A380 flight tests

A380 FLIGHT TEST CAMPAIGN

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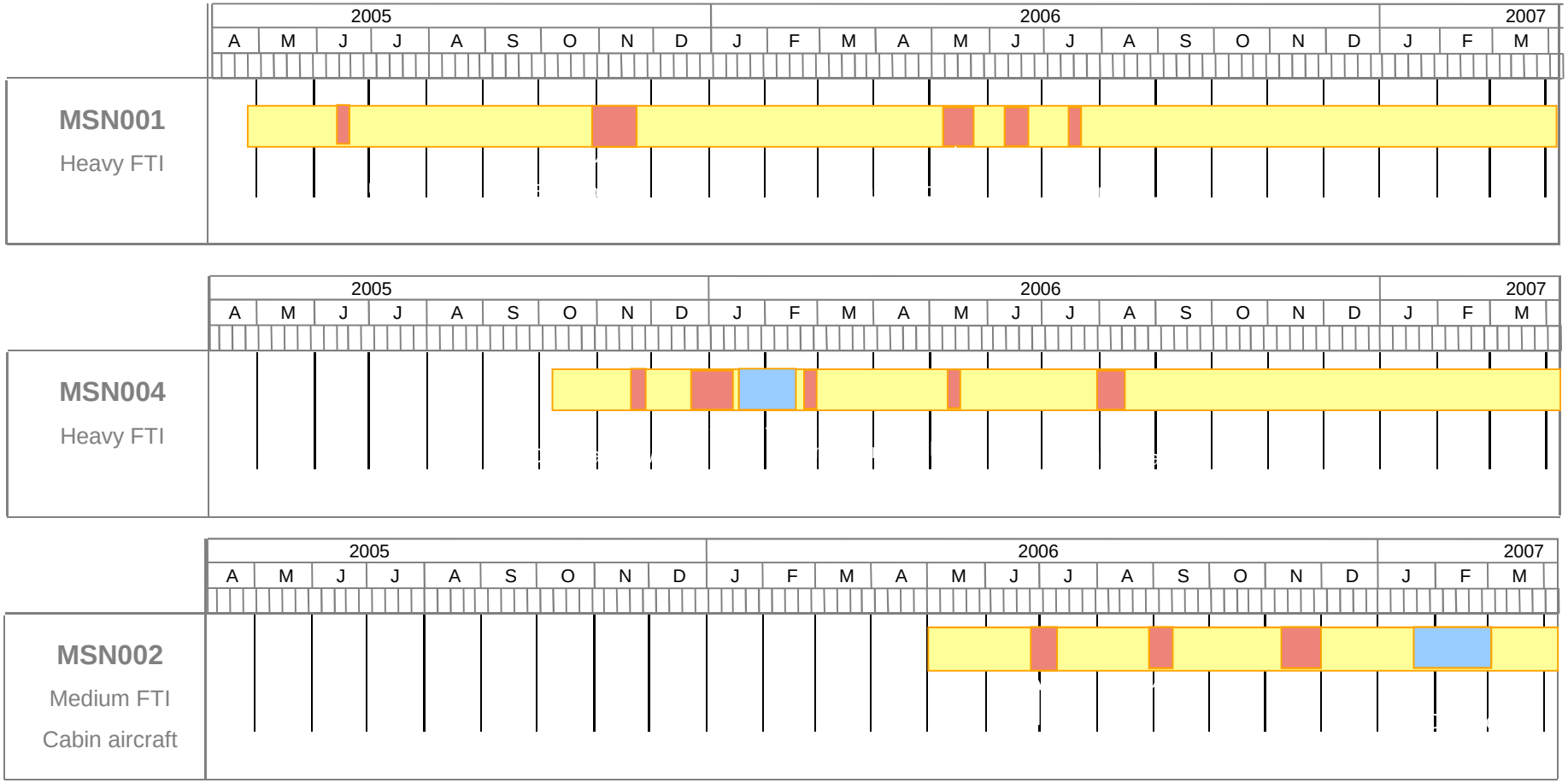
AIRBUS

A380 flight test campaign with Rolls Royce engines

- 4 aircraft used:
  - 2 without cabin and with heavy flight test instrumentation for basic technical development and certification.
  - 2 with cabin fully installed (last one arrived after basic certification) in order to validate all the various options requested by Customers and systems delivered by various suppliers.
- About 2200 flight hours for initial certification. It includes hours used for commercial tour.

Flight tests planning

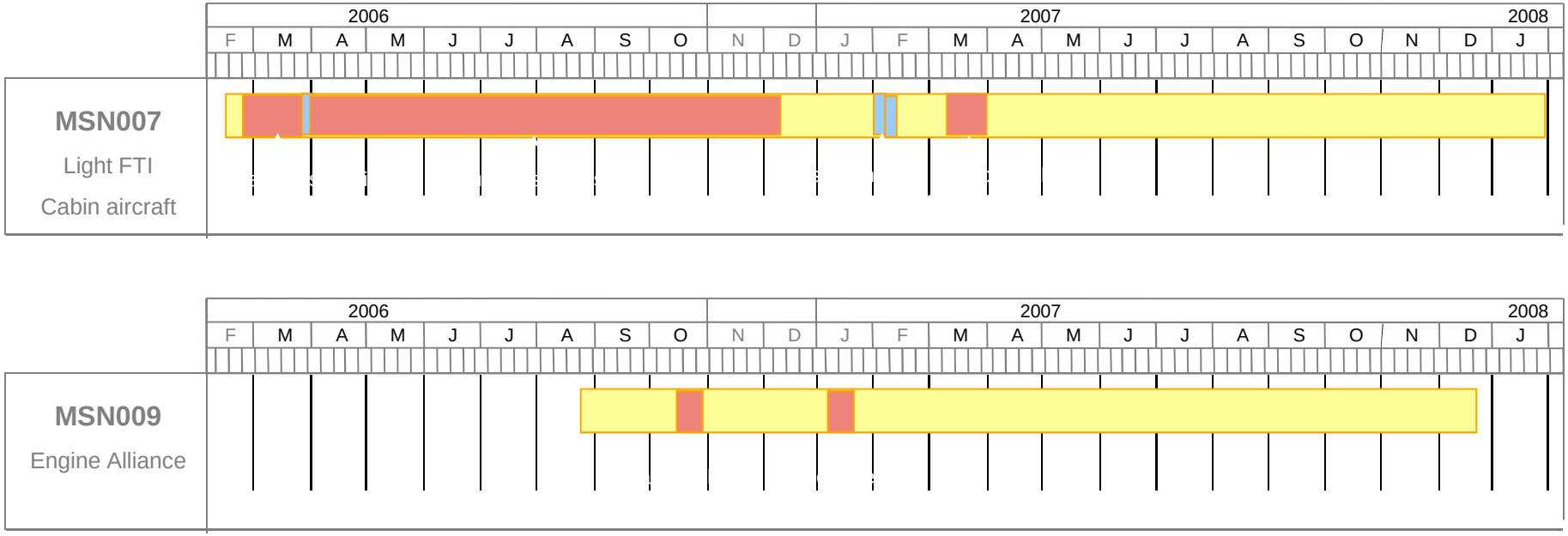
A380 flight tests



Initial evaluation | Development | Certification | Post-certification development

Flight tests planning

A380 flight tests



A380/Rolls-Royce flight test campaign: summary

- Main items identified during flight test campaign
  - Outstanding handling qualities confirmed by airlines pilots having flown the aircraft
  - Cruise performance as expected
  - Remarkable low Speed performance setting the standard (approach speed at Maximum Landing Weight 138kt, 17kt better than B747)
  - External noise Levels better than commitments (16 EPNdb margin against regulation – QC2 London departure & QC0.5 London arrival)
  - Cabin comfort (internal noise and vibrations) setting the industry standard (more than 3db better than B747 and B777)
  - A380 cockpit the quietest in the sky
- General configuration e.g. fuselage with doors, dimensions allowing the evacuation of 873 people in less than 80 seconds (certification requirement 90s)

First flight – 27th April 2005

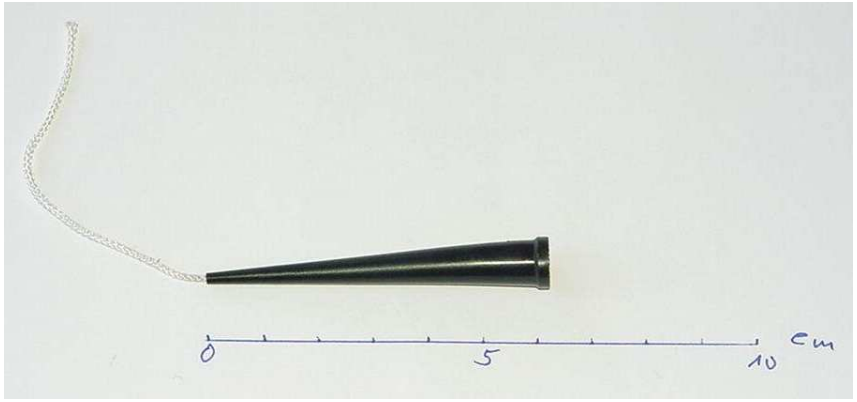
Performance: aerodynamic configuration freeze

