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STALL FLIGHT TEST OF COMMERCIAL TRANSPORT AIRCRAFT and UPSET RECOVERY TRAINING

Seminar for the Course of "Flight Dynamics" *December 12th, 2018*

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NOTE*: a part of this seminar is based on a joint Airbus-Boeing Lecture on Stall Tests, presented at Royal Aeronautical Society in London on March 2013.*

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- ***STALL DEFINITION AND REQUIREMENTS***
- *ENGINEERING PREPARATIONS*
- *PILOT PREPARATIONS & TEST CONDUCT*
- *UPSET RECOVERY TRAINING IN A FULL FLIGHT SIMULATOR*

STALL DEFINITION AND REQUIREMENTS

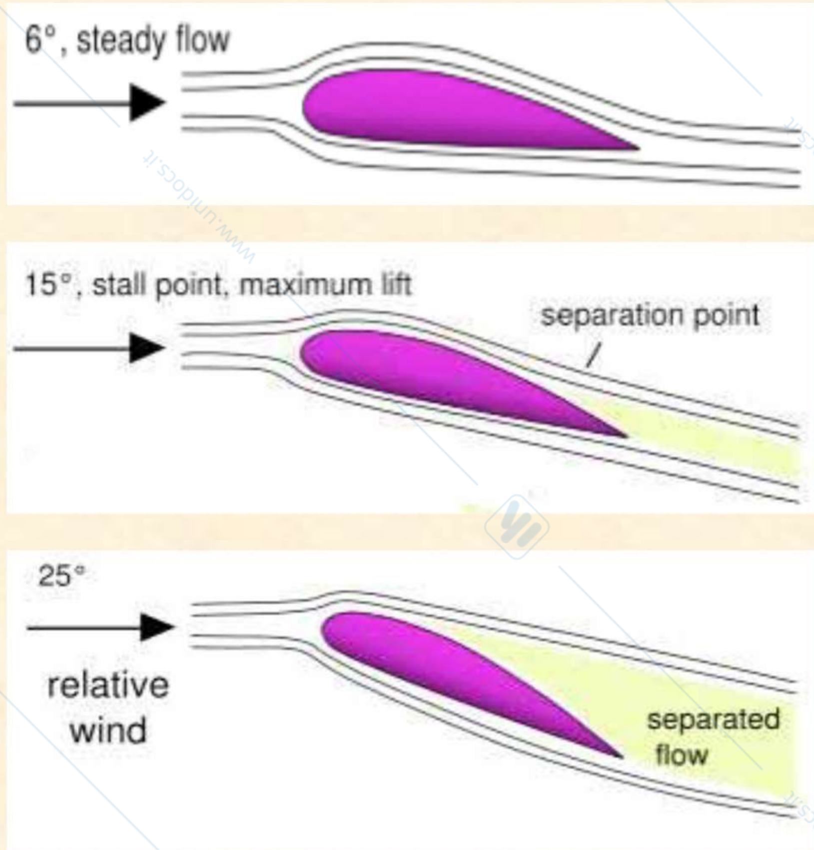
In the frame of a **new transport aircraft test campaign**, **stalls are performed early**, with the following targets:

- **Flight envelope** opening (towards low speed)
- **Optimization of aerodynamic** configurations to get a good compromise between low and high speeds
- **Aerodynamic identification** of the aircraft ($C_{L\alpha}$ curve of all aerodynamic configurations)
- Determination of the **stall speeds** (Vs_{1g}) on which a lot of **performances** are based (V_2 takeoff speed, V_{REF} approach speed, …)
- Local changes in angle of attack (**AOA**) at the horizontal **tail**
- Horizontal **tail structural loads**
- **Certification** tests

STALL

is the **reduction of Lift**
while increasing the Angle of Attack,
due to an extended separation of the boundary layer from the upper wing surface

Loss of Lift is accompanied by a **Drag increase** and a **change in pitching Moment**



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STALL DEFINITION AND REQUIREMENTS

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https://www.youtube.com/watch?v=SXwVyxorvno

STALL DEFINITION AND REQUIREMENTS

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Conditions for stall identification may be different according to Airplane Category, as specified by Certification Regulations:

- **CS-VLA**: *a stall is shown by:*
  - *an uncontrollable **downward pitching** motion of the airplane, or until the control reaches the **aft stop***
- **FAR/EASA CS-23**: *a stall is shown either by*
  - *an uncontrollable **downward pitching** motion of the airplane*
  - *A downward pitching motion of the airplane that results from the activation of stall avoidance device (i.e.: **stick-pusher**)*
  - *The **control** reaching the **aft stop***
- **MIL-F-83691**: *a stall is shown by a clear indication of either:*
  - *A definite **g-break***
  - *A rapid, uncommanded **angular motion***
  - *The **aft stick** stop has been reached and AOA is not increasing*
  - *Sustained, intolerable **buffet** is experienced*

STALL DEFINITION AND REQUIREMENTS

- **FAR/EASA CS-25.201 (d)**: *a stall is shown either by:*
  - *A **nose-down pitch** that cannot be readily arrested*
  - ***Buffeting**, of a magnitude and severity that is a strong and effective **deterrent** to further speed reduction*
  - *The pitch **control reaches the aft stop** and no further increase in pitch attitude occurs when the control is held full aft for a short time before recovery is initiated.*

CERTIFICATION REGULATION ⇒ ***FAR & EASA CS 25***

- 25.103 ⇒ stall speed **definition** ($V_{CL\,MAX}$, V_{SR})
- 25.201 ⇒ stall **demonstration** (eng thrust, CG position, long trim, …)
- 25.203 ⇒ stall **characteristics** (g-break, full back stick, roll, buffet, ..)
- 25.207 ⇒ stall **warning**

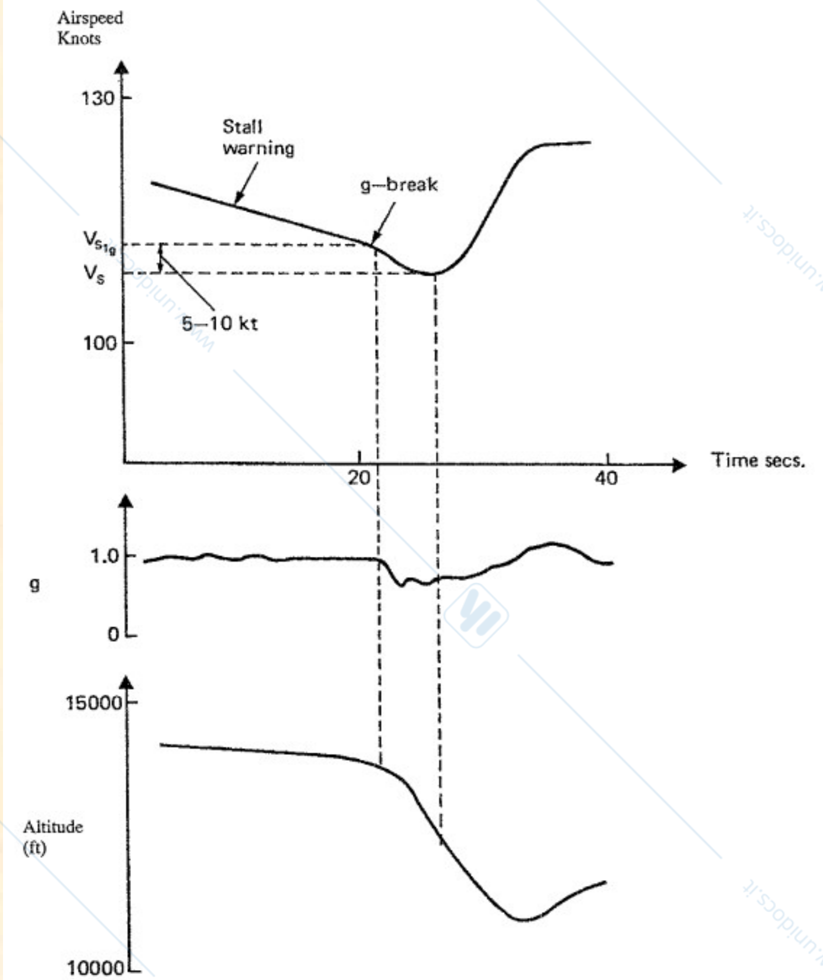
STALL SPEEDS:

Vs_{1g}

minimum Calibrated airspeed (CAS) at which the aircraft can generate enough Lift to maintain a ***controlled trimmed level flight (at 1-g)***

Vs

minimum Calibrated airspeed (CAS) at which the aircraft can generate enough Lift to maintain ***controlled flight***



According to Regulation FAR/EASA CS-25

Reference stall speed V_{SR} is the 1-g stall speed Vs_{1g}

STALL DEFINITION AND REQUIREMENTS

Airbus Stall speed definition

VS : Stalling speed.

For a conventional aircraft, the reference stall speed, VSmin, is based on a load factor that is less than 1 g. This gives a stall speed that is lower than the stall speed at 1 g. All operating speeds are expressed as functions of this speed (for example, VREF = 1.3 VSmin).
Because aircraft of the A320 family have a low-speed protection feature (alpha limit) that the flight crew cannot override, Airworthiness Authorities have reconsidered the definition of stall speed for these aircraft.
All the operating speeds must be referenced to a speed that can be demonstrated by flight tests. This speed is designated VS1g.

Airworthiness Authorities have agreed that a factor of 0.94 represents the relationship between VS1g for aircraft of the A320 family and VSmin for conventional aircraft types. As a result, Authorities allow aircraft of the A320 family to use the following factors :

V2 = 1.2 × 0.94 VS1g = 1.13 VS1g
VREF = 1.3 × 0.94 VS1g = 1.23 VS1g

These speeds are identical to those that the conventional 94 % rule would have defined for these aircraft. The A318, A319, A320 and A321 have exactly the same maneuver margin that a conventional aircraft would have at its reference speeds.
The FCOM uses VS for VS1g.

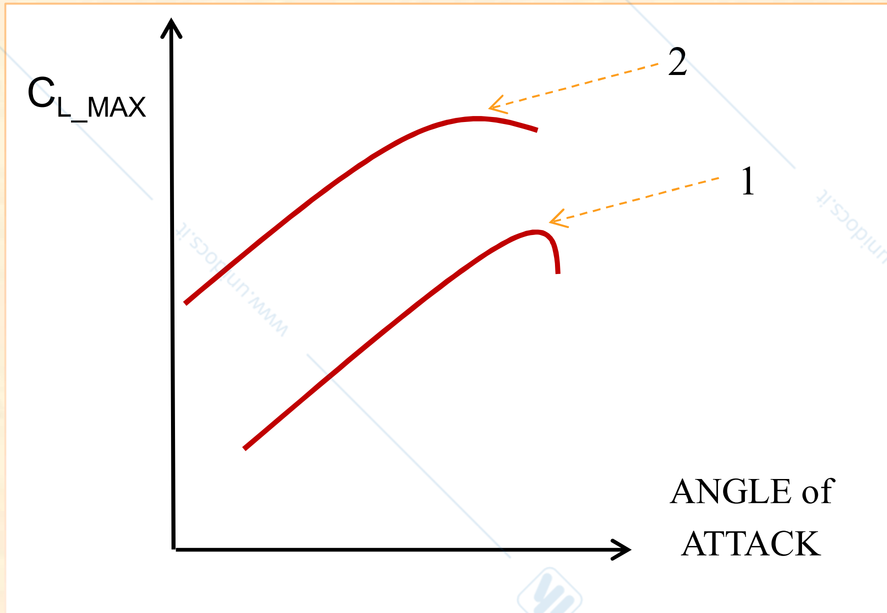
FCOM A320F, Airbus – from www.smartcockpit.com

LOW ALTITUDE STALL TEST

(up to ~10000 ft)

C_{L_MAX} is identified with one of the following *behaviors* (refer to figure):

1) **Sudden loss of lift** and vertical acceleration (g-break)
2) **Increment in vertical rate** of descent as the AOA increases



Other behaviors that identify $C_{L\ MAX}$ but ***may require further intervention*** on the aircraft are:

- Reaching full aft stop of longitudinal pilot stick without any further AOA increase
- Drop of a wing
- Sudden pitch up (aft-swept wing)

STALL DEFINITION AND REQUIREMENTS

For a given wing section,

C_{L_MAX} *and* **α_{MAX}**

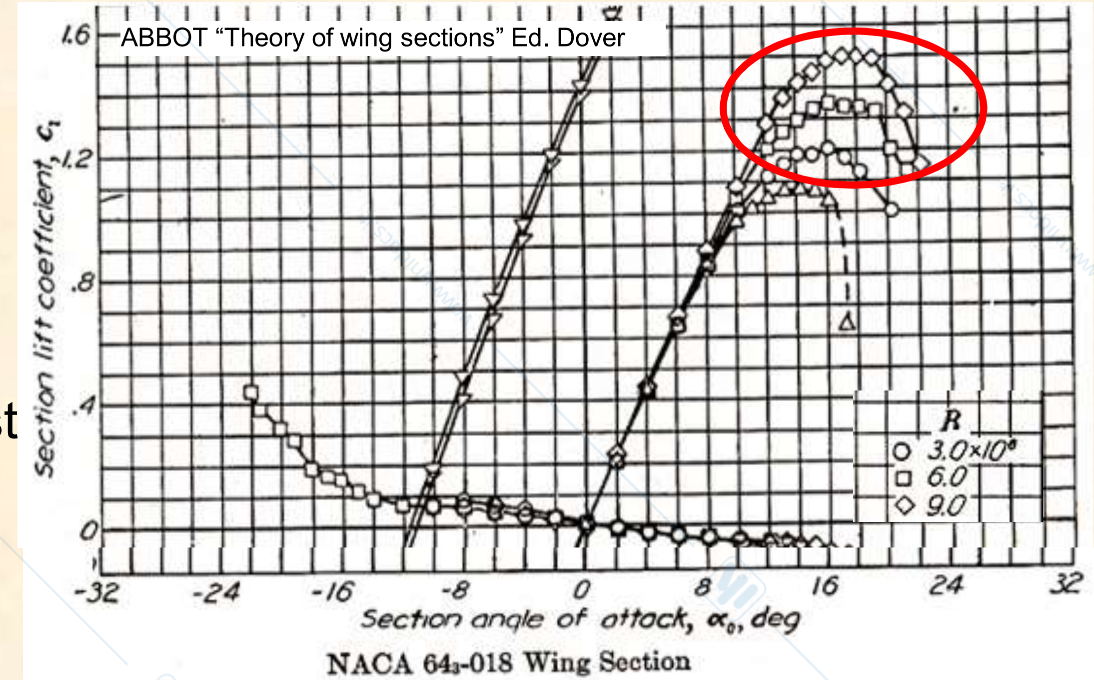
depend on

Reynolds Number

Flight envelope boundaries must be flight tested for certification, not extrapolated

(FAA/EASA 25.25 (b)(3)

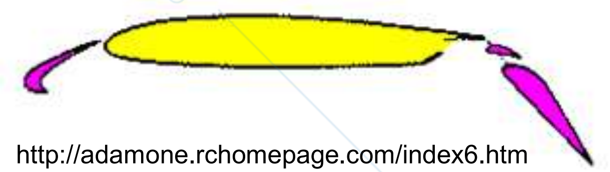
***minimum in-flight weight**)*



Stalling is fundamental for ***performance*** *determination (V_2 , V_{REF} , ..), but at the same time it involves* ***controllability*** *and* ***handling qualities***

