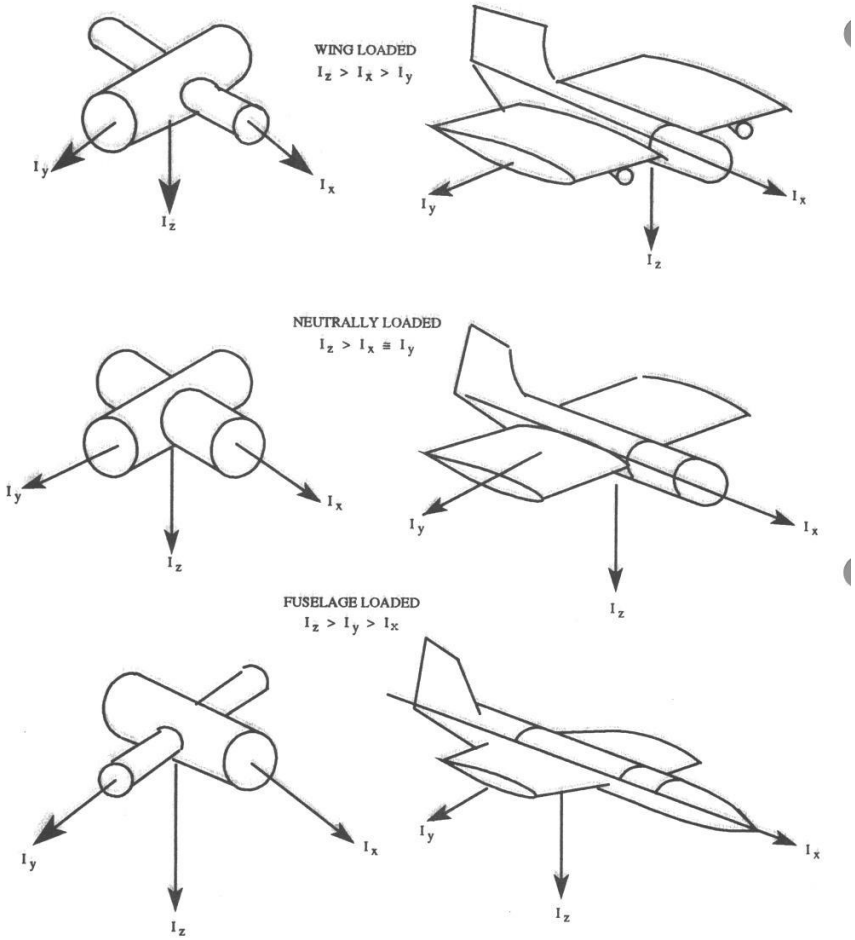
Upright vs Inverted Spin

- Upright Spin
  - Yaw & roll rate in same direction
- Inverted Spin
  - Yaw & roll rate in opposite direction



- How can I tell which way I am spinning?
  - Turn needle indicates direction of yaw rate correctly whether upright or inverted “Needle left, spinning left”

Aircraft Mass Distribution



Fuselage vs Wing Loaded Aircraft

- **Fuselage Loaded** Aircraft (e.g. Fighters)
  - Tend to spin flatter
  - Tend to have more oscillations
  - F-14 Spinning