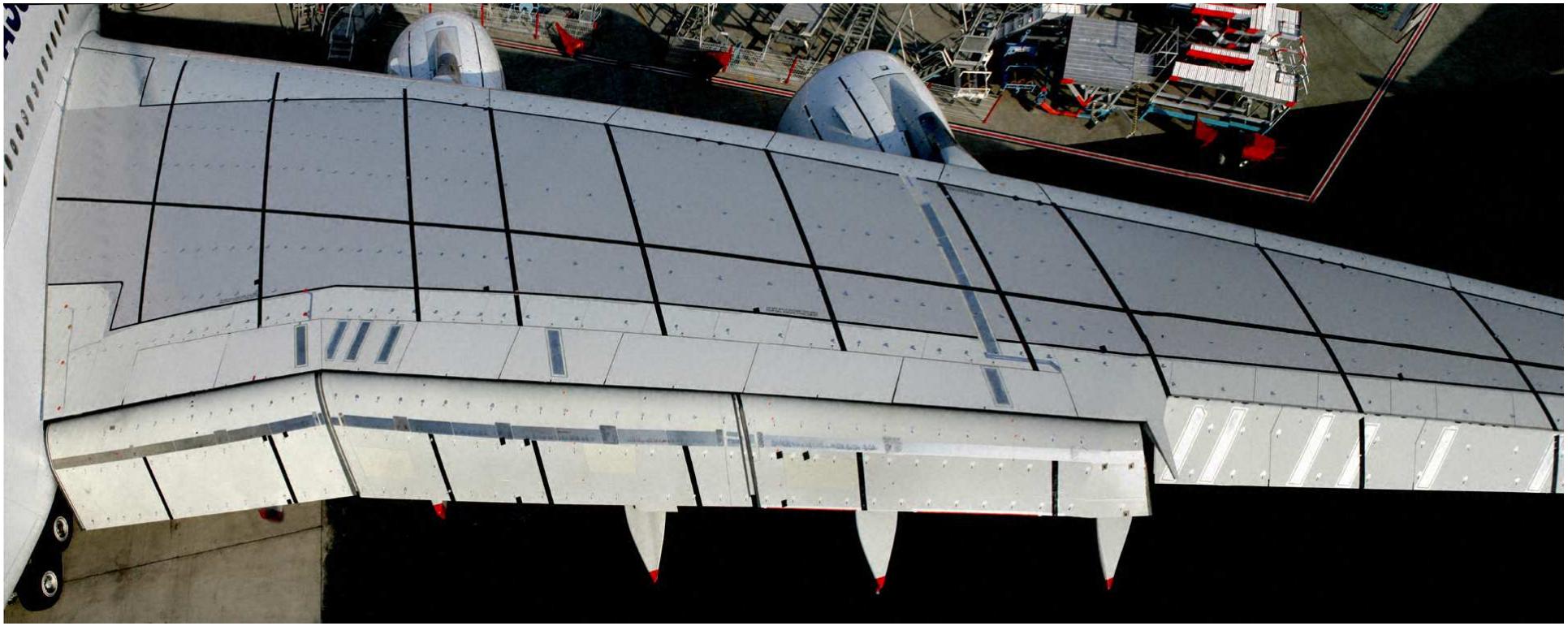
- Test objectives
  - Preliminary identification of the low speed performance
  - Evaluation of several slat / flap configurations to support freezing of final settings
  - Data gathered for all potential slat and flap settings
    - Climb performance with one engine inoperative
    - Stalls (more than 400 performed)
    - Minimum unstick speed (VMUs)

Tufting campaign

- Test objectives :

- Optimise low speed capability



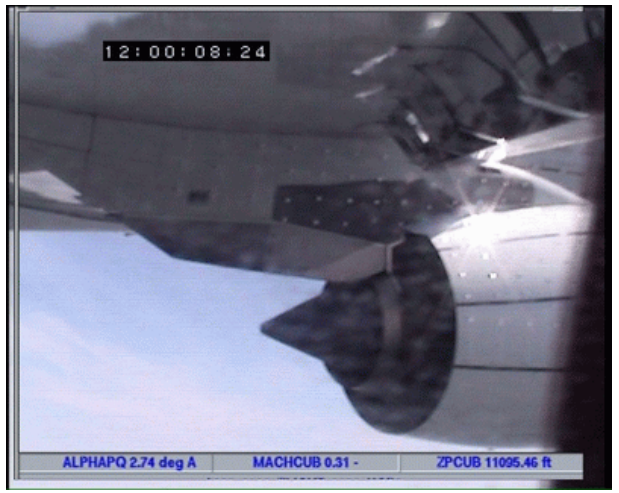


Tufting campaign – strakes effect

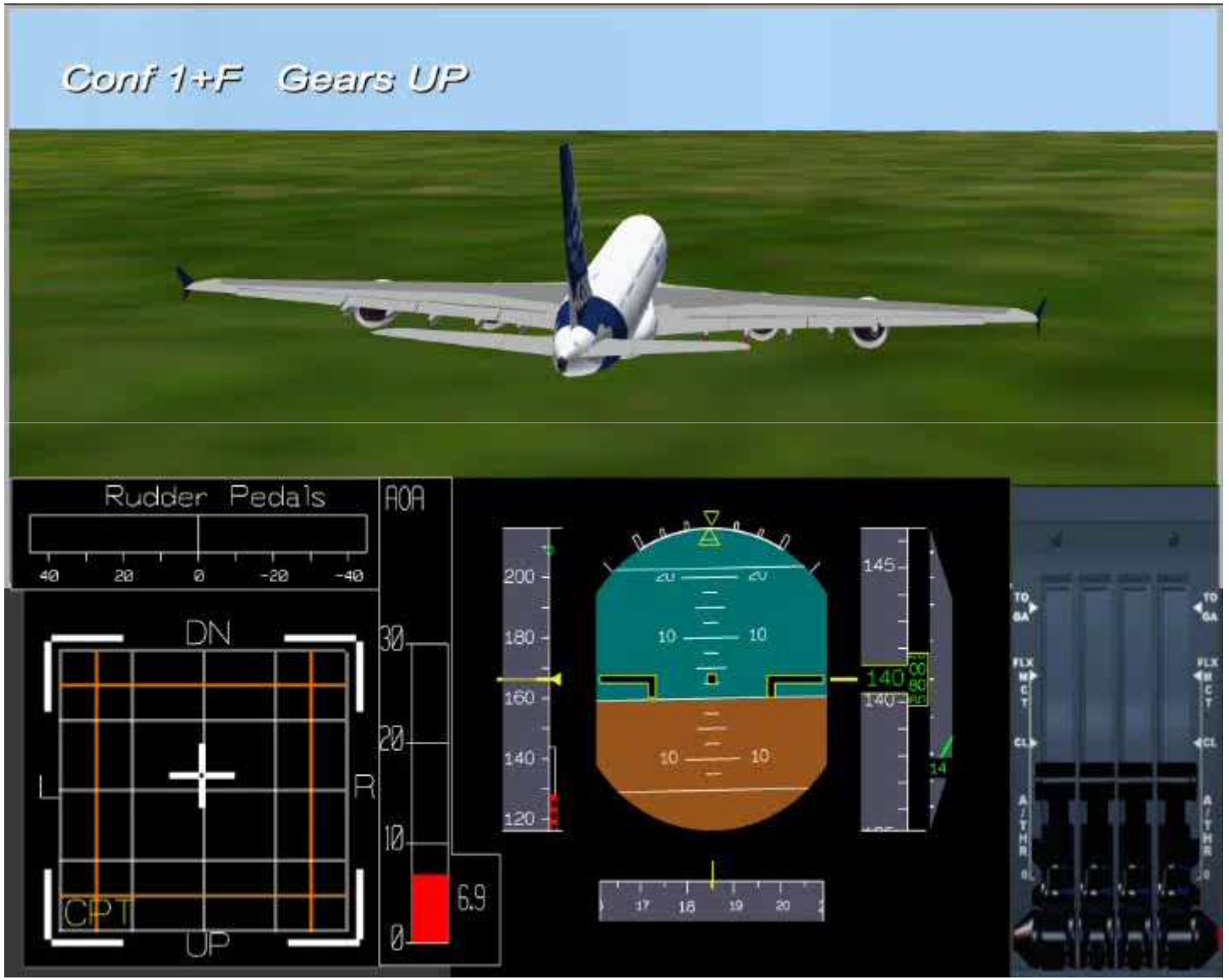
A380 flight tests

Tufting campaign - in flight

A380 flight tests



A380 flight tests



VMU: July 2005 and March 2006

- TEST OBJECTIVES

- Measure VMU with 2 different flap settings (26° and 29°)
- Early VMU's were required to identify the optimum flap deflection (July 05)
- Certification VMU tests were achieved in March 06

- TEST CONDITIONS

- Istres Air Base
- Weight: 540 t
- Tailskid replacement every 1 to 3 runs
- Geometry limitation demonstrated in all configurations

