DATA SUMMARY

LOCATION

Date and time	**23 January 2005; 13:06 LT**
Site	**Madrid-Barajas Airport**

AIRCRAFT

Registration	**TF-ATI**
Type and model	**BOEING B747-300**
Operator	**Iberia, L.A.E.**

Engines

Type and model	**GENERAL ELECTRIC CF6-80C2B1**
Number	**4**

CREW

	Captain	First Officer	Flight Engineer
Age	**58 years**	**34 years**	**55 years**
Licence	**ATPL**	**ATPL**	**Flight Engineer**
Total flight hours	**20,877 h**	**5,766 h**	**15,225 h**
Flight hours on the type	**4,994 h**	**1,298 h**	**1,313 h**

INJURIES

INJURIES	Fatal	Serious	Minor/None
Crew			**17**
Passengers			**318**
Third persons			

DAMAGE

Aircraft	**Minor**
Third parties	**None**

FLIGHT DATA

Operation	**Commercial Air Transport – Scheduled – International – Passenger**
Phase of flight	**Takeoff run**

REPORT

Date of approval	**25th July 2007**

Synopsis

Owner:	ILFC
Operator:	Iberia, L.A.E.
Aircraft:	Boeing B747-300, registration TF-ATI
Date and time:	23 January 2005, 13:06 LT
Incident site:	Madrid-Barajas Airport
Persons aboard:	335
Type of operation:	Commercial Air Transport – Scheduled – International – Passenger

Description

The crew aborted the takeoff after feeling a gradually increasing vibration during the takeoff run which became very violent past the 80-kt point.

Over the course of the investigation it was discovered that the vibration resulted from a self-sustained oscillation in the nose gear steering due to a malfunction in the steering system regulating valve.

1. FACTUAL INFORMATION

1.1. History of the flight

On Sunday, 23 January 2005, a B747-300 aircraft, registration TF-ATI, operated by Iberia, was getting ready to take off shortly after 13:00[1] from runway 36L at Madrid-Barajas airport. It was on a regularly scheduled flight, IB-6501, and aboard the aircraft were 318 passengers and 17 crew members en route to Santo Domingo (SDQ).

VMC conditions prevailed, with calm to slight winds, no precipitation and a temperature of 9 °C. The runway used, measuring 4,350 m, was dry. The total takeoff weight of the aircraft was 323,722 kg, including 106,540 kg of fuel. (The maximum structural weight was 377,842 kg.) The taxiing operation proceeded normally, covering some 3,500 m from the parking stand to the head of runway 36L. The aircraft entered the runway and started the takeoff with the fuselage landing gear steering locked and centered and using reduced power.

[1] All times are local (LT). To obtain UTC, subtract one hour from local time.

At a ground speed of 35 kt, the crew felt what they believed to be normal shakes and vibrations resulting from the irregularities of the asphalted surface. The hood on the captain's instrument panel started to vibrate, but stopped when the vibrations were dampened by a crewmember's hand.

The takeoff run continued and when the copilot called out the 80-kt speed, the vibrations of the hood and instrument panels increased considerably. The aircraft was jerking sideways and lurching abnormally, so the decision was made to abort the takeoff.

Noises, a smell of rubber and objects being thrown up were noticed along with the shaking. The instrument panels became loose. The strong jolts hampered the operation of the controls, and despite the nose gear steering control impacting the captain's hand, he managed to stop the aircraft within the runway. The vibrations increased during braking and did not cease until the aircraft came to a complete stop.

An emergency was declared and the crew informed the fire brigade of the high brake temperature, which responded immediately. The brigade verified that there was no fire and escorted the airplane some 5,000 m from the exit at the end of the runway via taxiway Z-2 to the parking stand assigned to the aircraft in the industrial area in front of Iberia hangar 3, to which it proceeded under its own power.

The passengers were informed after the rejected takeoff that they were returning to the parking area, where they were disembarked via the stairs onto ground crew shuttles as per normal procedures.