STALL DEFINITION AND REQUIREMENTS

DC9-30 Lift curves @ M=0.2 and Tail off



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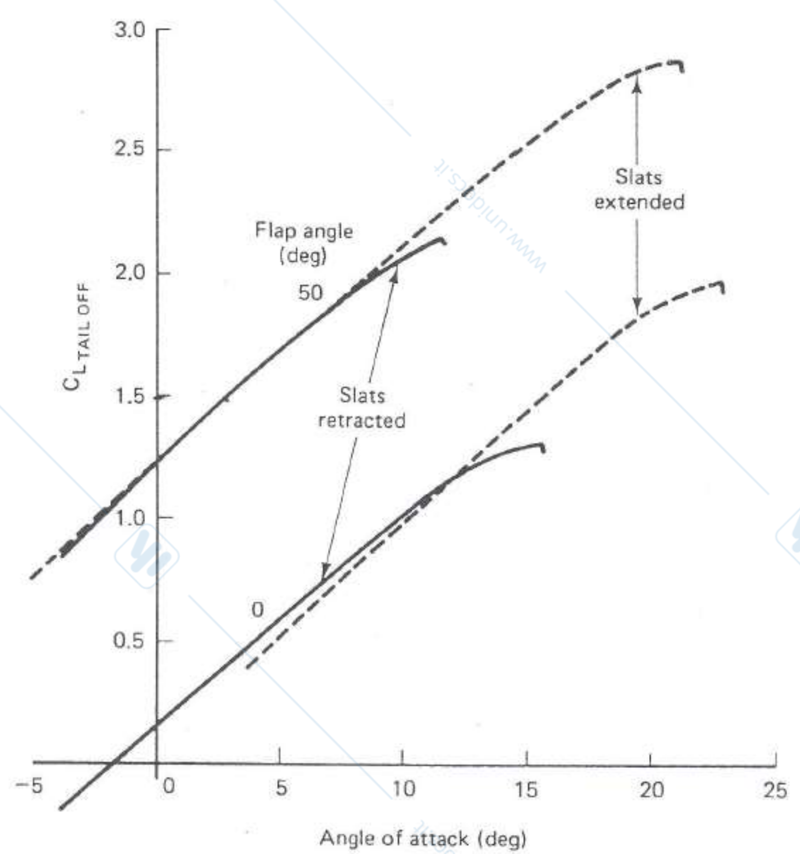
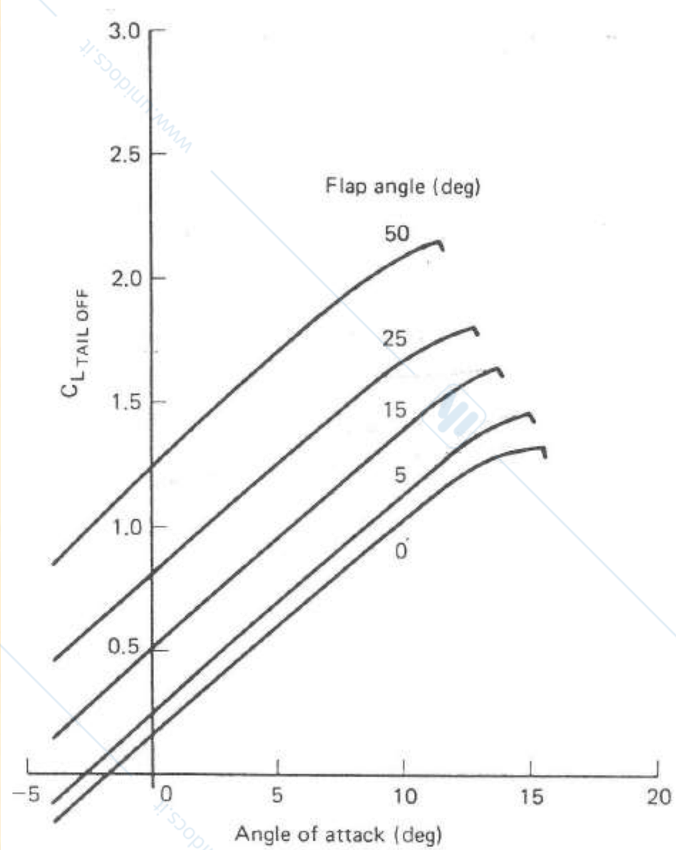


Slats effect (Flaps 0° and 50°)



Flaps effect (Slats retracted)

STALL DEFINITION AND REQUIREMENTS

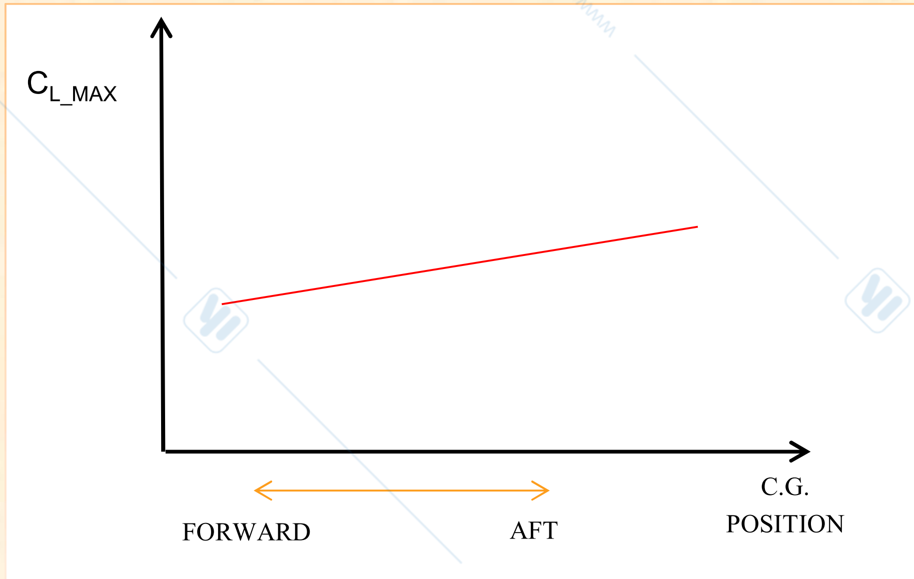
Several factors have an impact on C_{L_MAX} and consequently on Vs_{1g} and need to be identified and evaluated during flight testing:

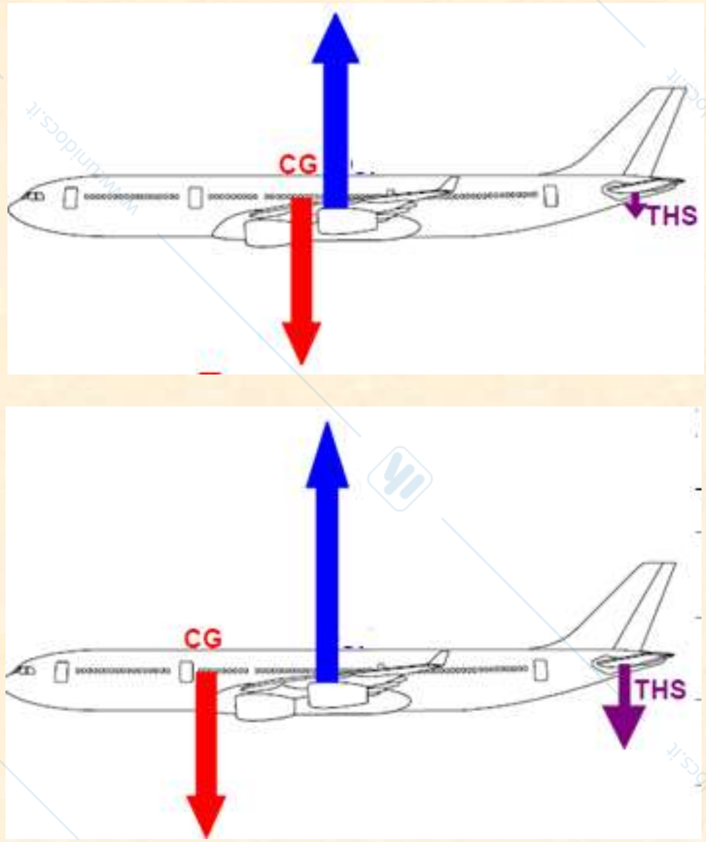
- **Longitudinal position of Center of Gravity (CG)**
- **Engine thrust**
- **Mach number (low and high altitude)**
- **Ground effect**
- **Airplane abnormal configurations and malfunctions**
- **Wing & Horizontal Stabilizer Icing**

STALL DEFINITION AND REQUIREMENTS

C_{L_MAX} vs CG: due to the down force of the horizontal stabilizer for pitch trimming.

For this reason, Vs_{1g} is computed with the ***foremost CG*** position.





Getting to Grips with Aircraft Weight and Balance, Airbus

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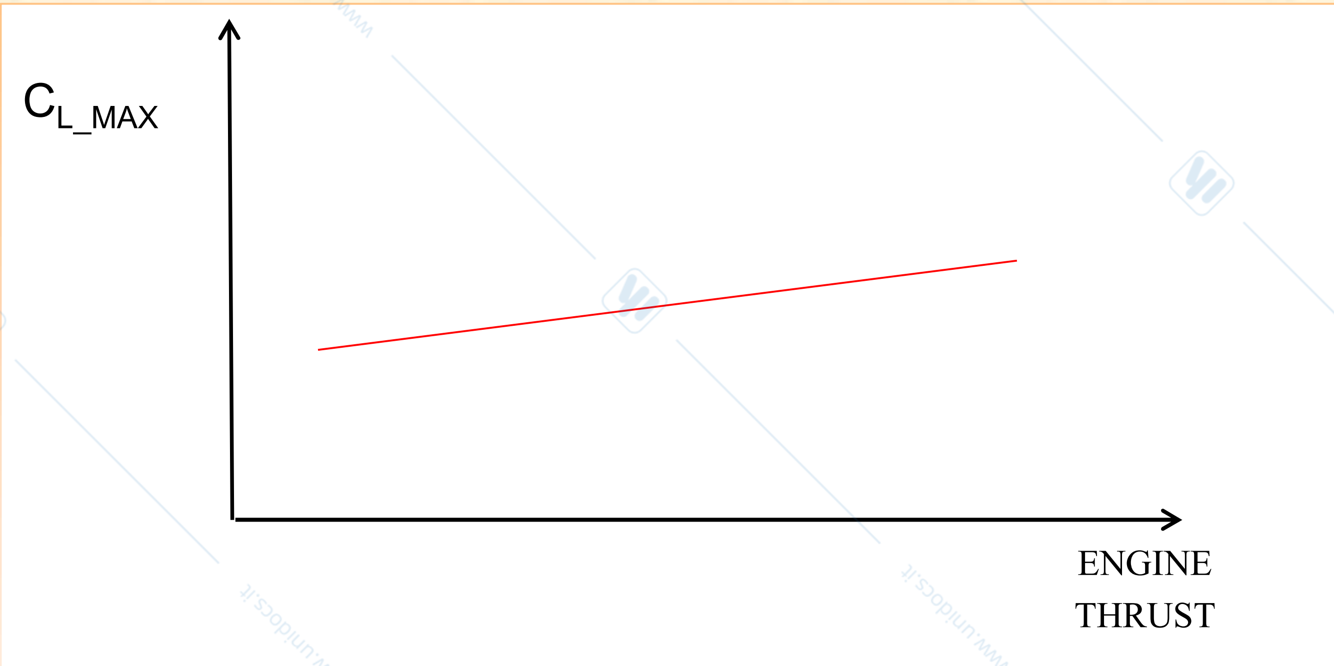
C_{L_MAX} vs Engine Thrust: due to the vertical component of thrust which is added to the Lift.

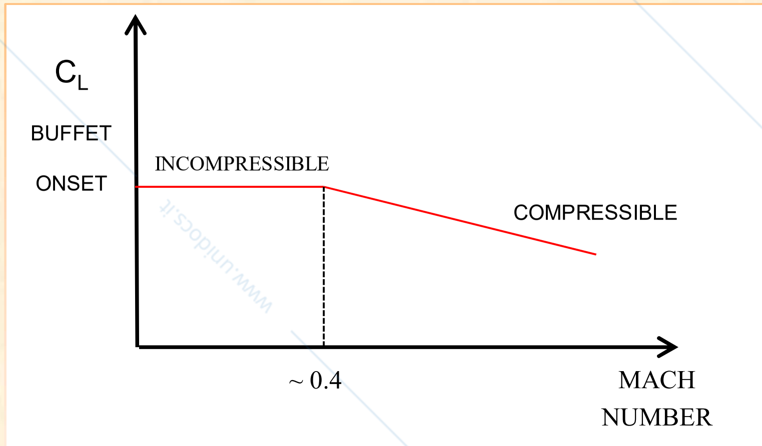
For aircraft with engines under the wing, recovery from «power stall» can be ***dangerous*** and not even feasible: they are performed with ~40% of thrust and data are then extrapolated.

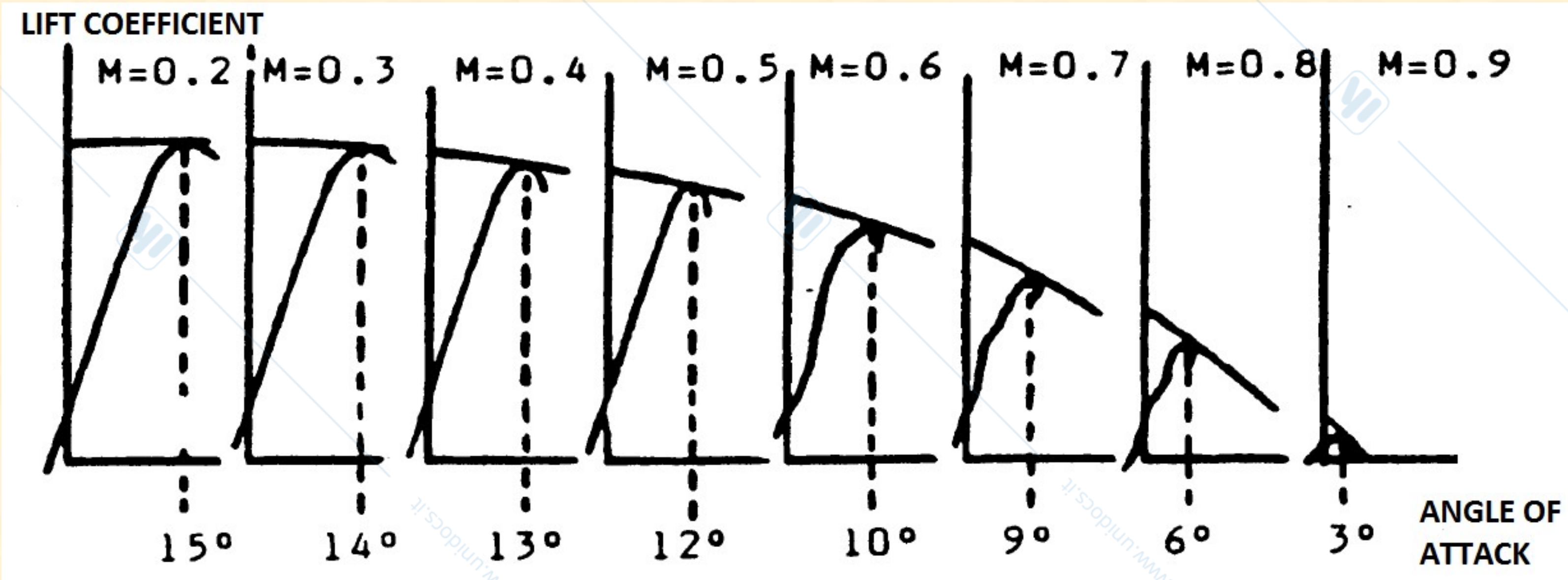


STALL DEFINITION AND REQUIREMENTS

C_{L_MAX} vs Mach Number: on transonic airfoils, due to compressibility effect, C_{L_MAX} and α_{MAX} decrease as Mach number increases.