VMU

A380 flight tests

VMU

A380 flight tests

VMU

A380 flight tests

Aerodynamic configuration : results

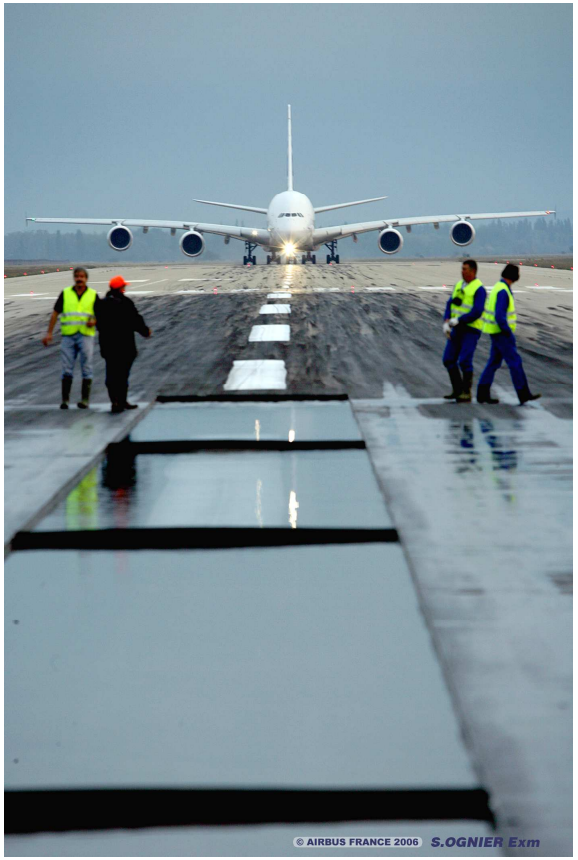
- Aerodynamic configuration frozen in less than 3 months
- Clmax better than expected
  - Approach speed : Vref = 138 kt at MLW
  - Actual Landing distance : 1200m
  - Take-off VMU limited
- Take-off performance on target

Water trough tests (October 2005)

A380 flight tests

- Water trough
  - 1 acceleration + 1 deceleration at ~70 kt
  - First tests stopped due to broken hydraulic pipes

Water trough tests (September 2006)



- Additional runs :
  - High speed
  - Engines water ingestion from NLG jet

Water trough tests (September 2006)

Performances

A380 flight tests

- First cruise performance evaluation done on MSN 1 shortly after first flight. MSN1 performances were as expected.

- MSN 4 was the aircraft dedicated to performance measurements and engines development, with standard representative engines.

- MSN 4 started with a full evaluation of cruise performance during 3 weeks.

- A low speed performance extensive evaluation was done in November/December 2005

MSN2 ferry to Hamburg
November 05

NO INJURIES !

Airport compatibility checks

- First visits at international airports
  - 29th October 05 : Frankfurt
  - 10th – 24th November : Singapore, Brisbane, Sydney, Melbourne, Kuala Lumpur, Dubai (airshow)

Airport compatibility checks :

- Positioning of airport bridges
- Upper deck catering vehicles
- Positioning of cargo loaders
- Check of ground support equipments (GSE)
- Ground services (toilets servicing, fuelling, electricity…)

Airshows

- Le Bourget 2005 (less than 2 months after the first flight!)
- Dubai 2005
- Singapore 2006
- Berlin 2006
- Farnborough 2006
- ……..

Hot & high campaign in Medellin (Colombia)

Cold weather campaign in Iqaluit (Canada)

Cold weather campaign in Iqaluit (Canada)

- TEST OBJECTIVES :
  - Collect data for structural justification
  - Check system readiness for full cold-weather campaign with cabin (on MSN2)
- TESTS DONE :
  - 4 days (2 taxis and 2 flights)
    - Overnight cold soak
    - After overnight cold soak, sequenced power-up
    - Run aircraft for various tests, record temperatures, and other data
- MAIN RESULTS :
  - Temperatures down to –29°C
  - Engines satisfactorily starting
  - All systems behaved satisfactorily

Cold weather campaign in Iqaluit (Canada) – Jan 07

TEST OBJECTIVES :

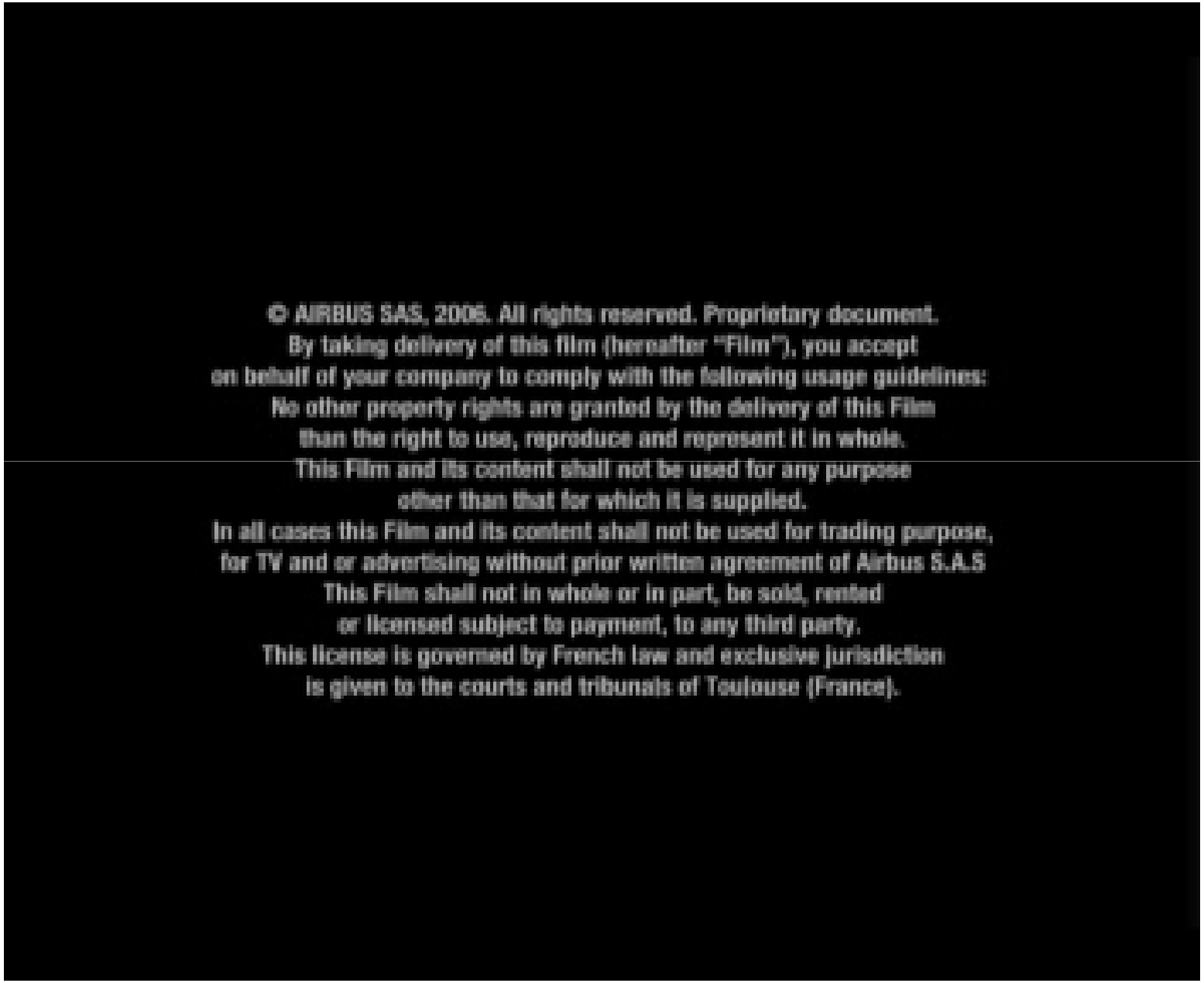
- Aircraft fitted with full passenger cabin and fully furnished cargo holds (MSN 002)
- Check cabin equipment and systems behaviour in extreme temperature conditions
  Minimum temperature reach

Cabin evacuation test
26th March 06

- MSN 7 fitted with a high density cabin
- 853 passengers + 20 crew members

Cabin evacuation test

A380 flight tests



Natural icing trials – May 2006

A380 flight tests

- TEST OBJECTIVES :
  - Assess wing anti-ice behaviour
  - Check aircraft behaviour with natural ice

- TESTS DONE :
  - 5 flights (in thunderstorms…)

- MAIN RESULTS :
  - Natural ice accreted are far less critical than artificial ice shapes
  - No handling qualities issue identified, even with wing anti-ice inactive
  - Side result : more than 100 lightning strikes. No problem

Natural icing trials – May 2006

380 flight tests

Artificial ice shapes trials

A380 flight tests

Negative g tests

- TEST OBJECTIVES :
  - Assess aircraft and systems behaviour during negative g manoeuvres (could be found in case of turbulence)

- MAIN RESULTS :
  - Aircraft behaviour cleared from all point of views
  - Handling qualities, electrics, engine loads, propulsion system, fuel, hydraulics

VMCA (minimum speed one engine out in the air)

- Tests delayed due to necessary reinforcement of vertical tail plane
- Results as aspected:
  - VMCL = 120 kt
  - VMCL-2 = 144 kt (2 engines out)

(70KB rating)

VMCG (minimum speed one engine out on ground

- Initial tests show insufficient ground control

VMCG

A380 flight tests

- Flight controls law modified to improve VMCG

External Noise measurements

A380 flight tests

TEST OBJECTIVES :

- Preliminary campaign October 2005
- Certification campaign June/July 2006

TESTS DONE :

Certification campaign :

- 5 specific flights
- Over 100 flyovers
- Approach and take-off noise measured

Cross wind

A380 flight tests

- Cross wind demonstrated at Keflavik (10th November 2006):
- Landing: 6 landings with average cross wind 42 kt, maximum gust 56 kt and maximum deviation from centre line 5.4 m.