Shortly after the aircraft came to a definitive stop, the high brake temperature caused a trip of the thermal fuses on the main left wing-mounted and fuselage legs, which deflated.

1.2. Personnel information

The flight crew, supplemented for a flight scheduled to last eight and a half hours, consisted of five members: the captain, two copilots and two flight engineers.

The cabin crew consisted of one steward and 11 attendants.

1.3. Aircraft information

1.3.1. *Airframe*

Manufacturer:	Boeing
Model:	B747-300

Manufacture No.:	24107
Year of manufacture:	1988
Registration:	TF-ATI
Owner:	ILFC
Operator:	Iberia, L.A.E.

1.3.2. *Airworthiness certificate*

Number:	24107
Issued by:	Icelandic Civil Aviation Administration
Issue date:	01-02-2000
Expiration date:	01-12-2005

1.3.3. *Maintenance record*

Total flight hours:	66,707 h
Total cycles:	11,549

The last maintenance checks made on the aircraft were as follows:

Last A4 check:	On 29-12-2004 with 66,597 FH
Last C (SP) check:	On 31-05-2004 with 64,620 FH
Last C2 check:	On 16-03-2003 with 60,390 FH

The A1 check, made every 650 FH, entails a general inspection of the aircraft's exterior and interior, with selected areas opened up for the performance of various services. The A4 check, made every 2,600 FH, involves inspections, services and functional checks in addition to those of the A1.

The C2 check consists of a general visual inspection of the condition and safety of systems and the adjacent airframe in specific parts of the aircraft, and includes the servicing and operational checks of various systems. It is performed every 11,000 FH.

Specifically, the C2 check verifies the torsion link freeplay of the nose gear. The clearance measured during the check on 16-3-2003 was 0.118" versus a limit of 0.19".

During the special C(SP) check made on 31-5-2004, only a visual inspection of the nose gear's condition was performed.

1.3.4. *Weight and balance*

A Weight and Balance sheet was drafted for the dispatch of flight IB-6501 that estimated a total takeoff weight of 322,544 kg, versus a MTOW of 377,842 kg.

This weight consisted of:

Total payload:	36,332 kg
Dry operating weight:	179,672 kg
Fuel weight at T.O.:	106,540 kg

The Center of Gravity at takeoff was at the 20.78% MAC position. The allowed limits for the takeoff weight specified are FWD 9.43%, AFT 32.05%.

A last-minute handwritten note in the Weight and Balance sheet indicated a decrease of 186 kg to account for two passengers who had not embarked, and their luggage, and a fuel weight at takeoff of 108,000 kg. Applying both corrections allows for a final estimated takeoff weight of 323,722 kg.

1.3.5. *Landing gear*

The landing gear consists of two wing-mounted legs, two fuselage legs and one nose leg.

The nose leg can turn about a vertical axis, thus enabling the aircraft to be steered on the ground. This leg consists of outside and inside cylinders. When the latter moves axially inside the former, it acts as a shock absorber. A set of torsion links allows for axial displacement between the two cylinders but prevents the wheels joined to the inside cylinder from changing their orientation with respect to the steering collar attached to the outside cylinder.

The orientation of the steering collar is controlled with the pedals or with the steering control, which mechanically displaces a lever on the regulating valve which in turn pivots the collar by means of two hydraulic actuators. The function of the regulating valve, then, is to direct the hydraulic pressure to the appropriate steering cylinder as requested by the pilot and, in addition, to center the wheel and dampen any zigzagging motion. An internal spring on the valve centers the wheels in case the signal from the pedals or from the tiller to the valve is interrupted.

The torsion clearance between the different components, fittings, torsion links, etc., can cause oscillations in the leg. Likewise, an alternating actuation of hydraulic liquid pressure on the steering cylinders can give rise to oscillations in the orientation of the nose gear.

Out of the remaining undercarriage legs, those under the fuselage can also be steered in tight ground turns to prevent excessive wear. During the takeoff run or when operating abnormally, the orientation of the fuselage legs can be locked and centered.