This important effect must be taken into account during stall recovery, to avoid to enter in a secondary stall.





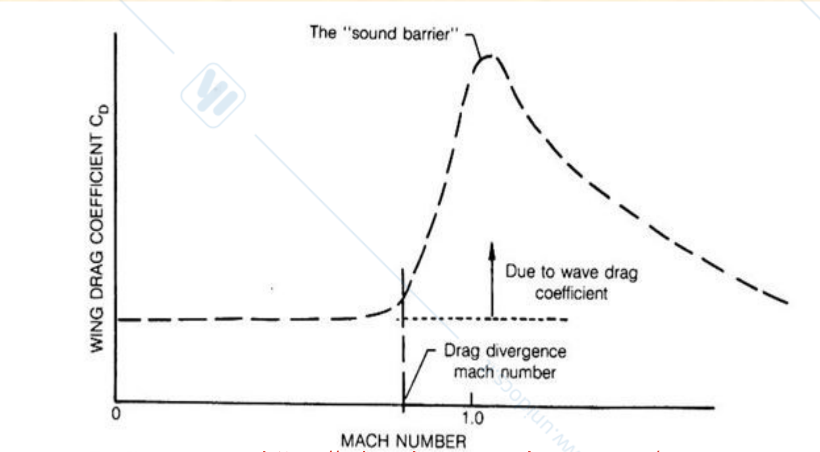
Mario Venuti, "Aerodinamica Oggi", 2° Ed, Editrice Totem

Is there any other phenomenon able to detach the boundary layer from the wing surface?

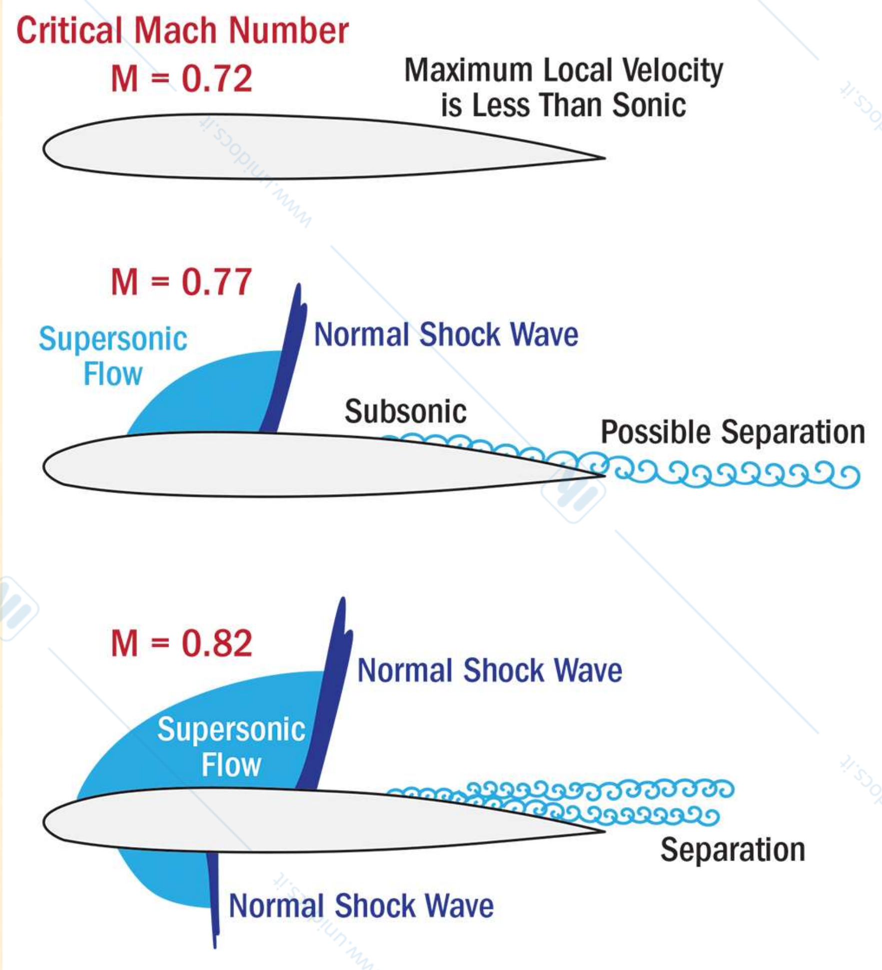
YES, the shock wave

On a **transonic airfoil** at high subsonic speed, the shock wave causes:

- Loss of LIFT
- Increase of DRAG



https://mhmaberry.wordpress.com/



http://aviationweek.com/AirlinerTech#slide-4-field_images-1368241

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HIGH ALTITUDE/HIGH MACH IMPENDING STALL:

It is accompained by a significant buffet called ***Buffet Onset***, which induces an **high frequency vibration at pilot seat**; in this case, C_{L_MAX} is identified when this vertical acceleration at pilot station reaches **±0.1g**.

Regulation requires that at the boundary of the flight envelope, the airplane must be able to sustain a **maneuver at 1.3g** before reaching the buffet onset as defined above.

In case of **turbulence**, the buffet margin is required to be **1.5g.**

STALL DEFINITION AND REQUIREMENTS

Aerodynamic Envelope of a transonic airfoil

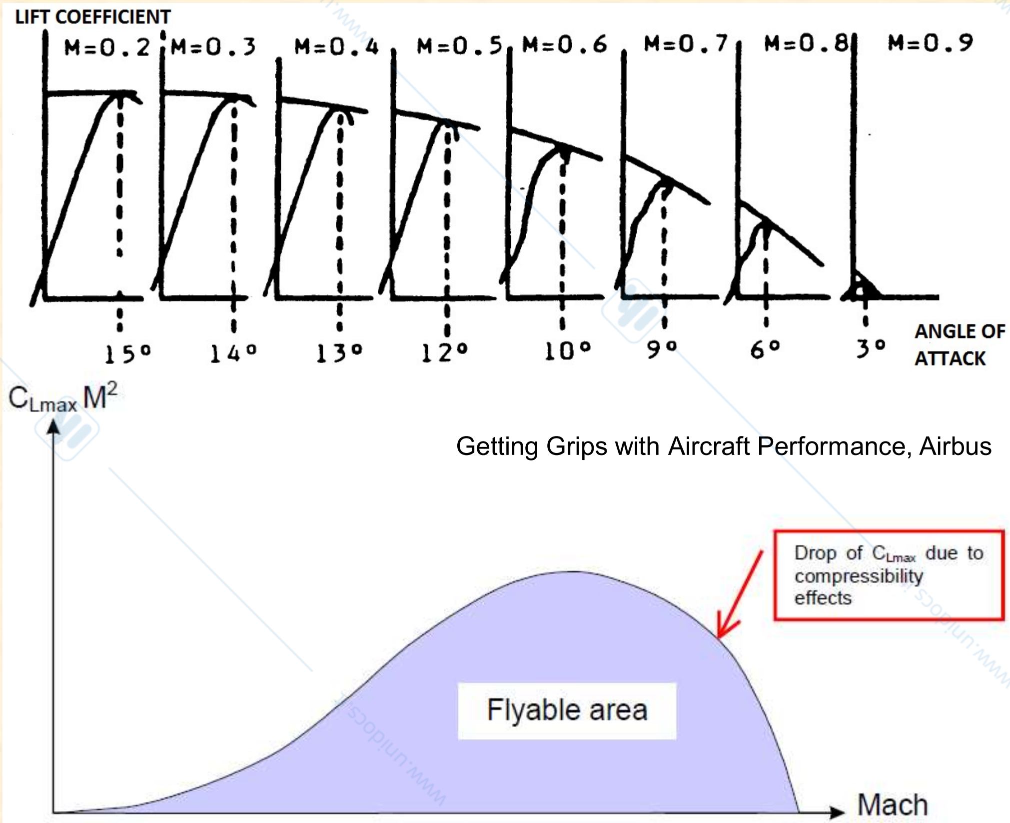
$$L = \frac{1}{2}\rho V^2 S C_L$$

$$M = \frac{V}{\sqrt{k\,R\,T}} \qquad P_S = \rho\,R\,T$$

$$L = 0.7\,P_S\,S\,C_L M^2$$

- Due to **compressibility effect**, C_{L_MAX} and α_{MAX} decrease as Mach number increases.
- Multiplying each C_{L_MAX} for the corresponding square Mach number, the term $C_{L\_MAX}M^2$ identifies the **boundary of the aerodynamic envelope**:

$$L = n\,W = 0.7\,P_S\,S\,C_{L\_MAX}M^2$$

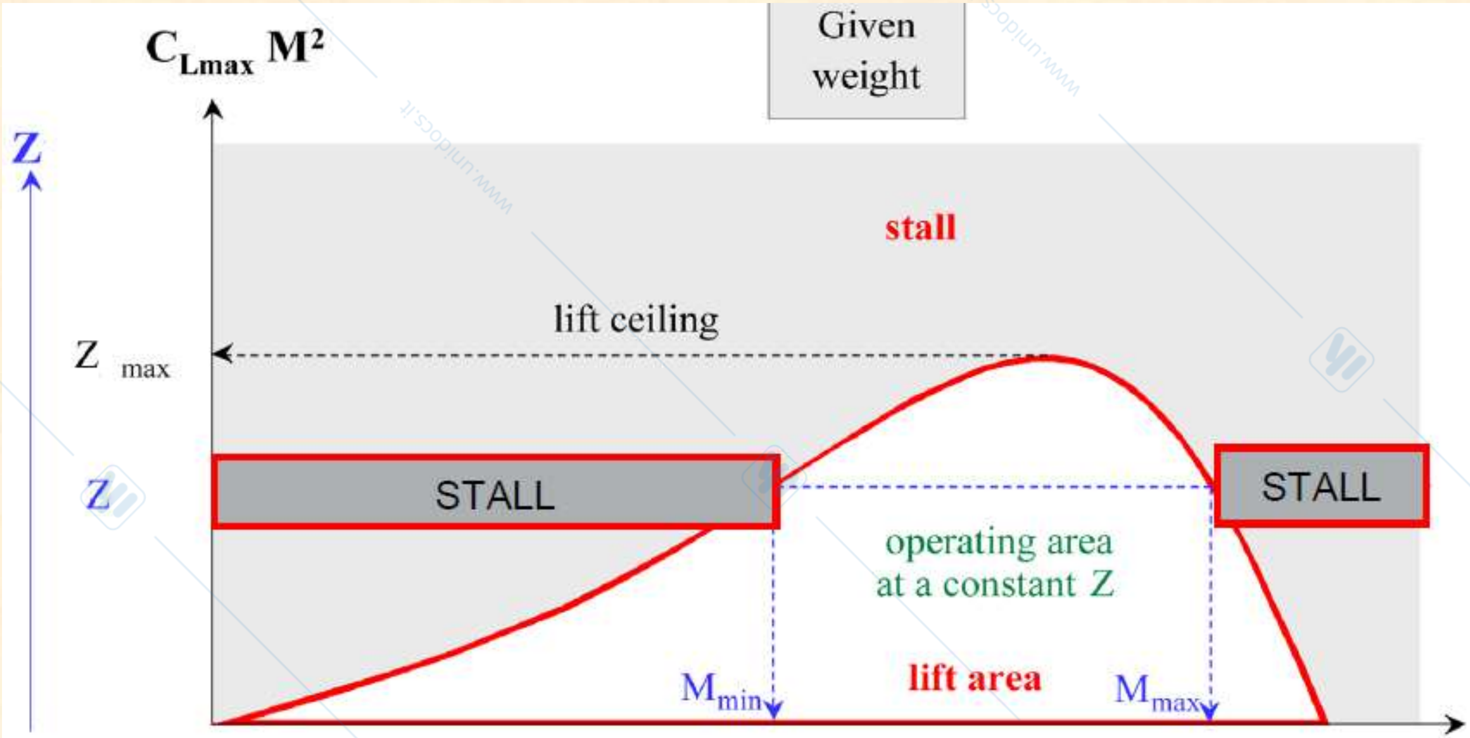


Getting Grips with Aircraft Performance, Airbus

STALL DEFINITION AND REQUIREMENTS

Aerodynamic Envelope of a transonic airfoil

$$C_{L\_MAX} M^2 = \frac{n\,W}{0.7\,P_S\,S} \quad \Rightarrow \quad C_{L\_MAX} M^2 \propto n\,W\,Z$$



Getting Grips with Aircraft Performance, Airbus

Typical Buffet Onset chart of a transonic airfoil

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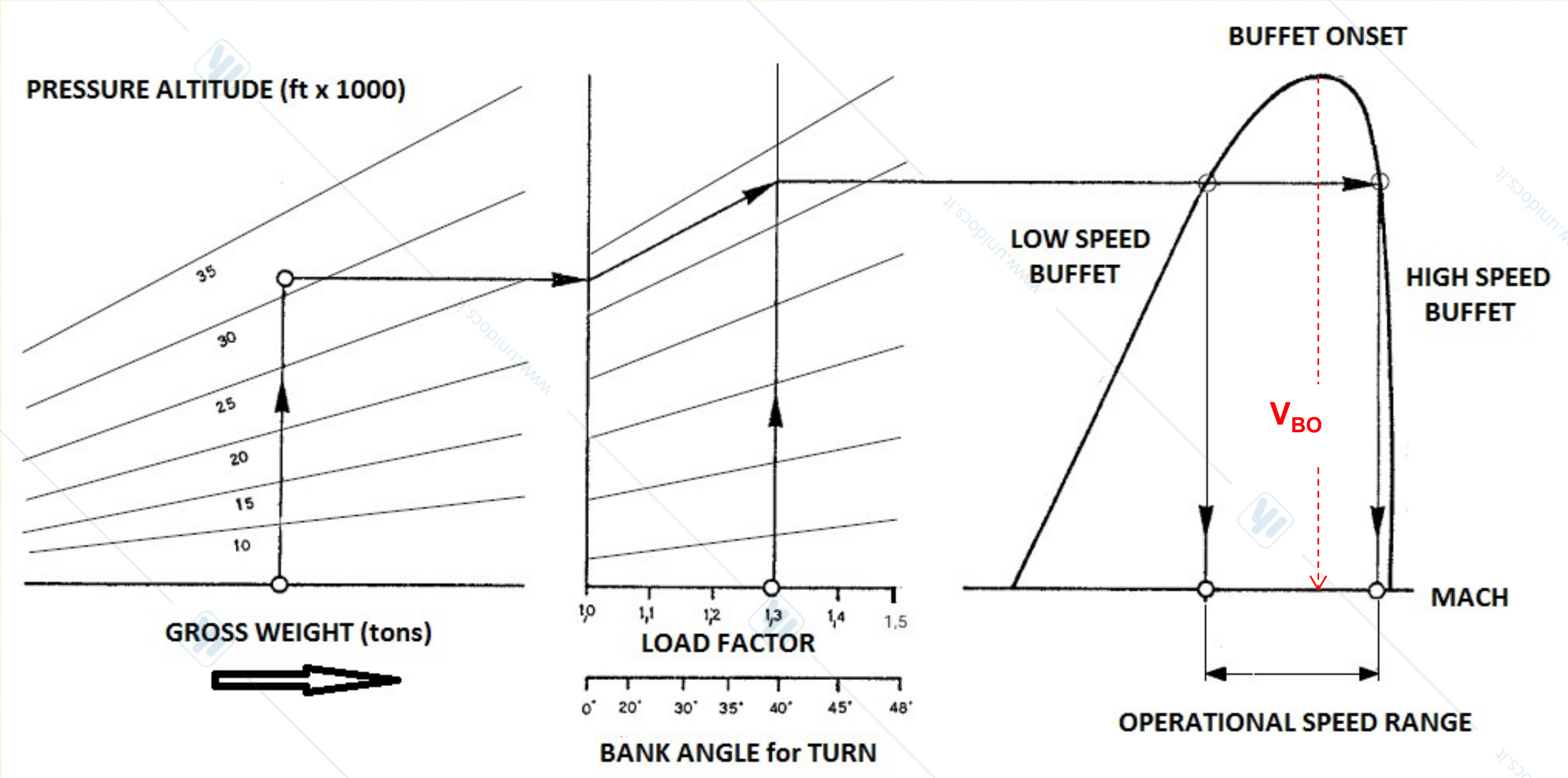