- Take off: 5 take off with average cross wind 39 kt, maximum gust 51 kt and maximum deviation 5.4 m.

Photo www.Airliners.net, photographer Baldur Sveinsson

Crosswind

A380 flight tests

New braking systems

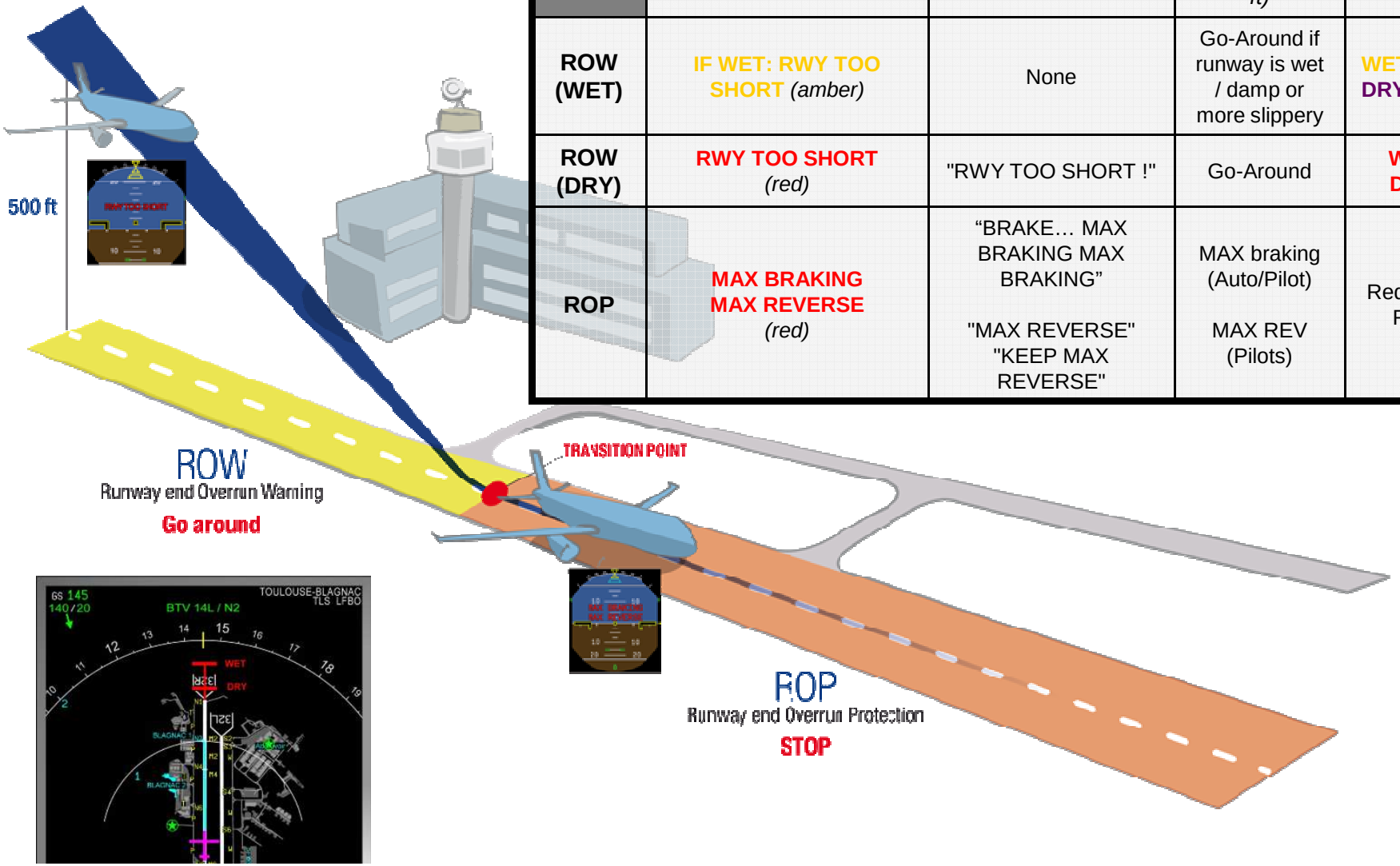
A380 flight tests

- BTV (Brake To Vacate) :
  - Optimisation of braking in order to vacate at the planned taxiway.
- Runway Overrun Prevention System (ROPS):
  - The crew is warned in real time if landing on the runway become impossible, according to its energy (too high, too fast, long flare...) and according to runway status (dry, wet).
  - When on the runway, and if there is an issue of distance to stop, max automatic braking is activated and an audio warnings asks the pilot to select max reverse and keep it at low speed.

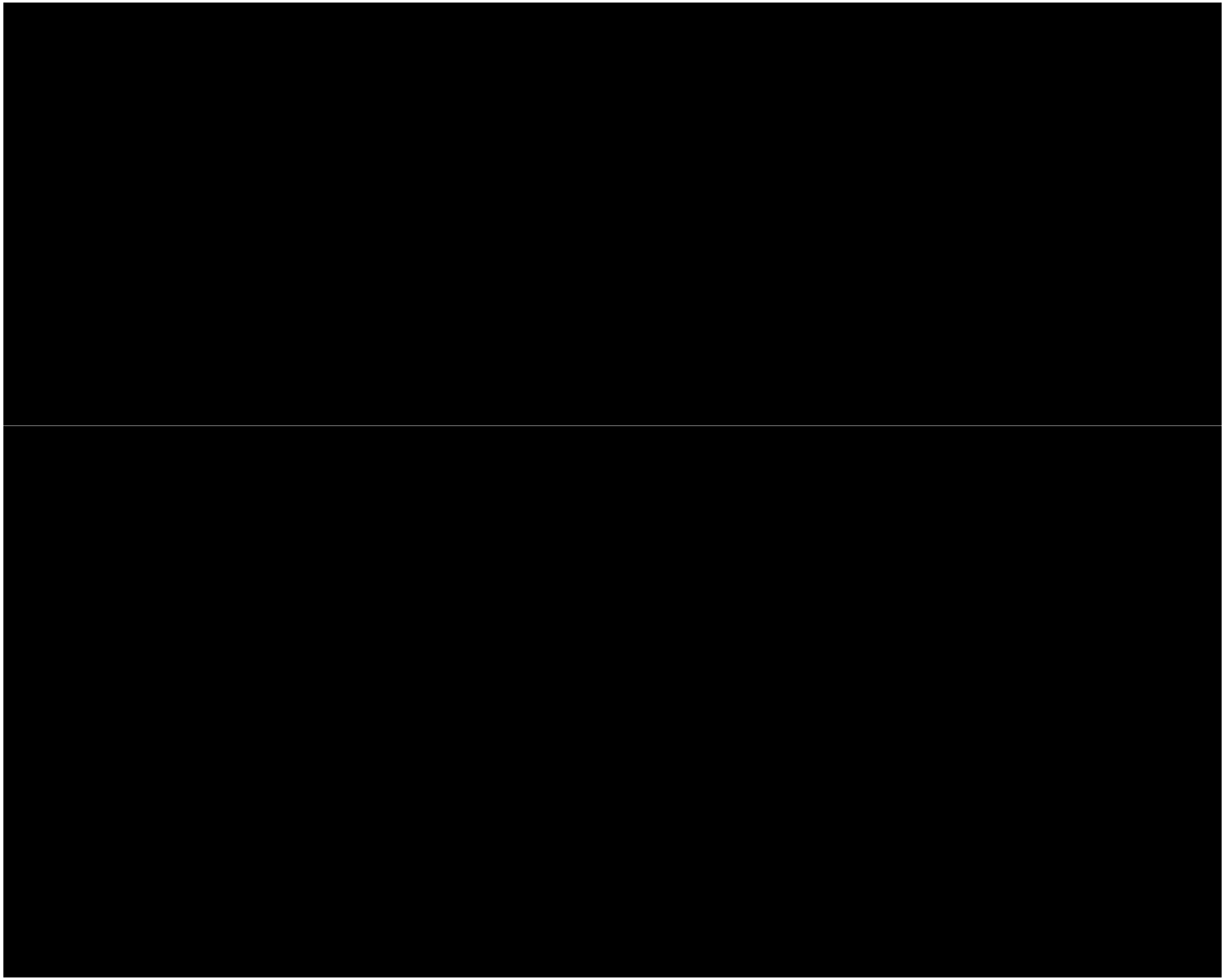
ROPS principles

A380 flight tests

	PFD (and HUD) *(Below 500 ft)*	**Audio** *(Below 200 ft)*	**Crew Actions** *(Below 500 ft)*	**AMM ND line symbols**
ROW (WET)	**IF WET: RWY TOO SHORT** *(amber)*	None	Go-Around if runway is wet / damp or more slippery	**WET** *(amber)* **DRY** *(magenta)*
ROW (DRY)	**RWY TOO SHORT** *(red)*	"RWY TOO SHORT !"	Go-Around	**WET** *(red)* **DRY** *(red)*
ROP	**MAX BRAKING MAX REVERSE** *(red)*	"BRAKE… MAX BRAKING MAX BRAKING" "MAX REVERSE" "KEEP MAX REVERSE"	MAX braking (Auto/Pilot) MAX REV (Pilots)	Red **STOP bar** Red **path**



ROPS vidéo



Maximum energy RTO (Rejected take off)

A380 flight tests

TEST OBJECTIVES :

- To demonstrate the maximum energy which can be safely absorbed by the brakes.
- 89 MJ demonstrated before certification and full test at 120 MJ performed after certification.