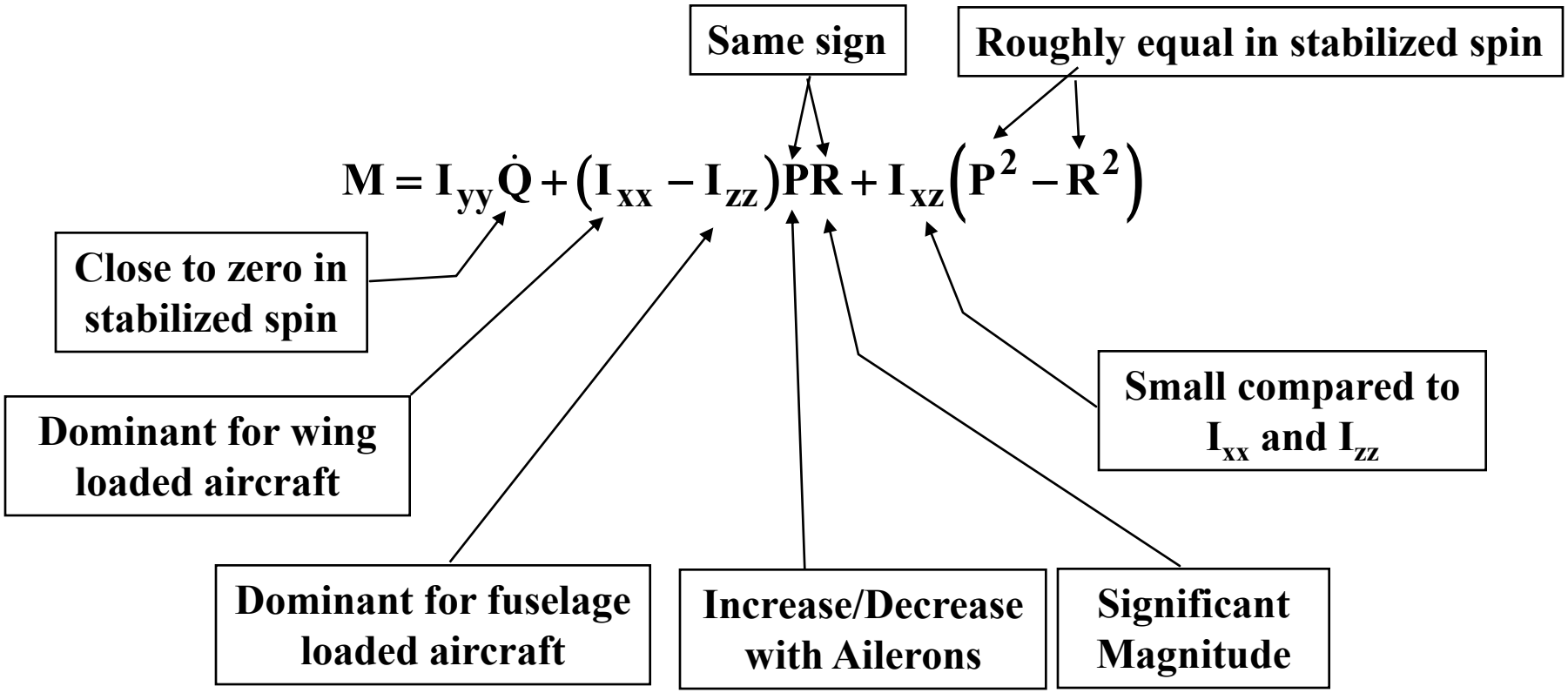


- **Wing Loaded** Aircraft (e.g. Gliders)
  - Tend to spin steeper
  - Tend to be smoother
  - ASK-21 Spinning



Spin Recovery: Aileron Effects

- Pitching Moment Equation (Aero 351/2)
  - For recovery from an upright spin, we want a more negative pitching moment



Spin Recovery: Aileron Effects

- Yawing Moment Equation (Aero 351/2)
  - For recovery from an upright spin with positive yaw rate, we want a more negative yawing moment

$$N = I_{zz}\dot{R} + \left(I_{yy} - I_{xx}\right)PQ - I_{xz}\left(\dot{P} - QR\right)$$

Close to zero in stabilized spin

Negative for fuselage loaded aircraft

Increase/Decrease with Ailerons

Increasing P makes whole term more negative

Spin/Departure Susceptibility FTT

- **Phase A -** Recover at initial stall
- **Phase B -** Controls briefly misapplied at stall (1 sec), recover
- **Phase C -** Pro-spin controls held for 3 seconds, recover
- **Phase D -** Pro-Spin controls held for 15 seconds or 3 spin turns (whichever is longer), recover

MIL-S-83691A Susceptibility/Resistance

Susceptibility/Resistance Classification

Test Phase	Classification	
	Departs	Spins
A - Stalls	Extremely Susceptible	Extremely Susceptible
B - Stalls with aggravated control inputs (1 sec)	Susceptible	Susceptible
C - Stalls with aggravated and sustained control inputs (3 sec)	Resistant	Resistant
D - Post-stall gyration, spin, and deep stall attempts (15 sec)	Extremely Resistant	Extremely Resistant

Interpreting Susceptibility/Resistance

- The category where departure/spin happened (else extremely resistant)

- A-37
  - Will not depart in Phase B stall
  - Will depart in a Phase C stall
  - Will not spin in a Phase C stall
  - Will spin in a Phase D stall

- Therefore, the A-37 is
  - Resistant to departure
  - Extremely Resistant to spin



Susceptibility/Resistance Classification

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Interpreting Susceptibility/Resistance

- T-38
  - Will not spin in a Phase D stall, *unless* unusually large pitch rates are used to "horse" the angle of attack up sufficiently high
  - Will continue to spin once spinning