1.3.6. *Abnormalities prior to takeoff*

In its statements, the crew commented that during the taxi-out in Madrid, when making sharp turns, neither the 'GEAR NOT CENTERED' nor the 'UNLOCKED' warning lights for the 'Body Gear' or fuselage legs illuminated. They proceeded to disconnect the system and follow the abnormal takeoff procedure with the fuselage legs locked, with the intention of logging the anomaly in the flight report for subsequent correction in Santo Domingo. No other warnings of a malfunction in the anti-skid, rudder-pedal steering, or in any other system which may have been involved in the incident were received.

1.4. Meteorological information

The METAR reports for the airport in the hours leading up to the incident were as follows:

METAR LEMD 231130Z 20002KT CAVOK 07/00 Q1020 NOSIG=
METAR LEMD 231200Z VRB03KT CAVOK 08/M01 Q1019 NOSIG=
METAR LEMD 231230Z 20001KT CAVOK 09/M02 Q1018 NOSIG=

In other words, winds were weak, there was no precipitation or cloud ceiling and visibility was in excess of 10 km.

The specific wind speeds recorded by the anemographs at the head of runway 36 were as follows:

Date	Time	VMD2C36L	DMD2C36L	VMA10C36L
23-01-2005	12:30:00	03	170	05
23-01-2005	12:40:00	03	160	05
23-01-2005	12:50:00	03	160	05
23-01-2005	13:00:00	03	160	05
23-01-2005	13:10:00	03	150	05
23-01-2005	13:20:00	02	160	04
23-01-2005	13:30:00	02	150	04

Where

- VMD2C36L is the average wind speed (knots) in the 2 minutes prior to TIME
- DMD2C36L is the average direction (degrees) in the 2 minutes prior to TIME

1.5. Aerodrome information

Madrid-Barajas Airport is at an altitude of 609.6 m (2,000 ft) and has several runways for use by landing and departing aircraft.

The runway used by flight IB-6501 in this incident was 36L, which measures 4,350 m long by 60 m wide.

Appendix B shows a then-current AIP chart for ground movements.

The aircraft left from its parking stand at the southern end of the airport. The length of the taxiing run to the threshold of runway 36L was of some 3,500 m.

The chart shows the area of the runway between taxiways V-1 and Z-1, where zigzag marks from the nose gear were observed. Also shown are the points on taxiway Z-2 where the aircraft came to a stop and from which it was escorted to the final parking position.

1.6. Flight recorders

The aircraft had a Digital Flight Data Recorder (DFDR) and a Cockpit Voice Recorder (CVR), both located in the rear of the fuselage. They were recovered undamaged.

1.6.1. *Digital flight data recorder (DFDR)*

The aircraft was equipped with a TELEDYNE CONTROLS 70-701YY Digital Flight Data Recorder.

The DFDR was in perfect condition and was taken to Iberia's recorder laboratory (S.T.A.R) for inspection.

The information recorded was verified to be correct, except for a 12-second data gap immediately following the recording of strong lateral accelerations and during which the crew was in the process of aborting the takeoff.

The DFDR recording generally indicates that after taxiing from its parking stand, the aircraft proceeded toward the head of runway 36L.

13:06:30 The takeoff run is initiated with reduced power, quickly reaching a longitudinal acceleration of 0.23 g.

13:06:54 Some 24 seconds later, at an IAS of 98.4 kt, the aircraft reduces takeoff power and starts to brake.

13:06:55 The aircraft's speed is still increasing during the following second, reaching a maximum of 98.9 kt IAS; its deceleration reaches 0.27 g and its pitch angle exceeds the –0.9 degrees maintained during the acceleration, to reach an angle of –1.3 degrees.

13:06:56 Two seconds later, the speed has reduced considerably to 62 kt (though this reading may be spurious), with the reverse thrust on engines 3 and 4 already engaged. Longitudinal and lateral acceleration readings, which are recorded every quarter of a second, fluctuate between ± 1g twice in this second.