TESTS DONE :

- Aircraft accelerated at 577 t (above MTOW) up to maximum decision speed (V1) for this weight: 167 kt
- Maximum braking applied to full stop without use of thrust reversers
- Wait for 5 mn after the stop before allowing the intervention of the fire brigade

MAIN RESULTS :

- Braking performance slightly better than predicted
- No significant fire developed within 5 mn after the stop
- All wheels and brakes assemblies changed within 12 hours after the test

Maximum energy RTO (Rejected take off)

Early long flights
September 2006

- TEST OBJECTIVES :
  - Assess all cabin functions in flight with a representative passenger and crew loading
  - 4 flights : 7h, 10h, 12h (night), 15h
  - 474 passengers + crew members

- PRELIMINARY RESULTS : Outstanding !
  - Cabin Systems & IFE already mature
  - Temperatures correct all along the cabin
  - Very calm and silent cabin
  - Cabin feels spacious

- Minor problems :
  - Some ventilation fine tuning to avoid condensation
  - Cooling system

Early long flights
September 2006

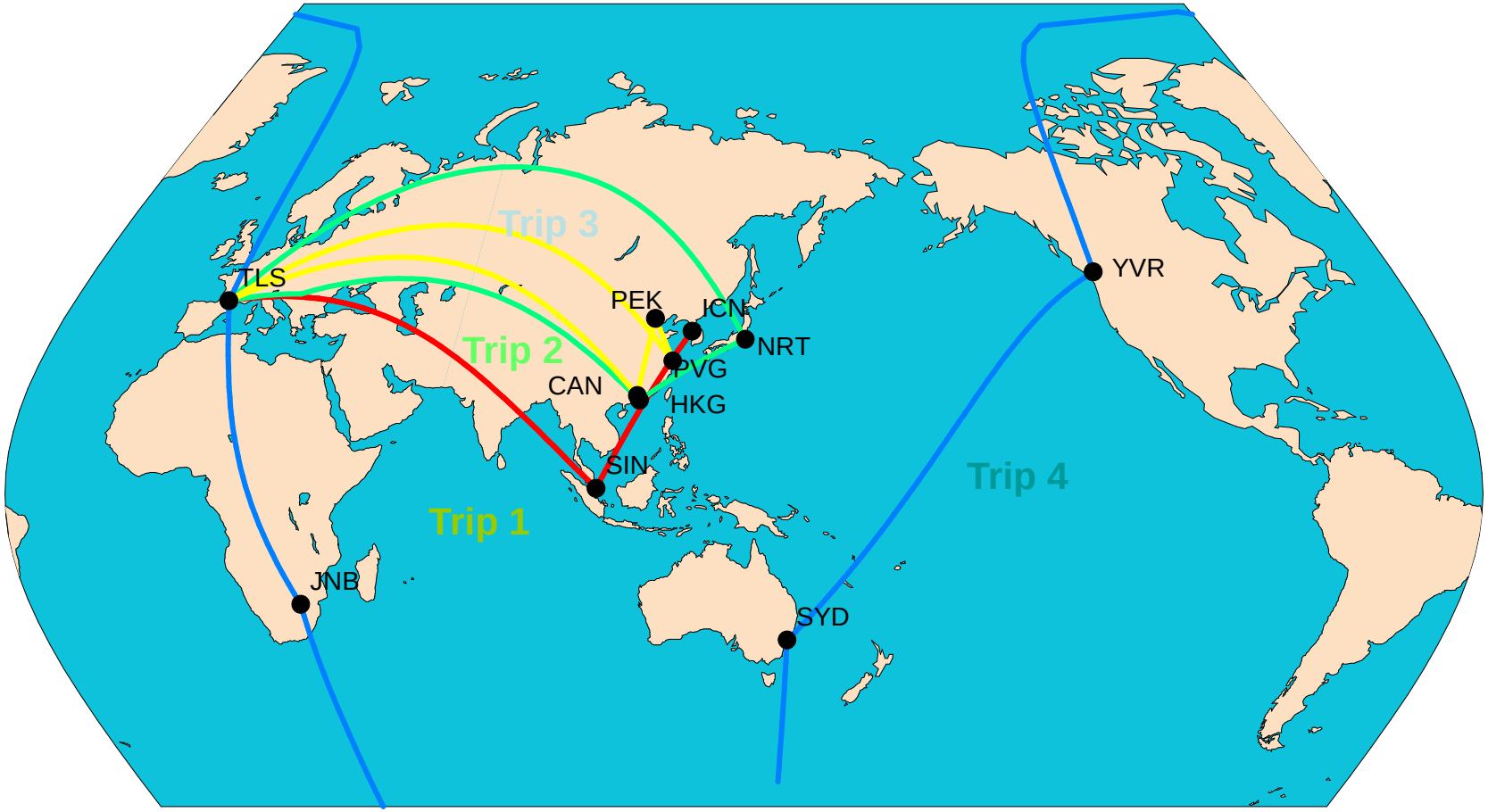
A380 MSN 2 technical route proving campaign

- Regulation: Airbus must show compliance to certification requirement JAR 21A.35 "Function and Reliability Testing" which requires accumulating 300 flight hours of representative flying.

- 150 flight hours performed on MSN 2 were already been credited towards this requirement (out of this campaign)

- The remaining 150 flight hours have been achieved by carrying out a dedicated technical route proving campaign on MSN 2 during which:
  - The aircraft has been operated on a continuous schedule, as though it were in service
  - The flights included a range of representative ambient operating conditions and airfields.
  - The aircraft has been operated, under Airbus responsibility, by Airbus and Airworthiness Authority (EASA and FAA) flight crews, and Airbus cabin crews

A380 MSN 2 technical route proving campaign



Trip 4 via South Pole and North Pole

A380 certification status

- All technical certification flight tests completed on October 30th. Route proving campaign was the last flight certification item completed 30th November

- **Type Certificate obtained on December 12th, 2006**

- FAA certification obtained the same day.