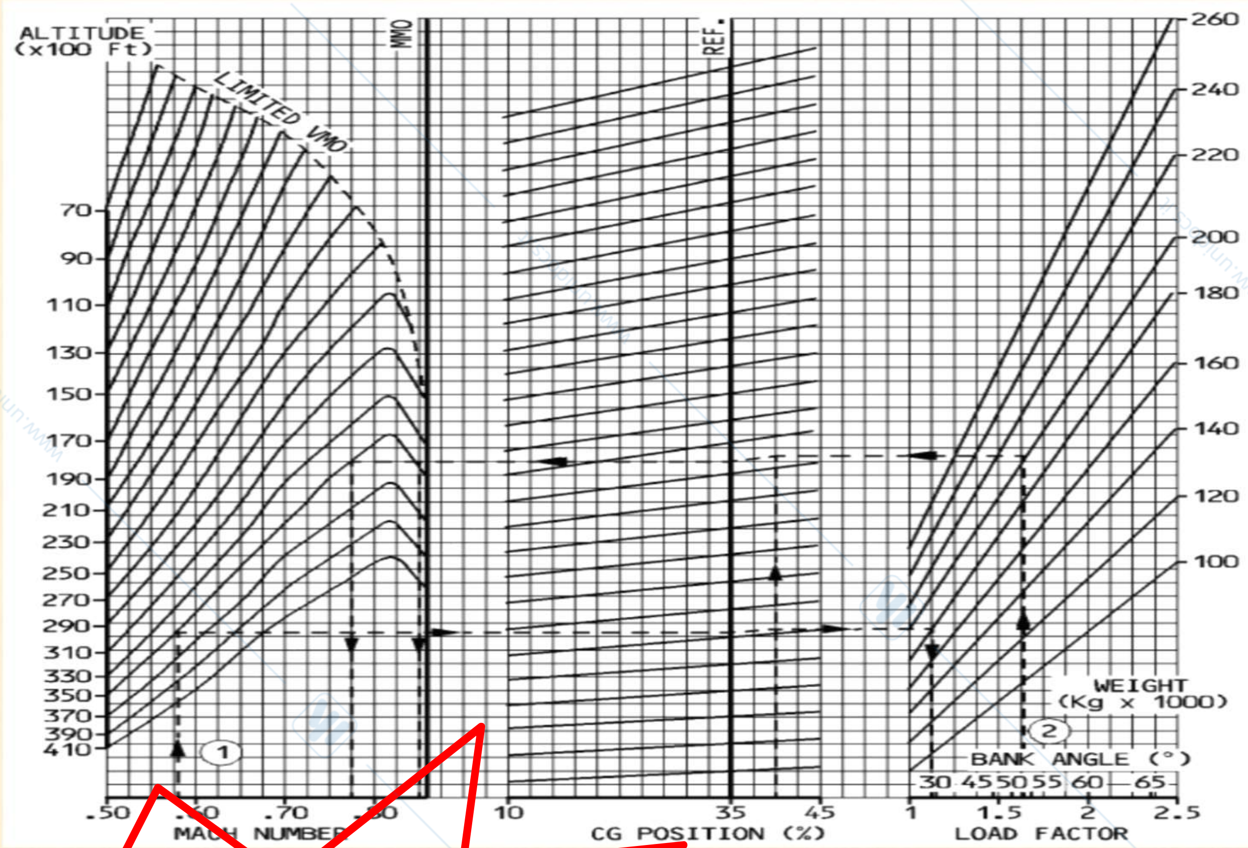
From the aerodynamic point of view, ***turbulence speed*** should be the one corresponding to the top of the buffet onset envelope, called V_{BO}.
(may be structural-limited to lower airspeed by gust-load diagram)

Buffet Onset diagram of Airbus 330

An **increase** of:

- Airplane weight
- Load factor
- Altitude
- Forward CG position

Reduces the aerodynamic envelope

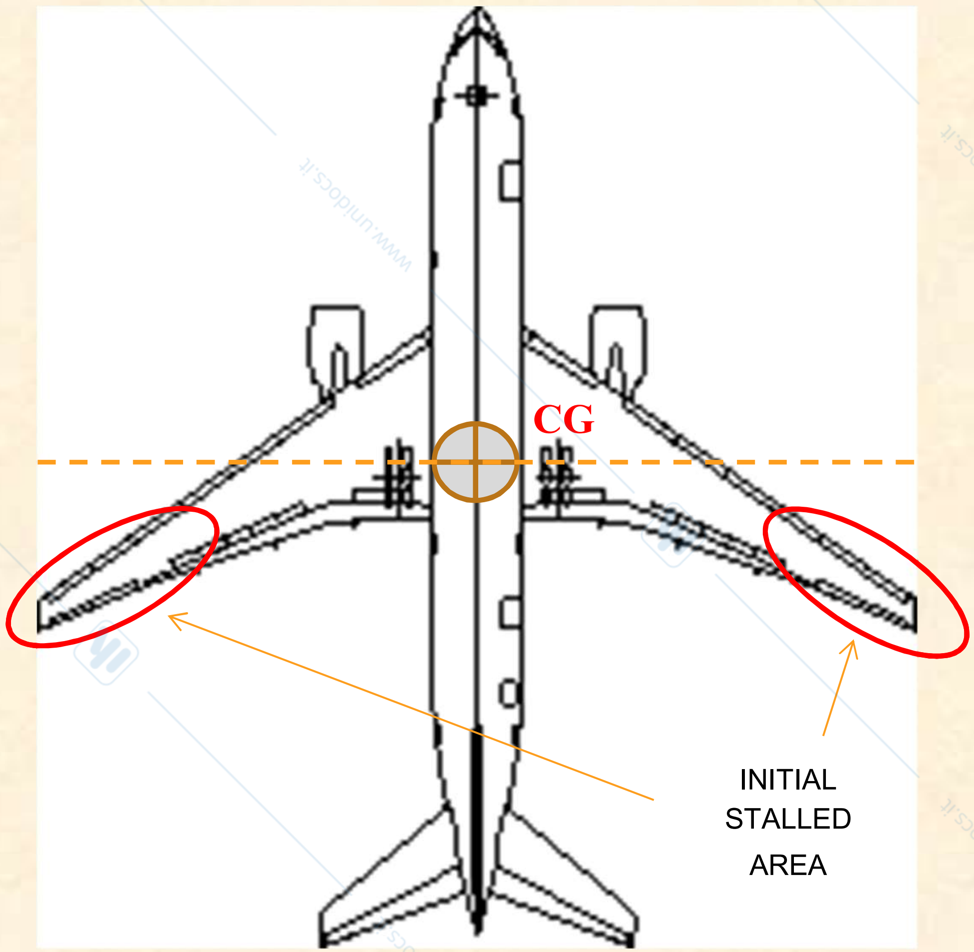


FCOM, A330, Airbus – from www.smartcockpit.com

LOW SPEED STALL is far more dangerous than HIGH SPEED STALL

STALL DEFINITION AND REQUIREMENTS

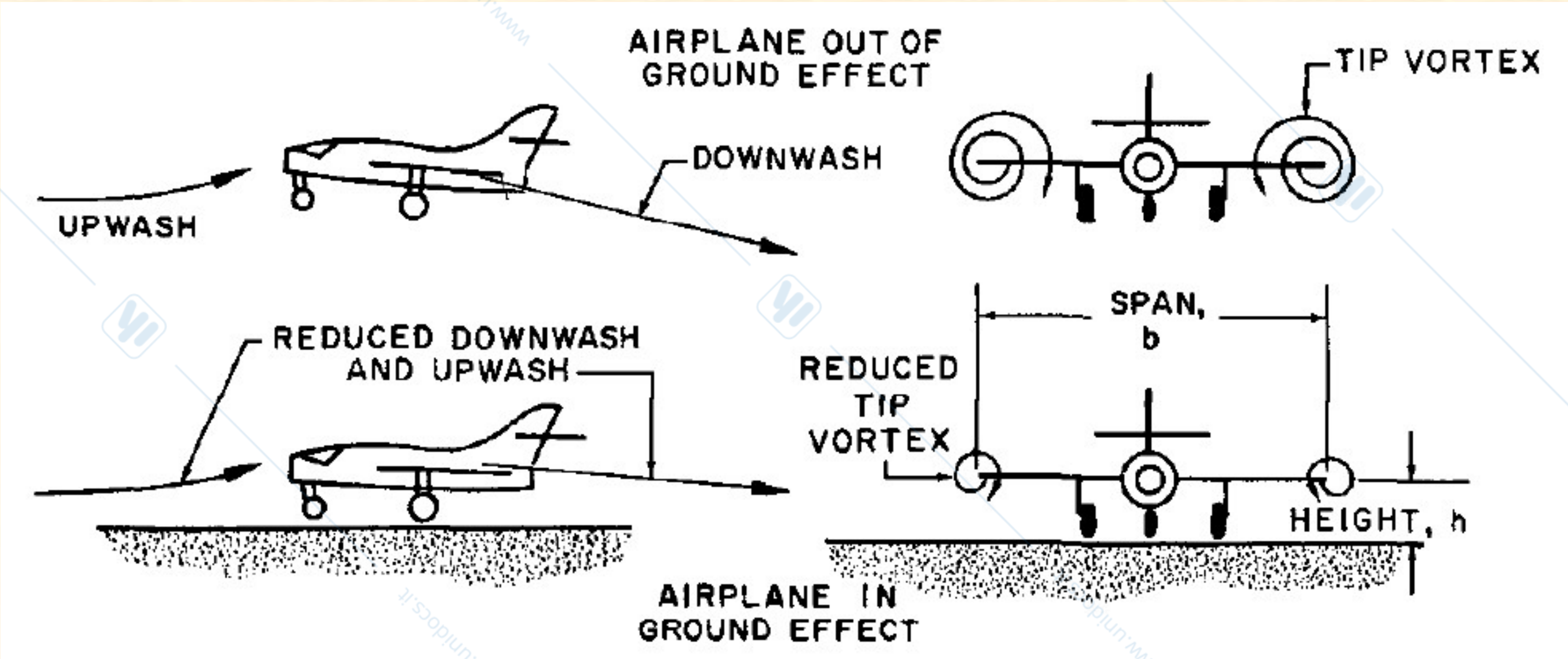
Another possible effect on swept-wing airplane when approaching the stall angle is a ***pitch up*** caused by initial stall of wing tips which are behind the center of gravity.



GROUND EFFECT

The proximity to the ground causes a «cushion» effect providing additional lift at the same AOA.

Effects of **wing downwash on horizontal tail AOA** must also be considered.



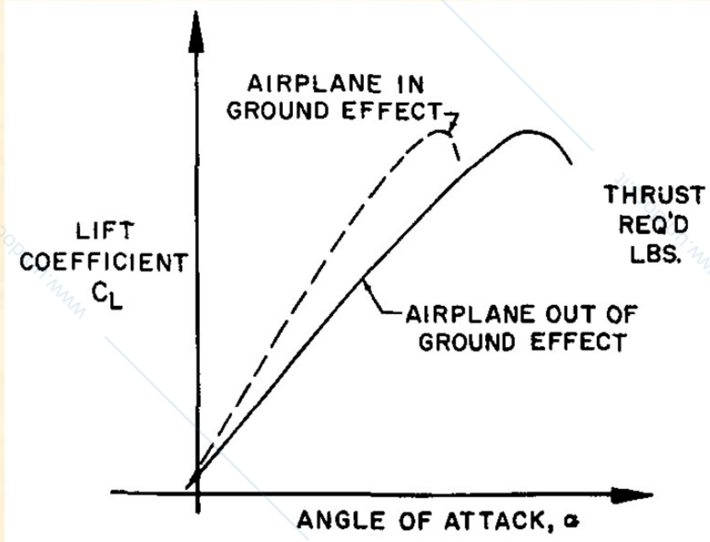
“Aerodynamics for Naval Aviators”, Hurt, U.S. Navy

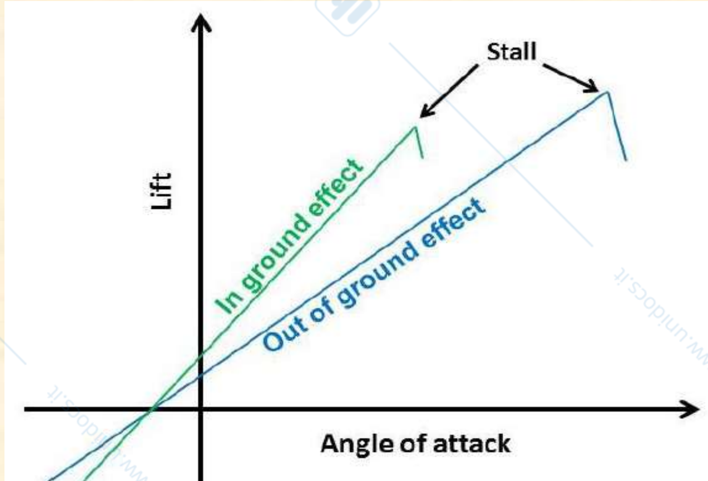
STALL DEFINITION AND REQUIREMENTS

Data for correction of C_L/α curve in ground effect are extrapolated from **Minimum Unstick** takeoff flight tests.

Beware that sometimes, however, there could be a **reduction in maximum lift** available in full ground effects.

"Aerodynamics for Naval Aviators", Hurt, U.S. Navy





NTSB Accident Report, G650, April 2, 2011

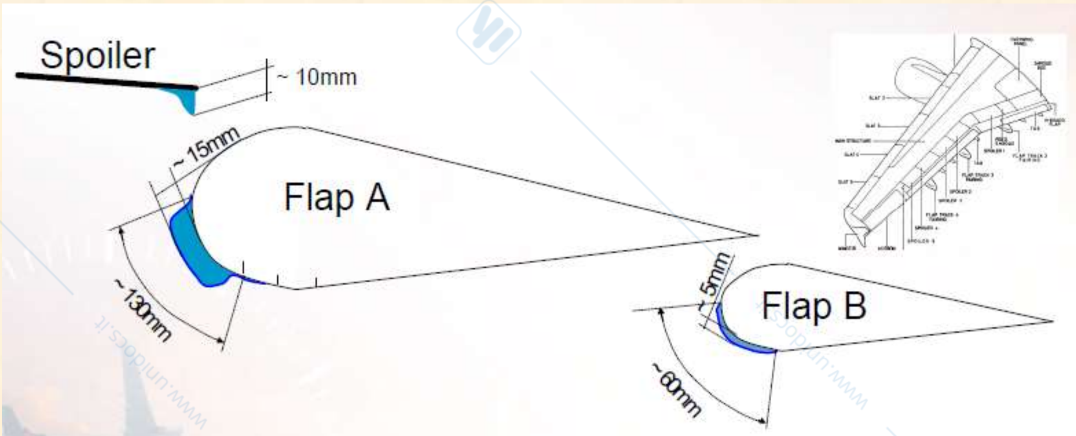
STALL DEFINITION AND REQUIREMENTS

Stalls are also performed in **abnormal configurations** corresponding to the most probable failure cases, such as:

- Abnormal flap/slat configurations, hydraulic failures, …
- Lateral center of gravity offset (fuel unbalance)
- Degraded Flight Control System for FBW (Alternate or Direct Law)

Stall are also performed in the worst case of **icing conditions** (holding patterns), according to regulation.