The DFDR then stopped recording for the next 12 seconds and by the time the recording started again, the aircraft had practically come to a stop.

The data from the recordings of LATG, LATA, LATB and LATC are plotted in one single time sequence on Figure 1.

A check of the recorder's Parameter Data Frame revealed that the amplitude, or range, of the lateral and longitudinal acceleration parameters is limited to ± 1g. Actual absolute values of these parameters experienced by the aircraft in excess of 1 g would not have been recorded.

The progression of the longitudinal accelerations is likewise shown in Figure 2.

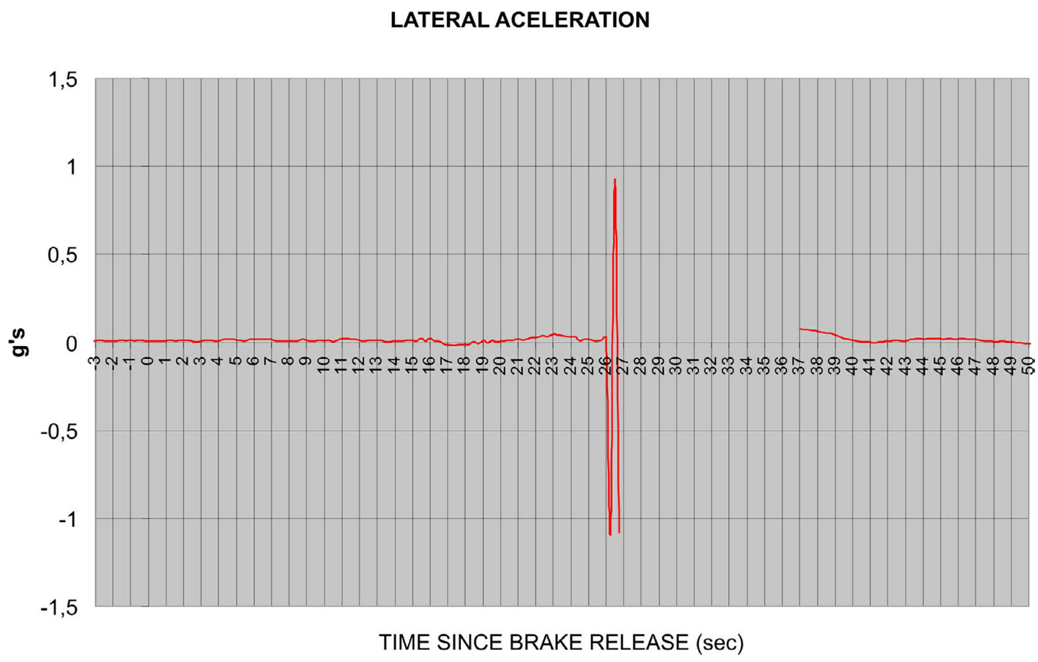

Figure 1. Graph of lateral acceleration

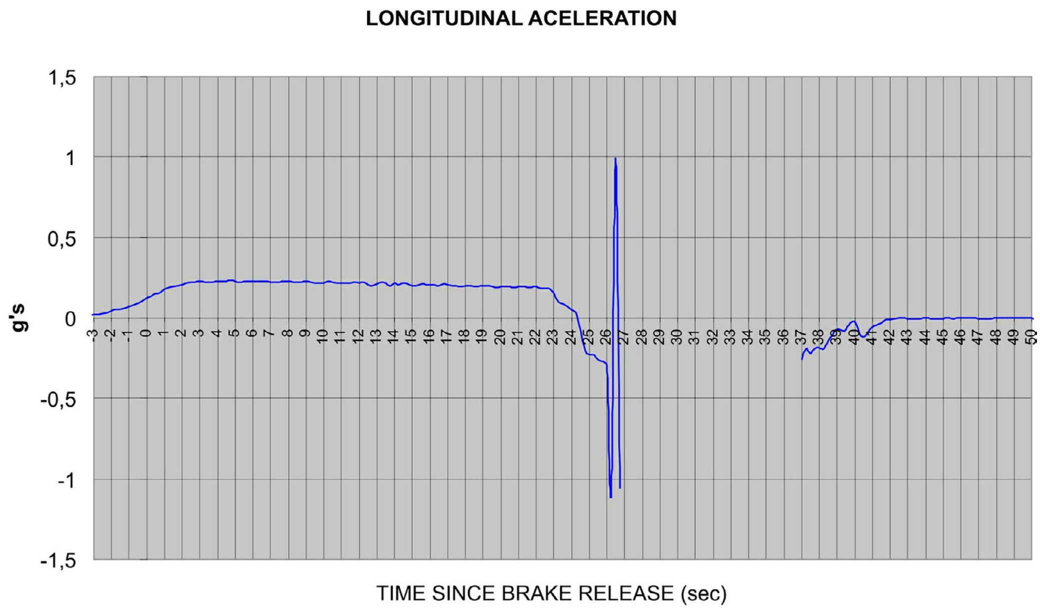

Figure 2. Graph of longitudinal acceleration

Fault indications while taxiing

It should be noted that the lateral acceleration readings while taxiing show values above ± 0.2 g at time marks 12:56:40 and 13:00:00, when the airplane was moving in a straight line on taxiways at speeds, not recorded, below 50 kt.

1.6.2. *Cockpit voice recorder (CVR)*

The aircraft was equipped with a FAIRCHILD Cockpit Voice Recorder, model A100A, P/N 93-A100-80 and S/N 10394.

It was read at the CIAIAC's sound laboratory, which yielded a proper recording on all four channels. However, since the time to stop and evacuate the aircraft exceeded the CVR's 30-minute recording capacity, the recording did not contain the sounds and voices associated with the event.

1.7. Wreckage and impact information

1.7.1. *Aircraft damage*

The aircraft was inspected by Iberia Maintenance which, among other tasks, performed checks associated with a hard landing and turbulence, serviced the shock absorber on the nose gear, tightened the bearings on the nose gear wheels and verified the torsion link freeplay on the nose leg. The clearance, as measured after the incident, was 0.11 in, versus the 0.19-in limit set by the manufacturer, Boeing.

Aside from the defects found in the regulating valve and transfer tubes noted in Section 1.9, the defects found were as follows:

The aircraft suffered various forms of damage in the cockpit, with dislodged instrument panels, instruments outside their respective panels or even on the floor, overhead panels and fairings that had fallen, both in the cockpit and in the main cabin. The ceiling support beam between rows 43 and 44 was cracked.

Figure 3. Flight Engineer's panel

Small anomalies were found on the exterior of the aircraft, such as excessive clearance in the nose gear, broken ground straps, a loose engine fairing panel with screws missing and a displaced nut in an engine mount. A hydraulic leak was detected in a transfer tube in the nose gear section.

The thermal fuses on all the wheels of the left main leg and of the fuselage legs were blown as a result of the elevated brake temperature reached during the aborted takeoff.

Figure 4. Main cabin overhead

No damage or abnormal wear was noted on any of the main or nose gear tires.

1.7.2. *Tracks on the runway*

An inspection of runway 36L by airport maintenance services following the incident revealed zigzag lines along the runway axis, apparently caused by the nose gear, from the taxiway V-1 intersection until taxiway Z-1.

1.8. Survival aspects

The cabin announcements, assistance provided by the cabin crew and prompt confirmation by the fire brigade that no fire existed allowed for an orderly deplaning of the passengers without creating any additional risk.

The coordination between airport services worked properly.

1.9. Tests and research

The tests and research focused on a component of the nose gear steering system, the metering valve, first in Iberia's component workshop and then at Parker, manufacturer of the component, under Boeing's supervision.

1.9.1. *Inspections and tests at Iberia's facilities*

The initial inspection of the nose gear steering metering valve revealed recent hydraulic leaks and that the control spool did not return to a neutral position after being manually actuated. All other actuation, flow, continuity and airtightness checks were satisfactory.