A380 Singapore Airline

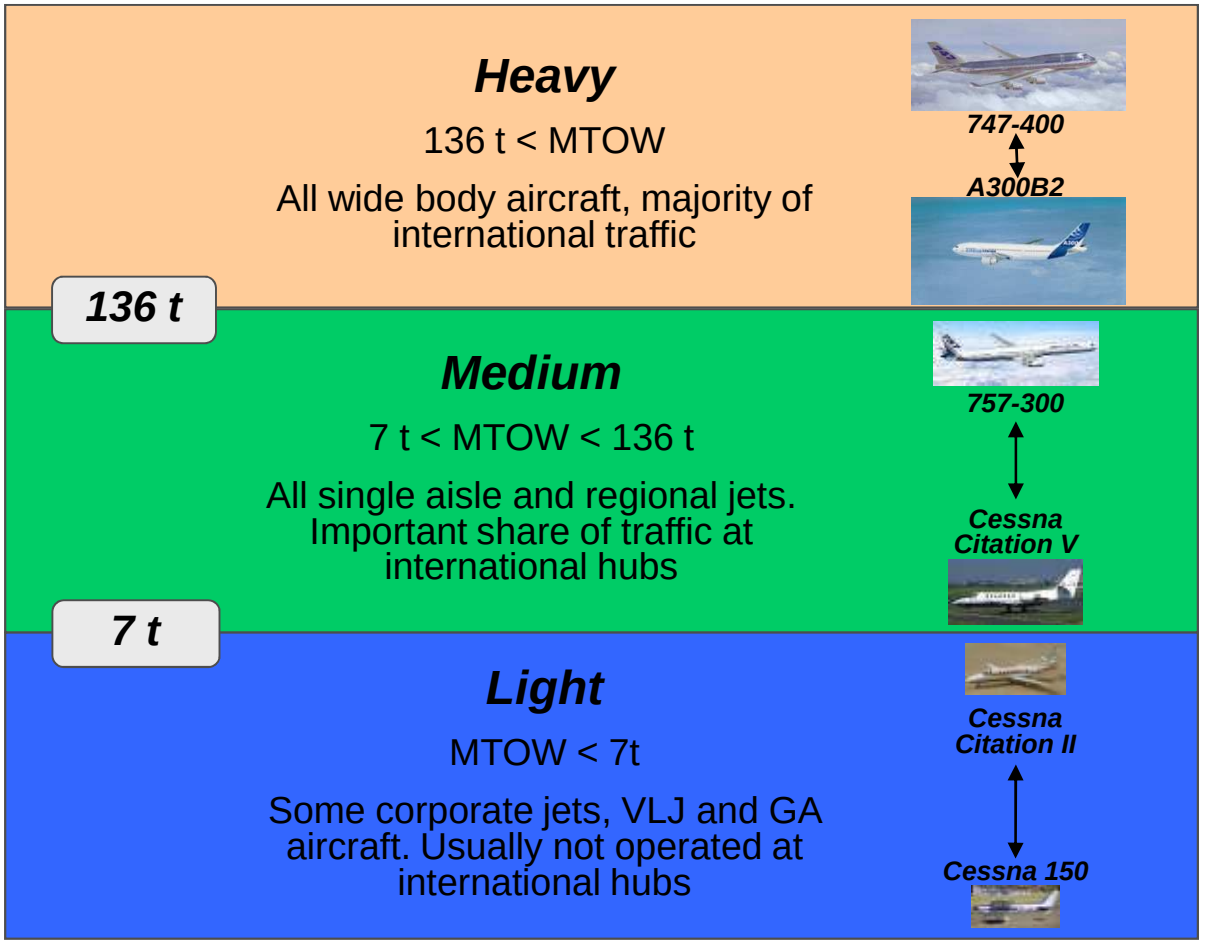
- First customer aircraft (MSN 3) delivered to SIA on 15 th October 2007.
- First commercial flight between Singapore and Sydney was a charity flight on 25th and 26th October.
- Full commercial service started on 28th October between Singapore and Sydney, 7 days a week (around 15 flight hours per day).

A380 Engine Alliance

- Engine built in cooperation between Pratt and General Electric
- Test performed on MSN 9
- First flight done 25th August 2006
- Certification 14th december 2007

A380WWWWe Wake vortex issues

ICAO wake vortex categories



Existing separation standards

A380 flight tests

- Separation categories based on aircraft MTOW
  - Example: **Landing** behind an “Heavy” :

Heavy following a Heavy

Medium following a Heavy

Light following a Heavy

- **Departure** : 2 minutes for light or medium, nil restriction for Heavy
- Lateral (**Cruise**) : 5 nm
- Vertical (**Cruise**) : 1000 ft

A380 wake vortex overview

- First campaign from May 2005 to December 2007
- Second campaign November and December 2010

- **TOTAL**:
- 91 flights (all aircraft)
- ***388 flight hours***
- ***627 ground-based LIDAR runs***
- Airborne LIDAR measurements in cruise
- 167 wake encounters in cruise
- 1308 wake encounters during approach
- ***1475 total wake encounters***

This is the largest campaign ever conducted to investigate all aspects of the wake vortex characteristics of one specific aircraft

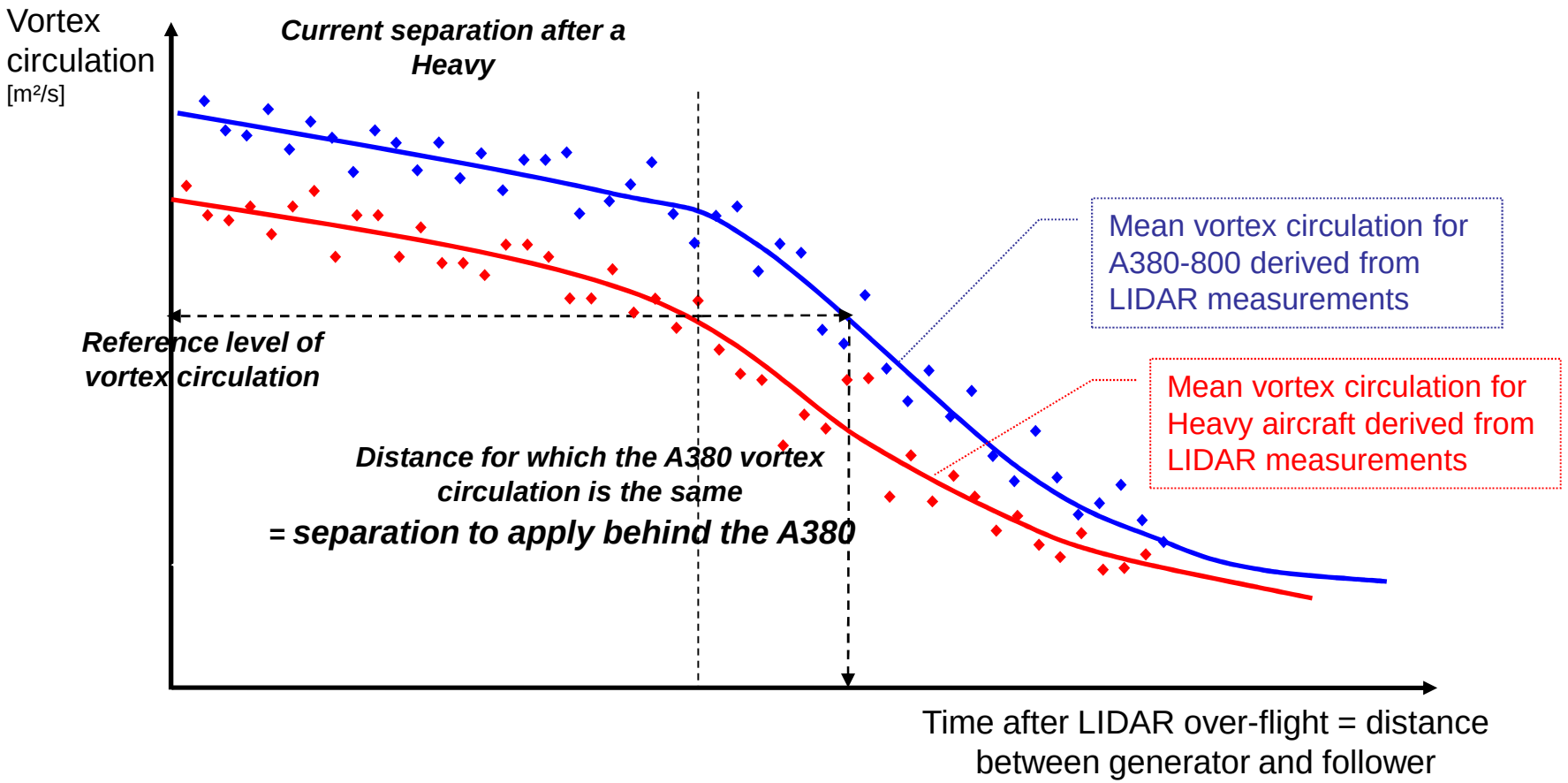
Approach: back to back LIDAR data collection

Example of LIDAR data analysis

A380 flight tests

Comparison of circulation decay curves

Basic assumption: separation for heavy aircraft is today's reference and has proven to be safe



Limitations when using LIDAR data for separation standards

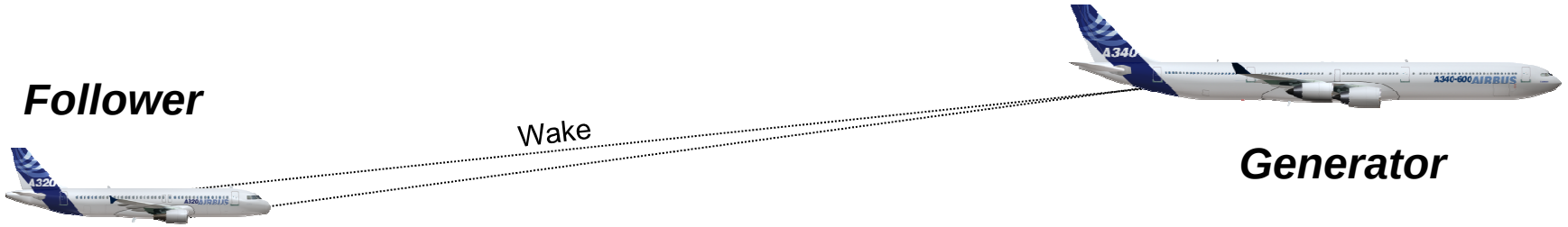
A380 flight tests

- Vortex circulation was used to provide an indication of the severity of a wake encounter.
- Limitations of this approach: Vortex circulation represents the maximum static rolling moment on a encountering aircraft, assuming the aircraft axis is aligned with the vortex axis and centered in the vortex core.
  - This is a theoretical situation.
  - Current LIDAR technology has its own specific limitations with some modeling.
- What are the effects of the vortices considering the weight, roll inertia, wingspan and roll capability of the follower?