Operational Liaison Meeting, 2004, " A321 Lateral Control in Turbulence and Icing Conditions", Airbus – from www.smartcockpit.com

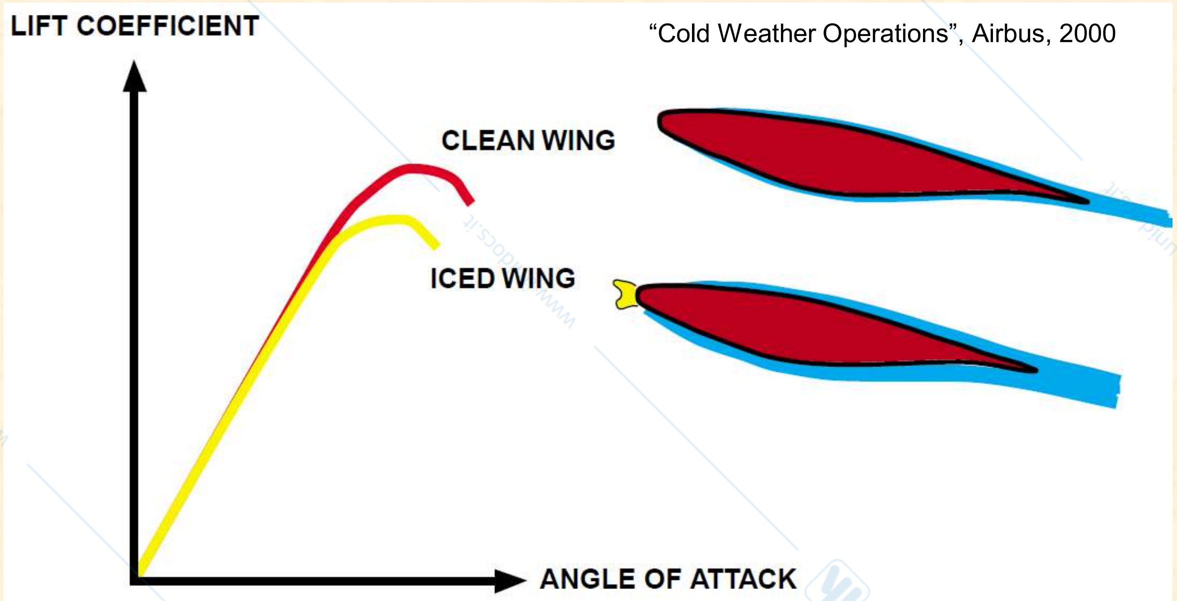


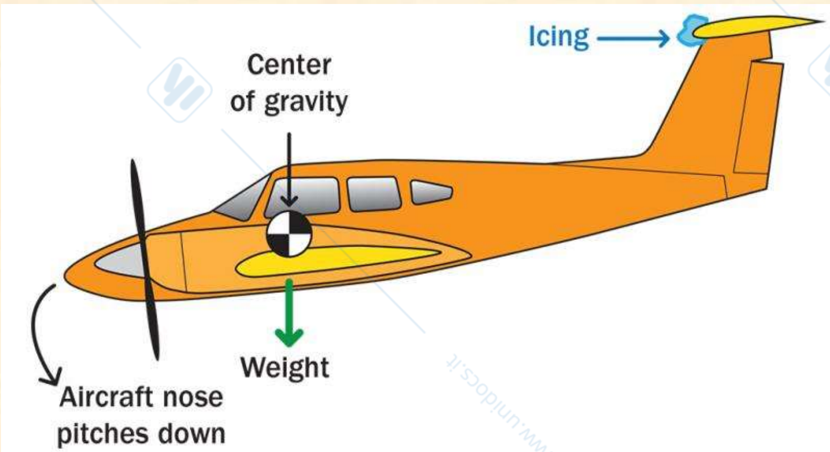
www.unidocs.it - Appunti e dispense per superare i tuoi esami universitari

Effect of ICING on Wing and Horizontal Stabilizer

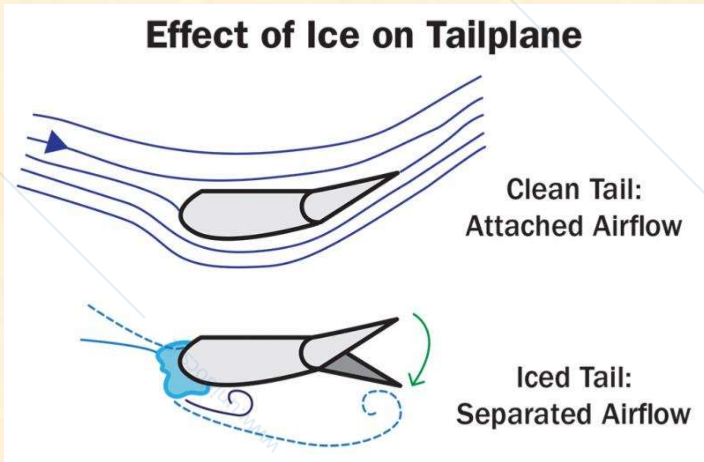
If **Appr & Ldg** in icing conditions, consider:

- Use reduced Ldg Flap
- Increase V_{APP}





http://aviationweek.com/business-aviation/how-recover-tailplane-icing



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ENGINEERING PREPARATIONS

- Initial predictive data are obtained from **wind tunnel testing**, which are used to create a **math-model** of the aircraft for simulations
- Extensive **flight characteristics predictions** are made to look for unacceptable trends
- **Pilot-in-loop simulation** are used for handling qualities evaluations during design phase, to drive airplane changes when required
- **Flight test missions** are reviewed in company simulators shortly before the real flight
- **Simulators** have proved to be very useful for **normal flight envelope** evaluations up to the point of stall
- **Post-stall simulator** capability is still problematic due to highly unsteady aerodynamic behaviors

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INSTRUMENTATION PREPARATION

Pilots are provided with **additional information** normally not available in a standard cockpit:

- **Angle of Attack**
- **Angle of Sideslip**
- **Vertical load factor n_Z**
- **Tail load structural monitor**
- **Tail angle of attack**

Dedicated **sensors** for Static and Total pressure are provided for instruments calibration

ENGINEERING PREPARATIONS

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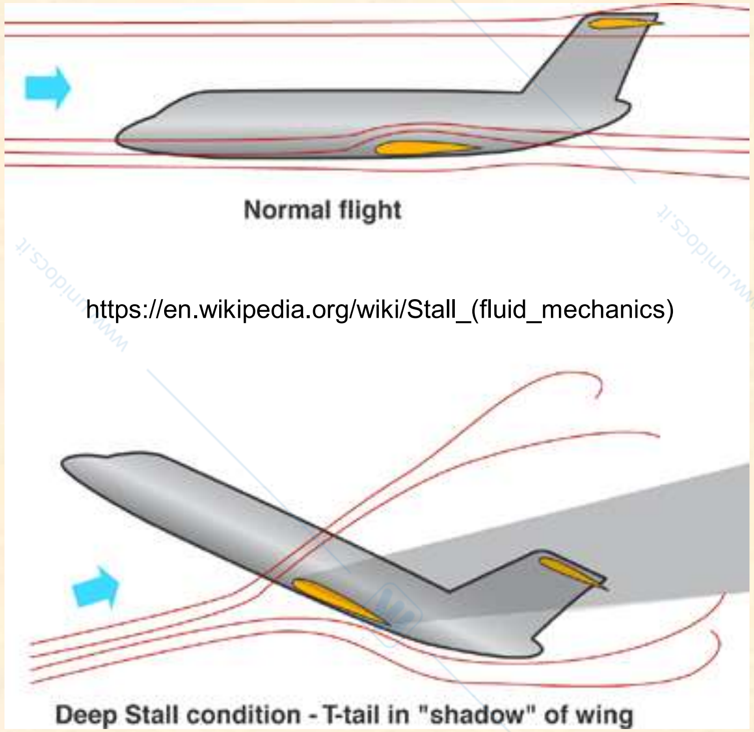
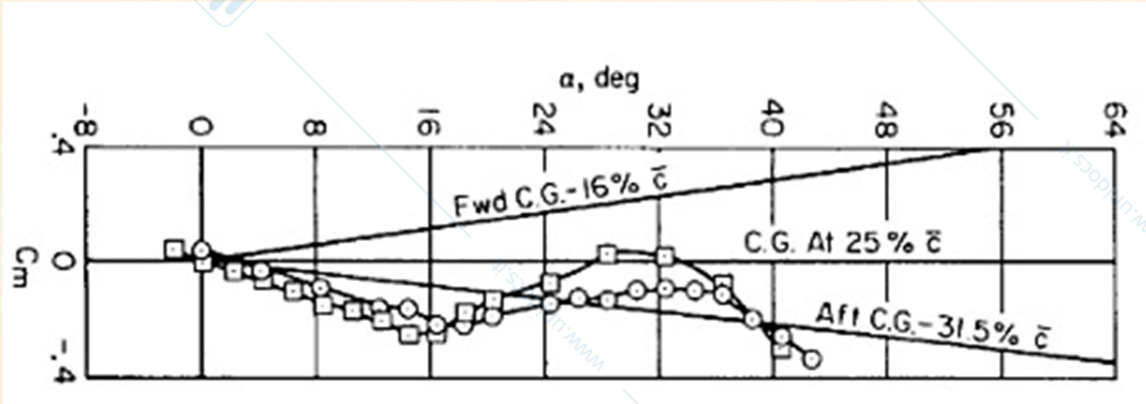
Additional attention must be provided when performing stall tests on ***T-tail*** airplanes, due to the risk of ***DEEP STALL,*** which is a **longitudinally stable condition** where the horizontal tail is blanked by the wake of the wing, with a **total loss of elevator function**.



https://en.wikipedia.org/wiki/Stall_(fluid_mechanics)

A **Tail Booster** can be provided on test aircraft as a last resort to recover from a deep stall *(picture of Airbus A400M)*



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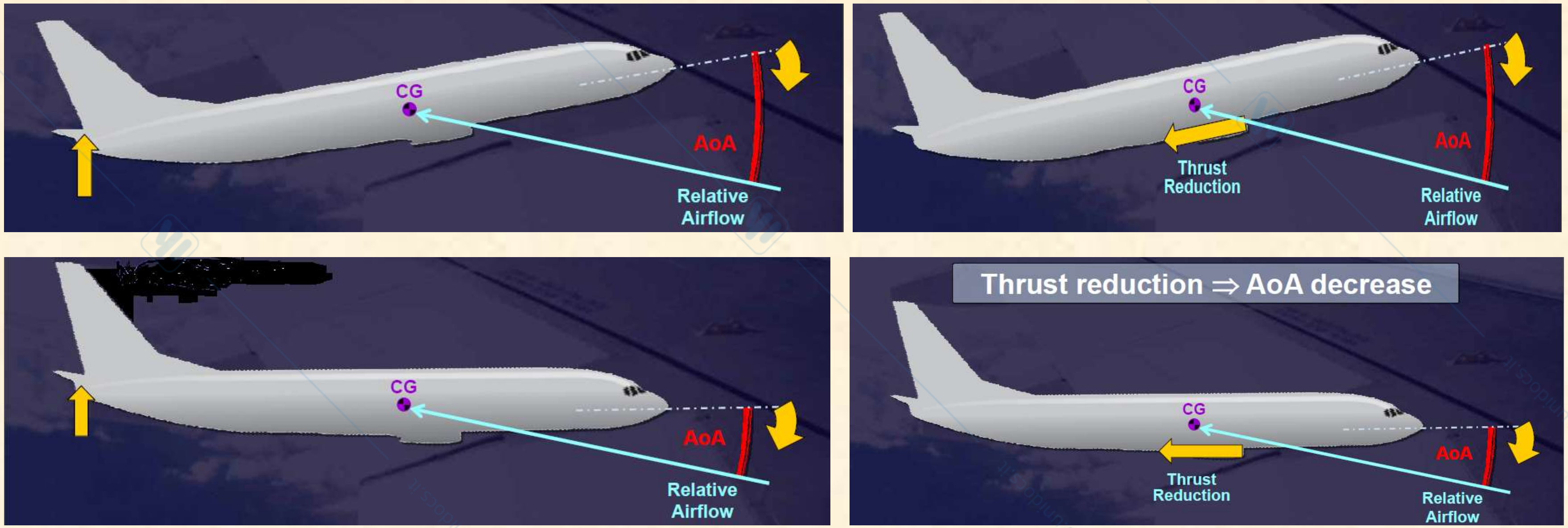
STALL RECOVERY TECHNIQUE:

1. Lower the nose: ***AOA reduction*** far more important than altitude loss
2. Be very careful with ***engine thrust*** (pitch-up will delay stall recovery)



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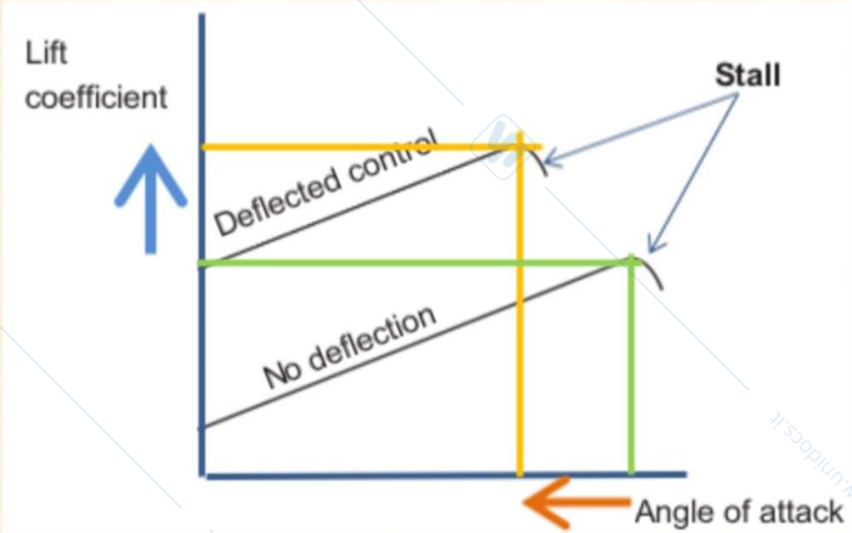
Recovery techniques from TURNING STALL:

- A **sequential two-step** approach works best (UNLOAD & ROLL)
  1) ***Lower the nose*** with elevator (full elevator & pitch trim may be needed)
  2) As airspeed builds-up, ***smoothly roll back*** to the horizon

- A **simultaneous** pitch & roll axis recovery ***not recommended***:
  - Ailerons & spoilers may not be effective above CL_{MAX}
  - Increases tail loads (torque)
  - Delays recovery