- Therefore, the T-38 is
  - Extremely Resistant to spin



Susceptibility/Resistance Classification

Test Phase	Classification	
	Departs	Spins
A - Stalls	Extremely Susceptible	Extremely Susceptible
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Characterizing Spins

- "SARO"

SPIN MODE MODIFIERS			
SENSE	ATTITUDE	RATE	OSCILLATIONS
Erect (upright)	Flat ($\alpha > 70°$)	Slow ($\omega < 60°/s$)	Smooth
Inverted	Steep ($35° < \alpha < 70°$)	Fast ($60°/s < \omega < 120°/s$)	Mildly Oscillatory
	Extremely Steep ($\alpha \leq 35°$)	Extremely Rapid ($\omega > 120°/s$)	Oscillatory
			Highly Oscillatory
			Violently Oscillatory

Example Spins

- Flight Test Film Clip
  - Characterize each spin using SARO
  - Glider (1 min in)
  - F-16
  - People

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			Highly Oscillatory
			Violently Oscillatory

Example F-18 Spin

- **Flight Test Film Clip**
  - **Note the the way the fuselage loaded F-18 Spins**



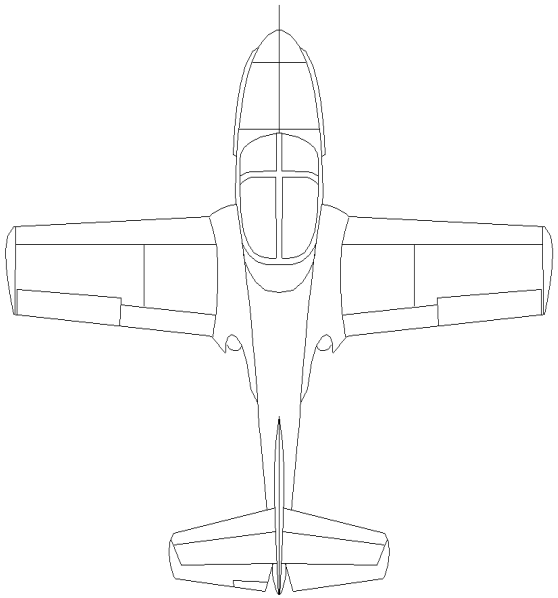


Spin Recovery

- Key to recovery :
  - reduce the yaw rate
  - reduce the angle of attack
- Recovery technique (if any) will vary between aircraft
- NASA recoveries (4) - standardized approaches

Spin Recovery: Wing Loaded

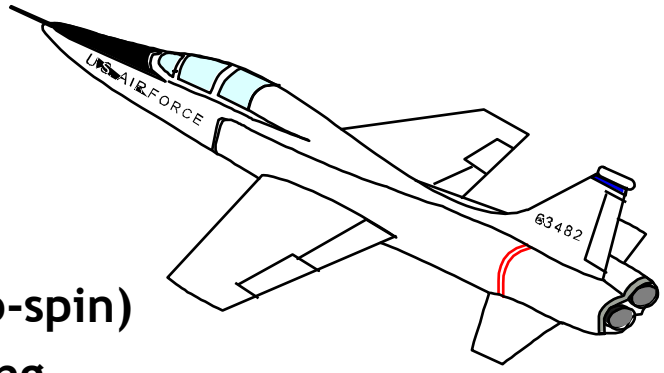
- T-37
  - Throttles idle; ailerons neutral, full opposite rudder; after one turn stick full forward; recover from dive
  - Rudder reduces yaw rate
  - Elevator reduces angle of attack



- DA-40
  - Throttle - idle
  - Rudder - full opposite direction of the spin
  - Stick - full forward
  - Ailerons - neutral
  - Flaps - up
  - Rudder - neutral (after spinning stops)
  - Recover from dive

Spin Recovery: Fuselage Loaded

- **T-38**
  - Throttles idle; ailerons with the spin; recover from dive
  - Ailerons reposition inertial axes, coupling yaw rate into a negative pitch rate
  - Roll into spin



- **Effect of ailerons "with spin"**
  - Can be good or bad, depending on
    - Aerodynamics (drag of ailerons may be pro-spin)
    - Mass distribution (degree of fuselage loading
  - Can only be determined in flight test, but surmised from moment equations

- **F-15 and other fighters**
  - Similar to T-38
  - May include split throttles

Controllable High Angle of Attack Flight

- High alpha could be useful for gaining the advantage in aerial combat
- Generally requires thrust vectoring
  - Aerodynamic controls generally ineffective at high angles of attack
- F-22







Next Time

Flight 4