  ⇒This can only be determined by actual encounter testing

Encounter test principle

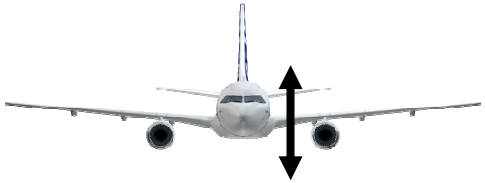
Airbus wake encounter flight testing methodology



- Encounter test consists of physically flying an aircraft through the wake of another to measure specific parameters.
- The probe aircraft flies encounters alternatively behind A380 and a suitable reference aircraft, with both wake generators flying side by side.
- Many parameters recorded with focus on the following flight parameters:

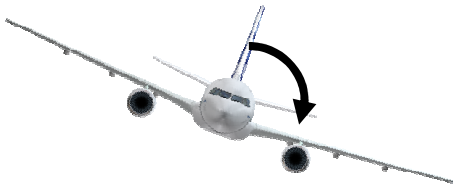
Altitude loss

Vertical acceleration



Roll rate

Roll acceleration



Flight test procedure
Comparison flight tests in cruise

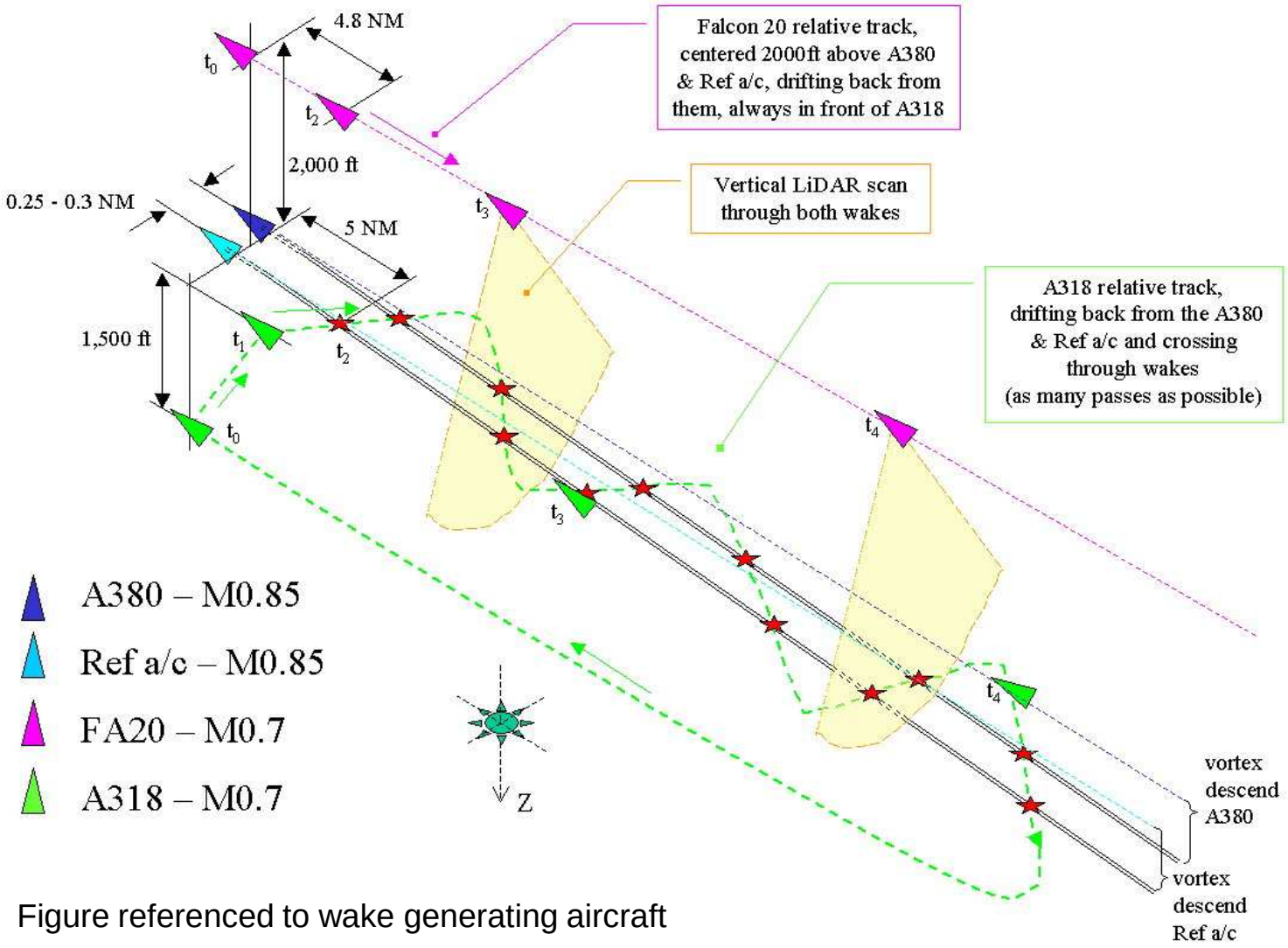


Figure referenced to wake generating aircraft

Cruise test techniques

- Numerous preparation flights were necessary to tune the flight test techniques.
- Observation of the rate of descent of vortex of both aircraft was an important issue due to RVSM.
- Tests were performed from 5 NM, standard separation for the B747 up to 15 NM, distance approved for the A380 at the time of the tests.
- Encounters results confirmed by Lidar observations.
- For the comparison flight between B747 and A380, the FAA A380 Chief Test Pilot was on board to make an appreciation of the severity of the encouters behind both aircraft.

Example results (cruise)
Video recording

Example:

- A318 11.4 NM behind A380

Video

A318msn1599fl783leg3vtp_082700b

Cruise test results

- Rate of descent of vortex of both aircraft is identical. It reach –1000 ft at a distance between 12 and 15 NM.
- In some cases, rough encounters were obtained.
- For some parameters, the decrease with distance is rather slow.
- Looking at all the parameters, it was found that the A380 and the B747 are similar.
- The pilots impression was that no difference could be felt.
- All that was confirmed by the results of the on-board Lidar of the Falcon 20.

In cruise, same separations of the A380 than the other Heavies has been approved.

Approach wake encounters

- Results obtained in approach thanks to Lidar tests were found unrealistic and somewhat against common sense:
  - A light aircraft can fly 6 NM behind a B747.
  - A B747 has to be 6 NM behind the A380.

- Airbus has identified a benefit of using wake encounters to reduce separation in approach and a full process has been launch to built smoke generators, prepare specific aircraft and review flight test techniques.