- **Rudder** normally is not needed and can add high asymmetric loads to the ***tail*** (***overtorque***)



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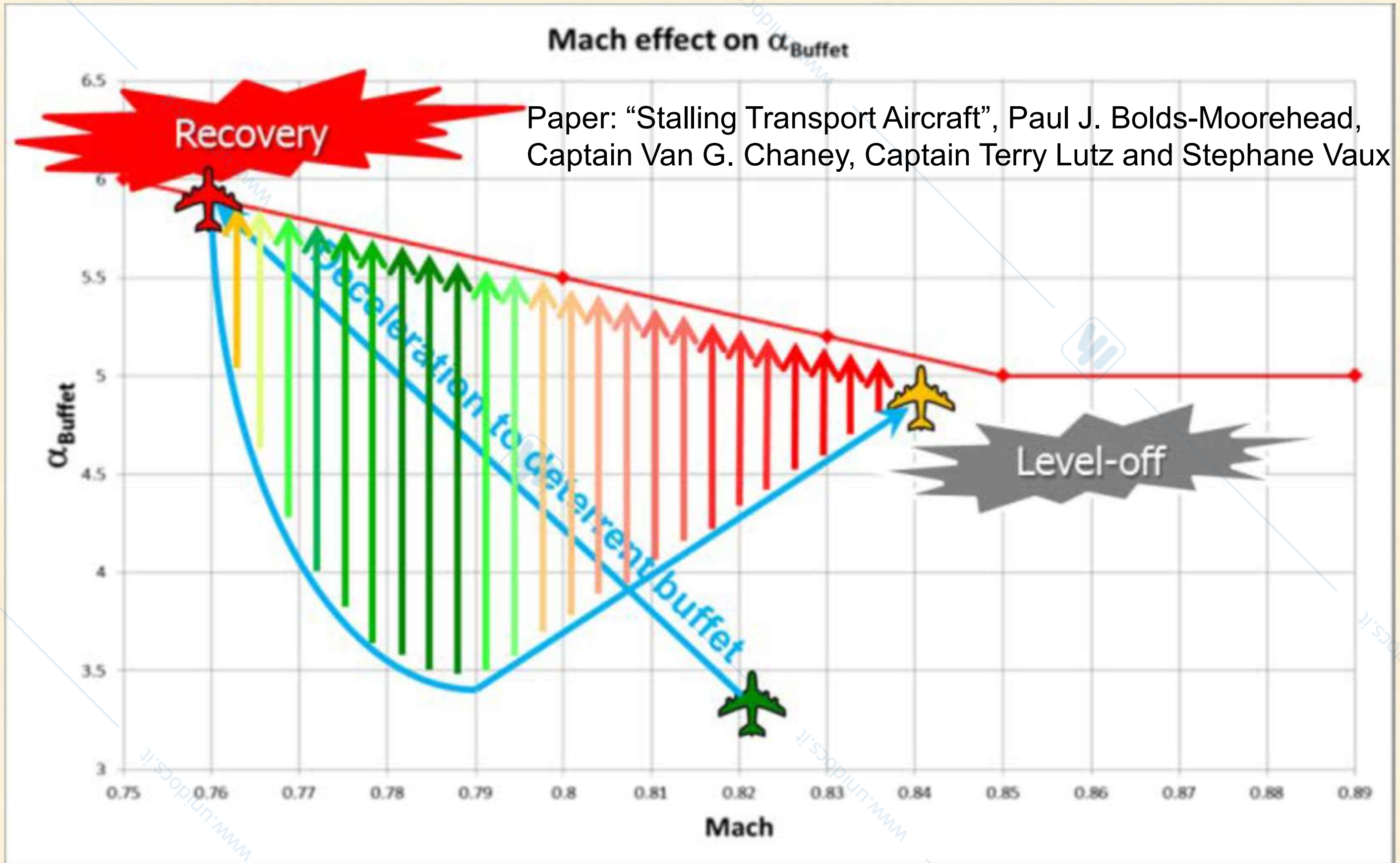
HIGH ALLTITUDE stall recovery:

1. **recovery is *slow***
2. ***Higher risk to enter a secondary stall*** (*as* Mach increases, *AOA margin* decreases)



Paper: "Stalling Transport Aircraft", Paul J. Bolds-Moorehead, Captain Van G. Chaney, Captain Terry Lutz and Stephane Vaux

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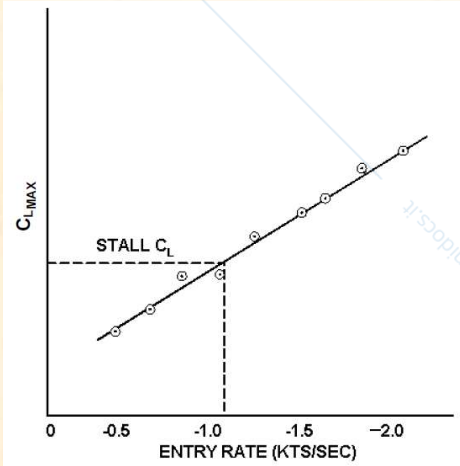
GENERAL CONSIDERATIONS ON STALL



- **Stall speed** must be determined with a **deceleration at 1 kt/sec**
- **Altitude loss**:
  - Low altitude: 2000-3000 ft
  - High altitude: 5000- 7000 ft
- **Stall at FORWARD CG**: *Risk of **horizontal tail stall** during recovery, especially in full flap configuration*
- **Stall at AFT CG**: higher risk of ***pitch-up*** *and* ***Lateral departure*** (sideslip)

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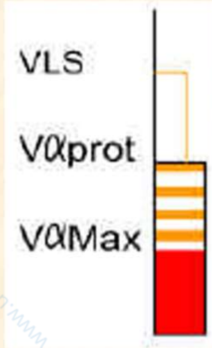
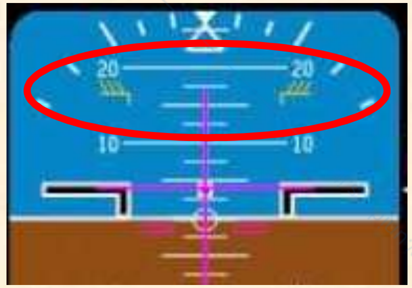
UPSET RECOVERY TRAINING IN FFS

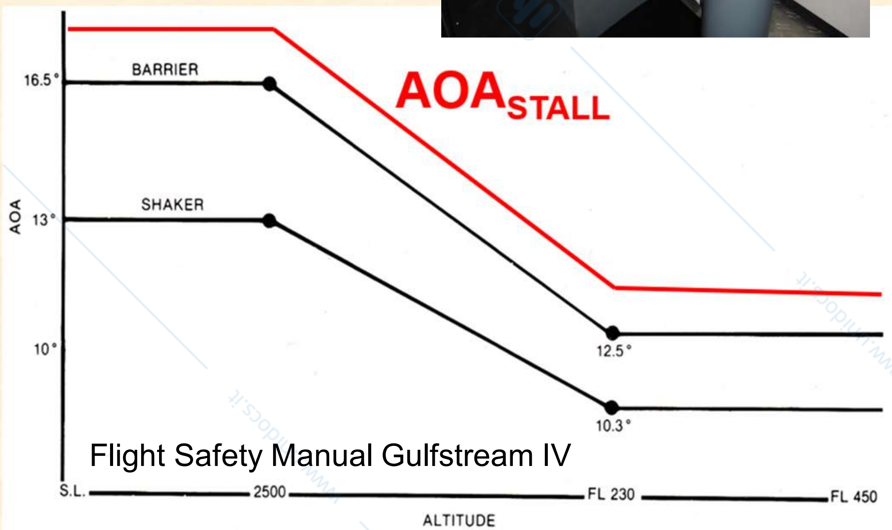
AIRPLANES HAVE MANY FEATURES TO WARN PILOTS OF AN INCOMING STALL (VISUAL – ACOUSTICAL – TACTILE)

- **Speed bands** on ASI
- ***Pitch Limit Indicator*** on ADI
- ***Auto Thrust*** protection
- "***Airspeed low***" voice caution (Low energy)
- "**STALL**" voice warning
- Pitch ***trim inhibited*** inside Amber Speed band
- ***Autopilot*** prevent to enter Amber Speed band
- ***FBW* envelope protection**
- **Stick SHAKER & stick PUSHER**





Boeing 737
Stick Shaker



Flight Safety Manual Gulfstream IV

UPSET RECOVERY TRAINING IN FFS
AF447

https://www.youtube.com/watch?v=BR5kFOHVnUU

UPSET RECOVERY TRAINING IN FFS
AF447

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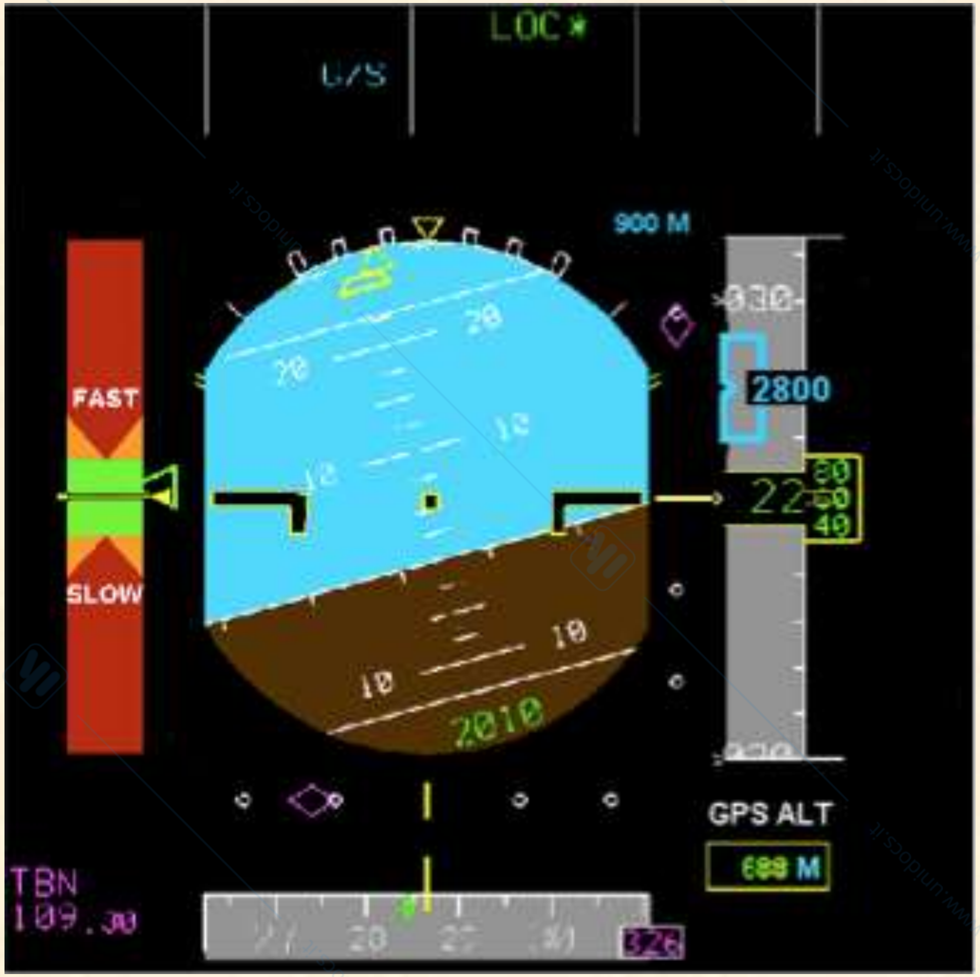
https://www.youtube.com/watch?v=BR5kFOHVnUU

https://www.youtube.com/watch?v=BR5kFOHVnUU

Back Up Speed Scale
(Airbus retrofit)

According to the emergency procedure ***Unreliable Speed Indication***, by switching all ADR OFF it is possible **to fly the airplane referring to AOA** instead of Airspeed

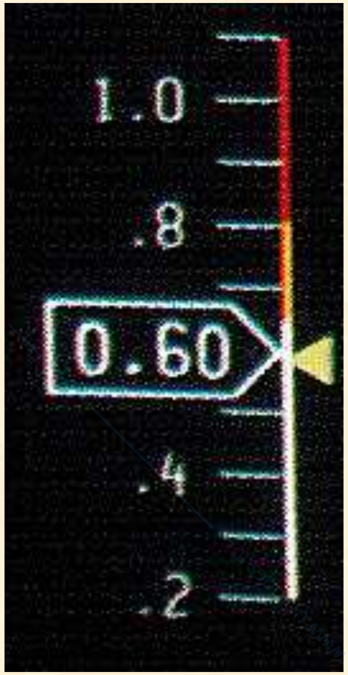


http://aviationtroubleshooting.blogspot.it/2009/06/af447-unreliable-speed-by-joelle-barthe.html

Normalized Angle of Attack (AoA) indicator

on Primary Flight Display (PFD)

1.0 always means **AoA_{MAX}** (stall), according to **Flap** configuration and **Mach** number

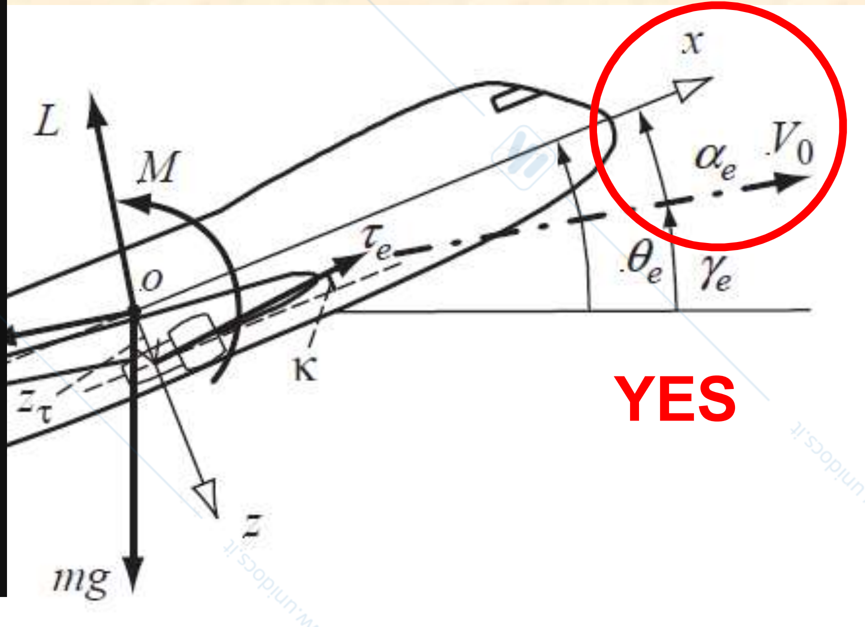


Honeywell SPZ-8000 Pilot's Manual: Gulfstream IV PFD

UPSET RECOVERY TRAINING IN FFS

http://www.pprune.org/tech-log/452973-fpv-fpv-cage.html

IS IT POSSIBLE TO EVALUATE THE AOA, even without the AOA indicator?



YES

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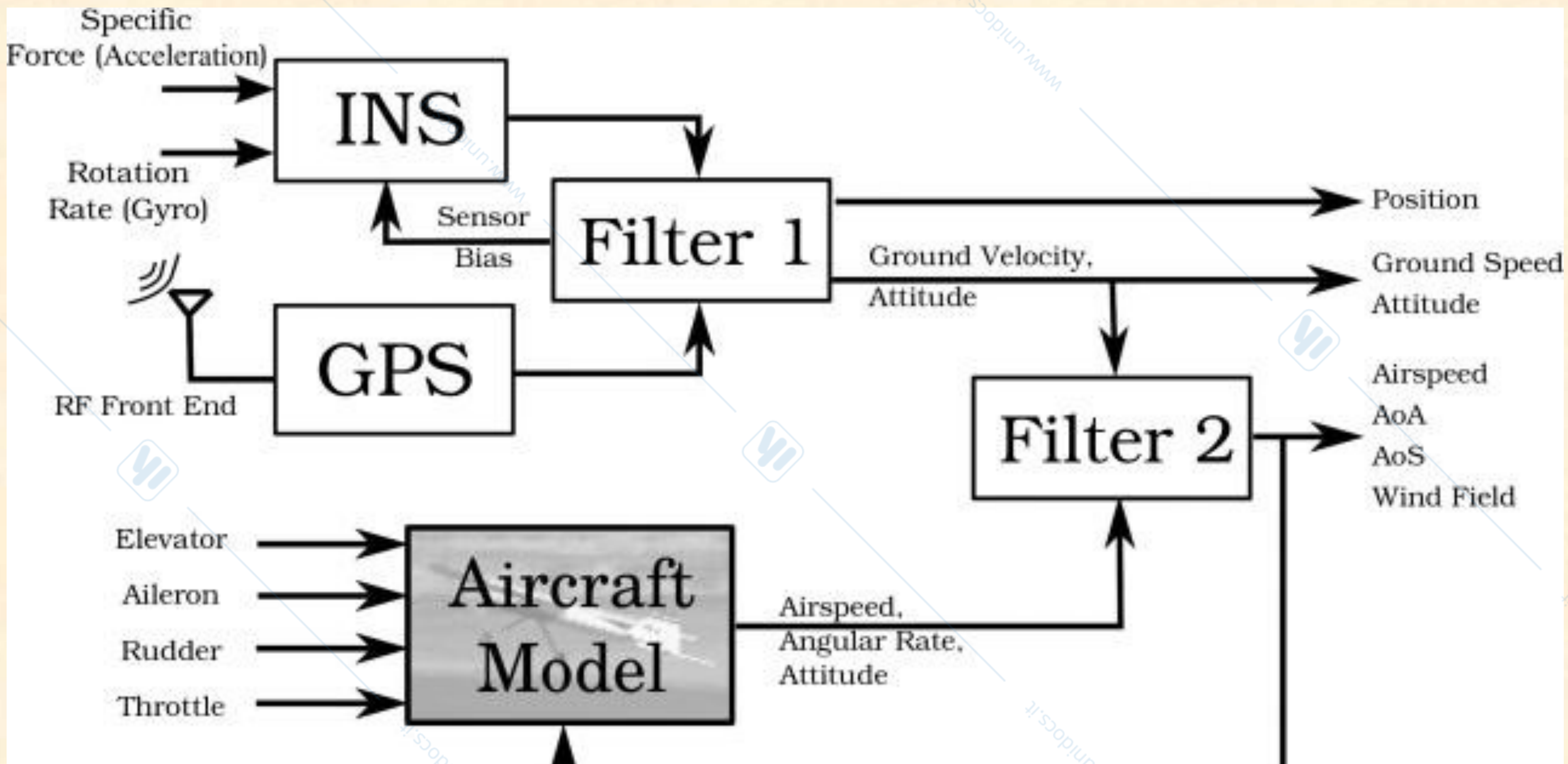
SYNTHETIC AIR DATA SYSTEM

To provide **analytical redundancy** to traditional Air Data Sys, using Kalman Filters (optimum **observers**)



JOURNAL OF AIRCRAFT vol. 50, No. 4 Jul-Aug 2013, p.1234

UPSET RECOVERY TRAINING IN FFS
Colgan Air 3407

https://www.youtube.com/watch?v=vMy8kZ2_TMs

WHY PILOTS NEED UPSET RECOVERY TRAINING?

(https://www.icao.int/safety/LOCI/AUPRTA/index.html)

- **2015 IATA statistics**: Loss Of Control events are more than twice the fatalities rate than Controlled Flight Into Terrain [source: AW&ST]

- **Some recent accidents**, such as Colgan Air (Buffalo, 2009), Air France 447 (Atlantic Ocean, 2009) and Air Asia (Indonesia, 2014), have shown that pilots can find or put themselves **well beyond stall AOA**

- **FAA** recently issued the Upset Prevention & Recovery Training Program for commercial pilots, in an extended AOA-Sideslip envelope.

  Full Flight Simulators are required to accurately reproduce handling characteristics **up to 10° beyond stall AOA** which, according to NTSB, covers most of the pitch excursions seen in accidents [source: AW&ST]

Use of simulator beyond a valid aerodynamic model database could provide "negative training"

HOW CAN THESE AERODYNAMIC DATA BE OBTAINED?

- In the **past decades**, extensive research has been addressed to the **aerodynamic modeling and wind tunnel test methods of military fighters at high AOA & Sideslip**, to reduce the risk of stall/spin during air-to-air combat

- In the frame of **NASA Aviation Safety & Security Program** (**1998**), extensive **wind tunnel tests** have been performed since 2001 at Langley Research Center, to investigate aerodynamic characteristics of **large transport airplanes** at **upset flight conditions,** using modeling and test methods developed by military experience

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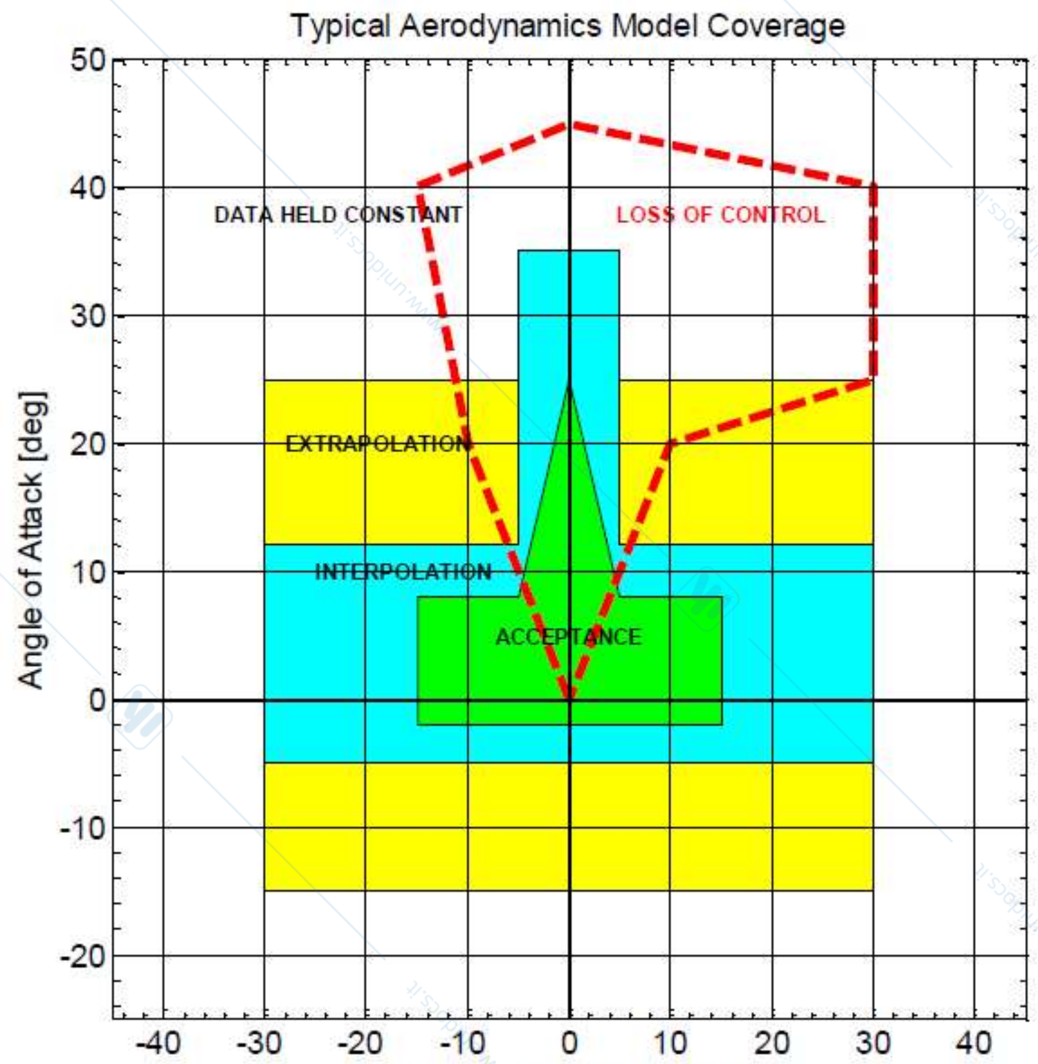
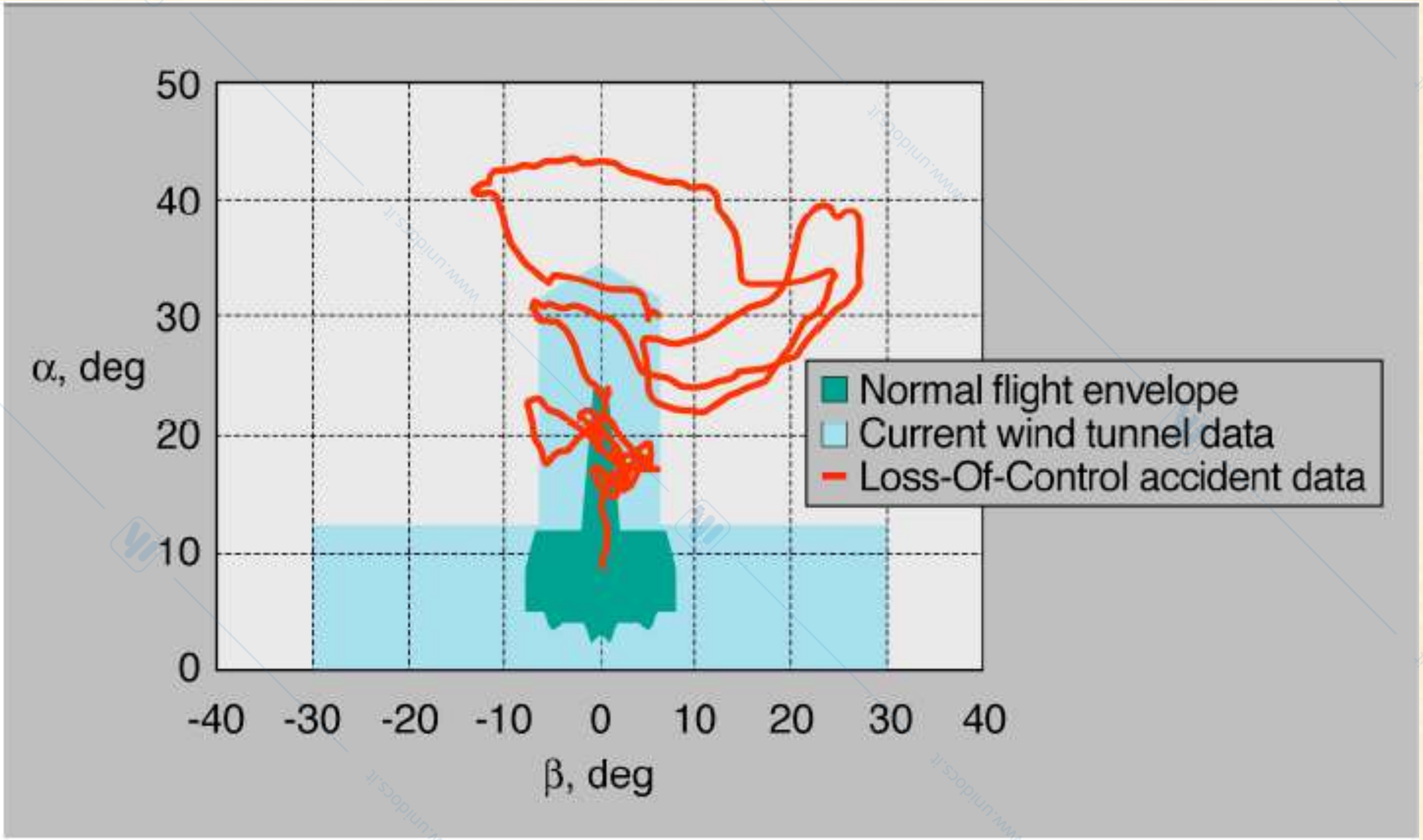
WHAT DATA ARE STORED IN A CONVENTIONAL FLIGHT SIMULATOR DATABASE?

- **Green**: flight validated
- **Cyan**: wind tunnel/analytical
- **Yellow**: extrapolated
- **White**: constant data



Paper: AIAA 2012-4568

WHAT DATA ARE NEEDED FOR UPRT TRAINING?



Paper: AIAA 2005-5933

HOW CAN WE MODEL THE REQUIRED DATA?

Rigid body aerodynamic **forces and moments** produced during **highly dynamic post-stall motions** (departures, spin), are **difficult to predict** due to highly non-linear and time-dependent aerodynamic behaviors typical of **separated flows**.

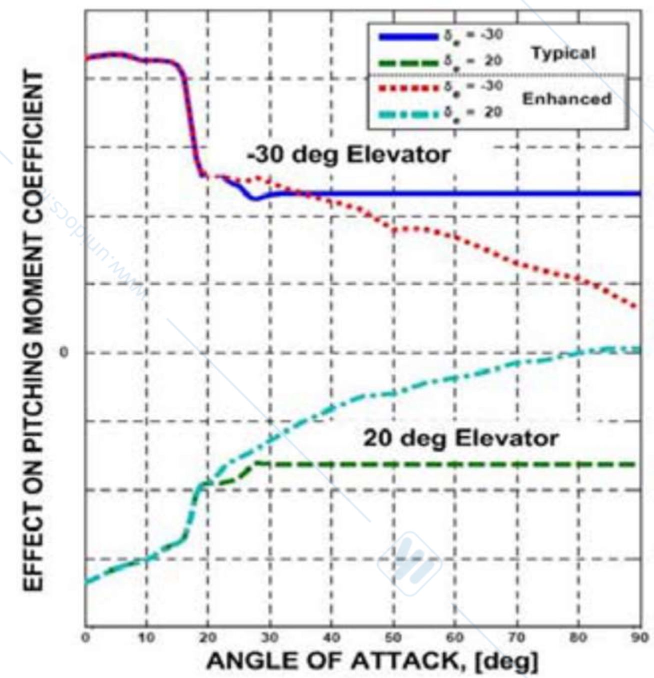
According to **ICATEE** (International Committee for Aviation Training in Extended Envelopes, 2009), aerodynamic enhanced database should provide the following stall/post-stall characteristics: [Paper: AIAA 2014-1003]

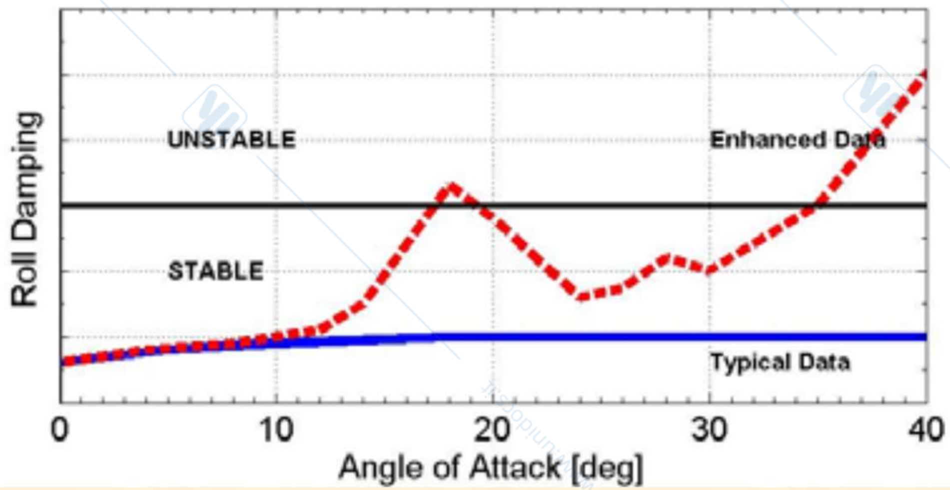
- **Degradation** in static/dynamic **lateral-directional stability**
- **Degradation** in control **response** (pitch, roll, yaw)
- **Uncommanded roll response**, or roll-off, requiring significant control deflection to counter
- Apparent **randomness** or non-repeatability
- **Changes** in **pitch stability**
- **Mach** effects

TYPICAL vs ENHANCED AERODYNAMIC DATA

THE AERONAUTICAL JOURNAL Jan 2012
Vol 116 No 1175 p.67-86

- PITCH control (elevator)
- ROLL DAMPING





According to **ICATEE**, **Aerodynamic enhanced model** can be:

- **Type specific**: from aircraft specific engineering and flight test data
- **Type representative**: from computational aerodynamics and wind-tunnel test data (engines, wing and tail architecture)

Both methods require **validation from an Expert** (pilot) before acceptance.