Back to back encounters tests

A380 flight tests

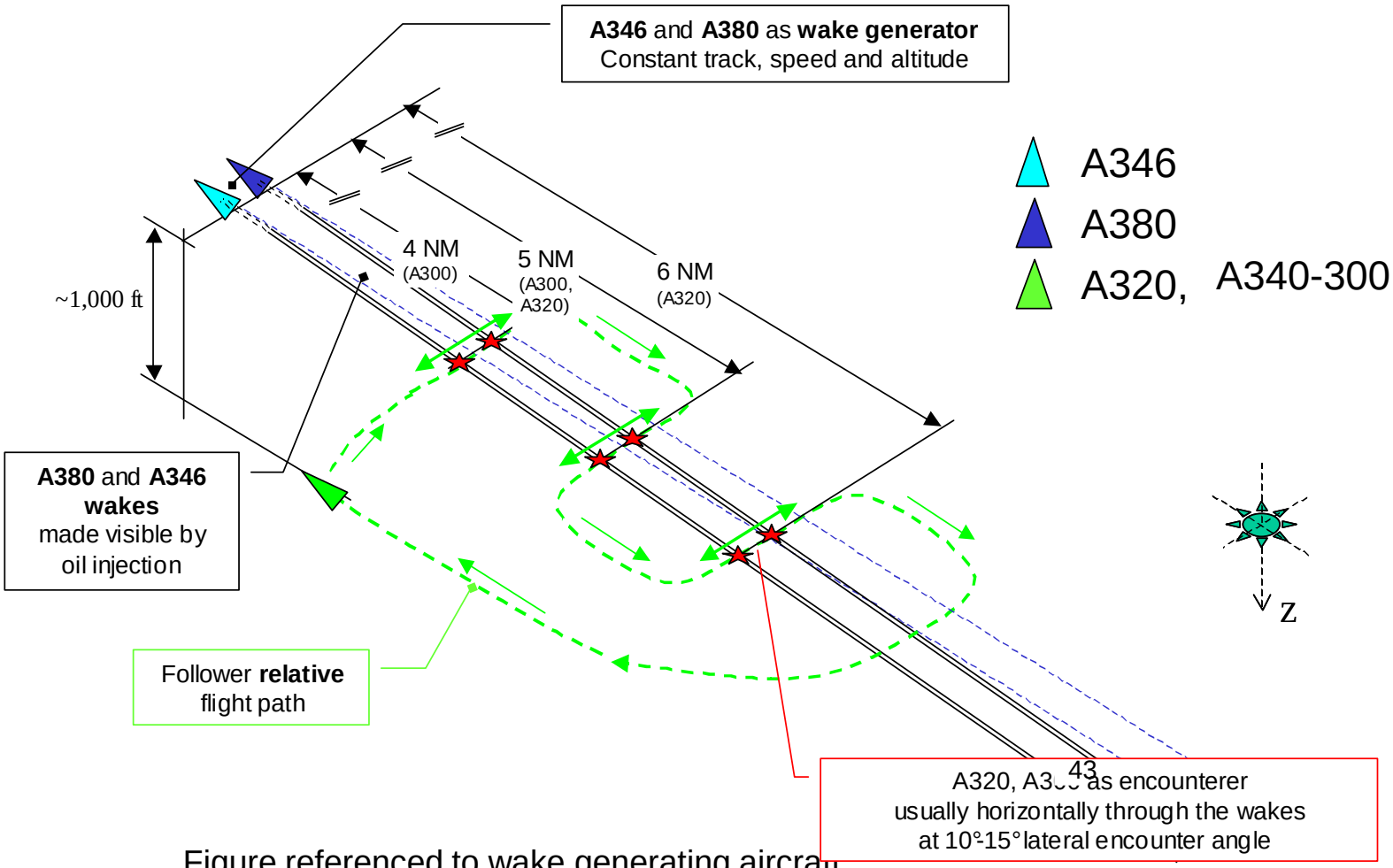


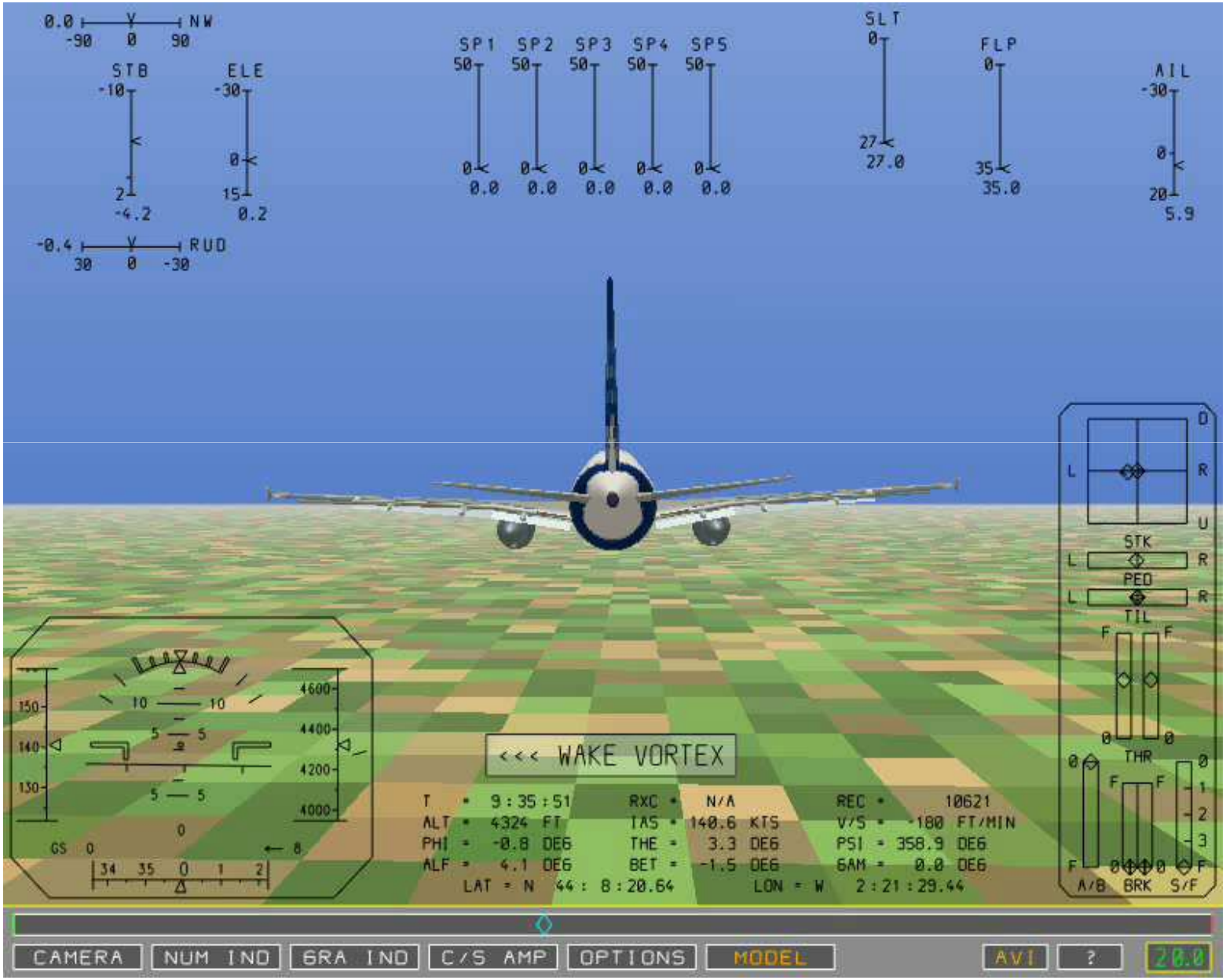
Figure referenced to wake generating aircraft

Encounter test - Video recordings

A380 flight tests

Encounter test - 3D animations

A380 flight tests



Encounter test – Video recordings and 3D animations

A380 flight tests

Stick-free encounters:

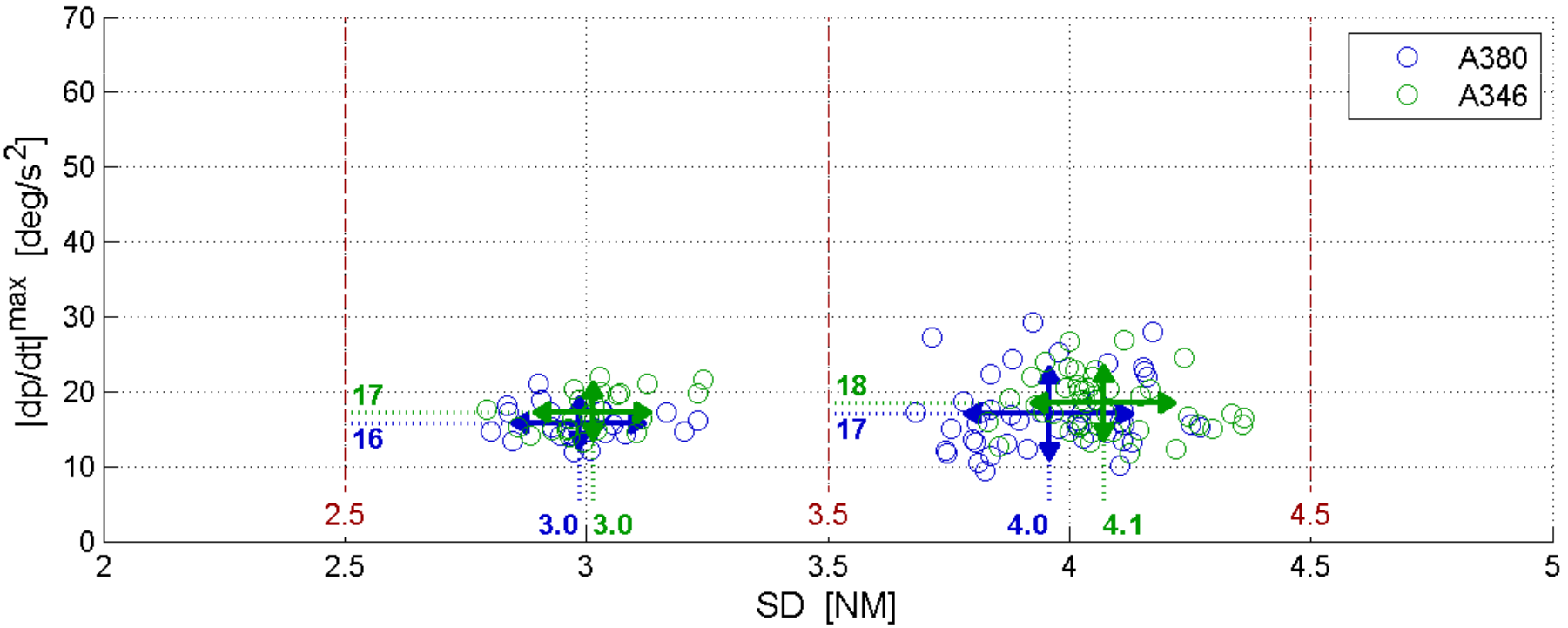
	Video	Vimosac3D
A320 4.6 NM behind A380 (#49)	A320_SBS2_Enc49_sf_380.avi	A320_SBS2_ap_sf_49_vimo_2.avi

Preliminary raw data - Flight F4

A343 (AP Off, Alt2 law) behind A380 and A346

- **Maximum absolute roll acceleration during WVE : $|dp/dt|^{max}$**

$|dp/dt|^{max}$ versus Separation Distance (data points, means and standard deviations)



Thank you

AIRBUS