HOW CAN THE TYPE REPRESENTATIVE ENHANCED AERODYNAMIC MODEL BE OBTAINED?

[Papers: AIAA 2005-5933, 2007-463, 2009-5828]

Enhanced Aerodynamic Database involves

***STATIC** & **DYNAMIC** data at*

high wing angles ("α" to 85°, "β" ± 45°) and

high angular rates (p, q, r)

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Collection of Dynamic Data

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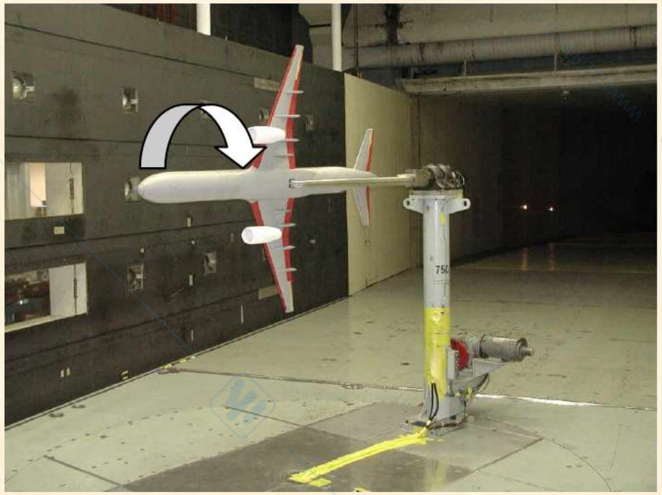
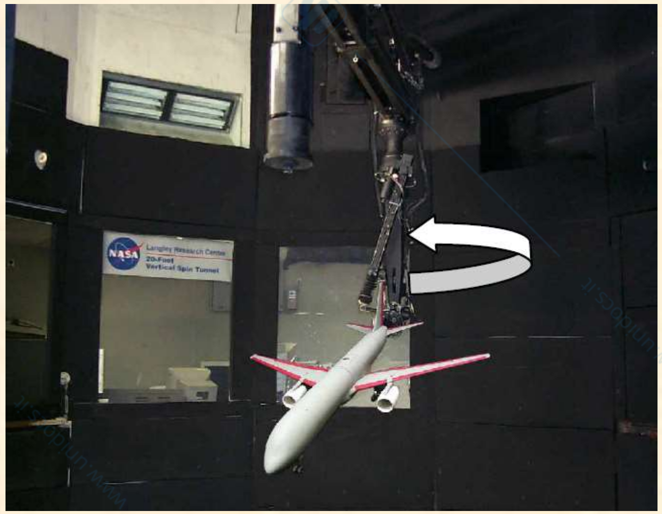
DYNAMIC wind tunnel data account for "**damping effects" of angular rates** (pitch, roll, yaw) on aerodynamic forces & moments.
They are obtained with **special wind tunnel tests**



Paper: AIAA 2007-463

Forced Oscillating test
at different frequencies & amplitudes
in a Conventional Wind Tunnel

Rotary Balance test
to predict stead spin dynamics
In a Vertical Spin Tunnel



Paper: AIAA 2007-463

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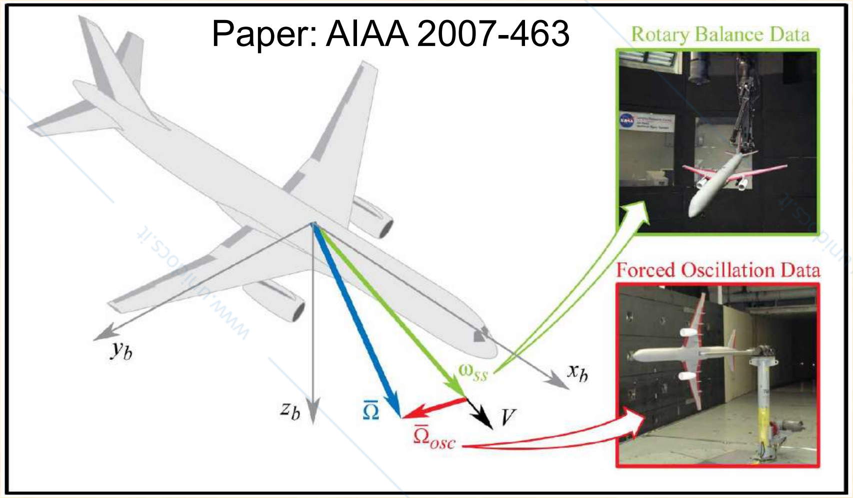
Dynamic wind tunnel data are then **BLENDED** (different methods available):

- Direct resolution
- Kalviste (and its variants)



STATIC & DYNAMIC

wind tunnel data are then

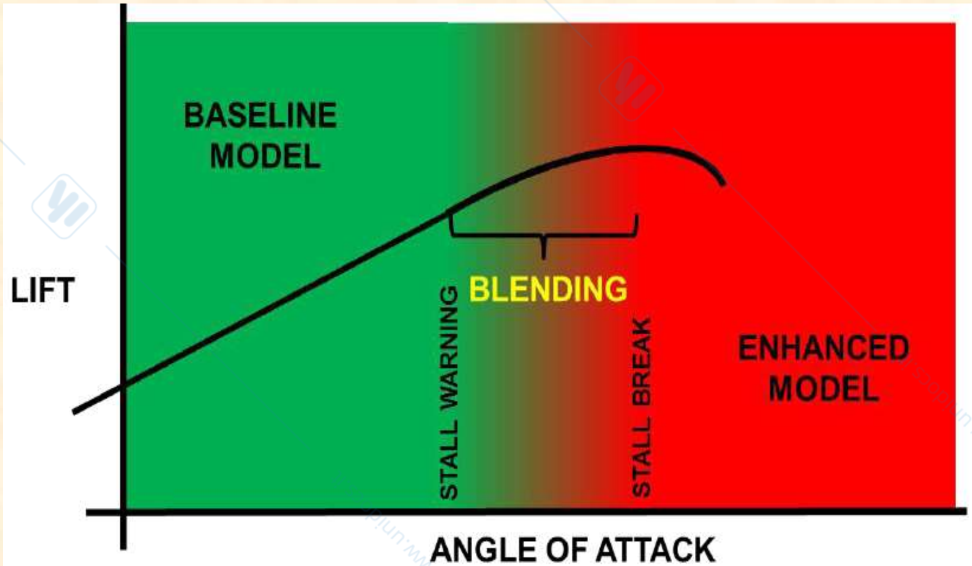
INTEGRATED

to provide the

enhanced aerodynamic data,

with **significant improvement in simulation fidelity**,

compared to current simulation models based on extrapolated data



http://www.stallbox.com

Summary of data modification for enhanced aerodynamic model

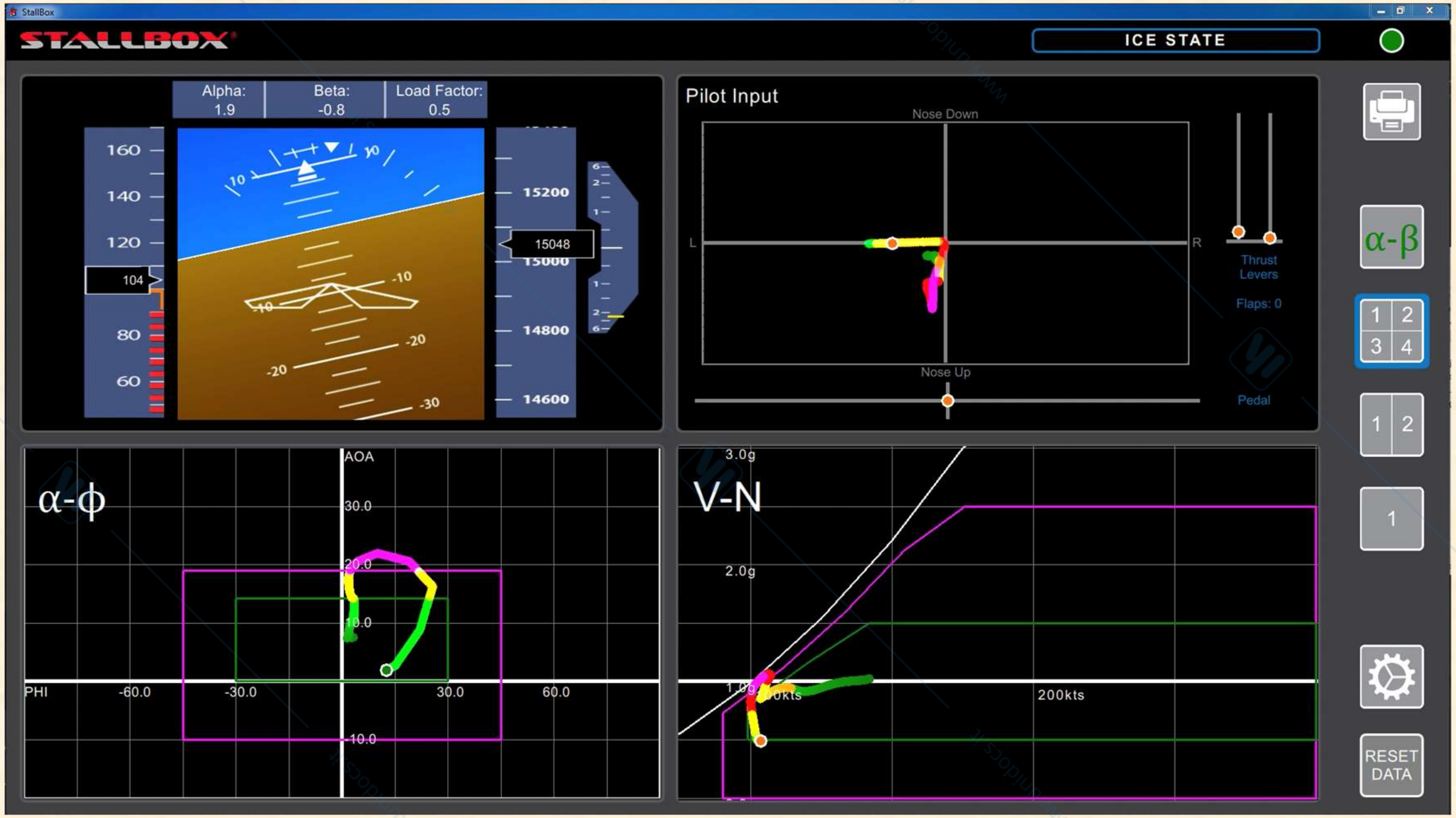
Aerodynamics Effect	Enhanced Model	
	Stick Shaker to Stall Angle of Attack	Past Stall Angle of Attack
Lift – Multiple Flap Positions	Use baseline which transitions at CLmax	100% Enhanced data to 60 deg AOA Larger post stall lift drop-off
Drag	Transition to Enhanced Data by CLmax	Data update
Longitudinal Stability	Transition to Enhanced Data by CLmax	Reduced stability at higher angles of attack
Longitudinal Control (Elevator & Stabilator)	Transition to reduced elevator effectiveness	Nonlinear elevator effectiveness function of α, δe
Longitudinal Damping	Transitioned to nonlinear damping with reduction of dynamic stability at stall, function of α, $\delta flap$	Reduced dynamic stability post stall
Lateral Stability	Transition to a reduction in stability and phased in a lateral offset with randomizing functionality in magnitude and direction.	Reduced Stability
Lateral Control	Transitioned to reduction of effectiveness at stall	Reduced nonlinear control effectiveness
Lateral Damping	Transitioned to reduction of dynamic stability at stall, rate functionality	Reduced dynamic stability, rate functionality
Directional Stability	Transitioned to enhanced model with reduction of stability and phased in directional offset	Reduced stability and includes regions of directional instability
Directional Control	Used baseline	Extended AOA
Directional Damping	Transitioned to reduction of dynamic stability at stall, rate functionality	Reduced dynamic stability, rate functionality

Paper: AIAA 2014-1003

UPSET RECOVERY TRAINING IN FFS

The **Instructor display** provides the instructor with quick interpretation of pilot response in upset conditions. Information provided are the following:

***V-n** diagram, **α-β** diagram, **Pilot inputs, PFD** repeater*



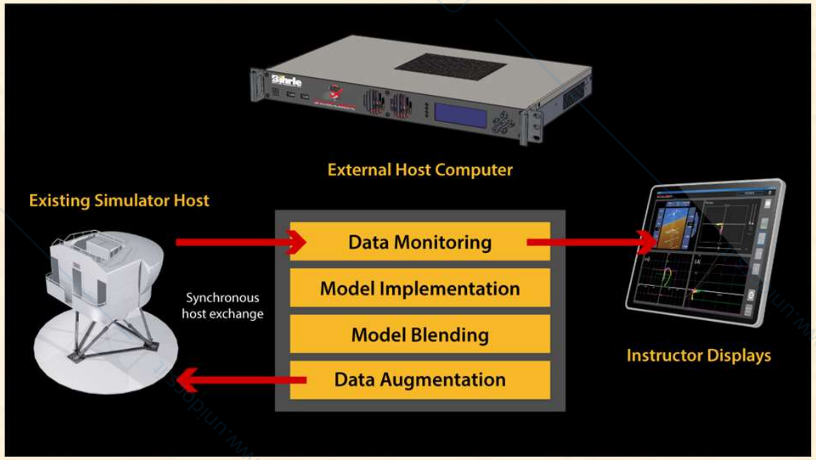
http://www.stallbox.com

FAA-CERTIFIED UPSET PREVENTION & RECOVERY TRAINING

FLIGHT SAFETY, training provider and simulator manufacturer, has worked with **Gulfstream Aerospace** to develop the enhanced aerodynamic database for the UPRT training program (G550)

http://www.gulfstream.com/aircraft/gulfstream-g550

STALLBOX is a commercial hardware that can be easily interfaced to flight simulators, able to provide the required database for UPRT training



http://www.stallbox.com