Once the valve was disassembled, it was discovered that the inner centering spring was displaced past its retainer.

External hydraulic fluid leaks were also found between one of the transfer tubes and the left swivel assembly.

1.9.2. *Inspections and tests at the manufacturer's facilities*

The regulating valve was sent to Parker, the manufacturer of the component, for inspection and testing under Boeing's supervision.

The tests were performed without the inner centering spring so as to avoid the possible damage and operational alterations that could have resulted from a loose internal component, and to try to reproduce the oscillation of the control spool under the conditions the valve was in when the incident took place. When the control valve piston was disassembled, an excessive friction force was noted although no scratches or scoring were present. The bypass valve slide exhibited deep scratches on the outer diameter. The inner diameter of the bypass valve did not exhibit scratches.

These tests were incapable of recreating the vibration, probably as a result of the excessive friction of the control valve.

These tests were unable to determine the cause of the shift in the centering spring. The possibility that the control valve's condition, especially insofar as the dimensions of the control and bypass flow areas and high internal friction are concerned, could have been the root cause of the event was confirmed. It is therefore possible that the spring shifted as a result of the vibration, instead of causing it.

It was also decided that further research would probably be unable to determine what triggered the event. Consequently, it was decided to refrain from further testing.

1.10. Additional information

1.10.1. *History*

The manufacturer of the metering valve, Parker, reported that, after reviewing this component's history of returns to its workshop, only one other similar case was found in its thirty-year design life. In that case, the returned metering valve had the centering spring displaced. A bench test of that valve had shown that, after requests to either side, the control spool achieved a self-sustained oscillation with a frequency of one to two cycles per second. Previously to the publication of this report, Boeing and Parker have reviewed record of returned metering valves as of July 2007 and found two reports: One was return due to heavy vibration, on 12th October 2005, and the other for severe nose vibration after takeoff, on 15th December 2006; in neither case were abnormalities found with the inner centering spring.

2. ANALYSIS

2.1. Flight background

Flight IB-6501 was dispatched normally on 23 January 2005. It was a regularly scheduled flight, and aboard were 318 passengers and a crew of 17 en route to Santo Domingo (SDQ). The weight and balance of the B747-300 aircraft, registration TF-ATI, were within prescribed limits. There was a slight wind with no precipitation and visibility was normal.

2.2. Aircraft response

The crew noticed no abnormalities during the taxiing or start of the takeoff run on runway 36L at Madrid-Barajas Airport. The data recorded by the DFDR, however, show that anomalies in the lateral and longitudinal acceleration values had already been recorded twice while taxiing out from the parking stand to the runway threshold. These may have been indicative of an existing malfunction.

Later, during the takeoff run, the crew felt a vibration prior to reaching 40 kt. This vibration got stronger and became very violent beyond 80 kt. DFDR data confirm the vibration, with lateral and longitudinal acceleration readings of ± 1g, which are the maximum the accelerometers can record. It is very possible that the actual accelerations were in excess of this magnitude. Just as these parameters were being recorded, and possibly because of their elevated value, the DFDR stopped recording for some 12 seconds, thus precluding the availability of data from the braking conditions experienced during the aborted takeoff.

The deflections from one side to the other of the nose gear are considered to have caused the skidding that resulted in the recorded values of lateral and longitudinal acceleration.

2.3. Crew actions

The crew aborted the takeoff when the speed reached the 99-kt mark. The runway's large dimensions, 4,350 × 60 m, prevented the aircraft from exiting the paved area during the deceleration despite the control problems induced by the vibrations and the high operating weight.

The energetic braking heated the brake components, though the maximum temperature reading was unavailable. The fire brigade responded immediately and escorted the aircraft to the assigned parking stand, where the passengers were smoothly and calmly disembarked via stairs and onto shuttles.

2.4. Origin of the vibrations

The zigzag marks left by the tires on the pavement and observed by airport personnel made it clear from the start that the strong vibrations resulted from a zigzagging motion of the nose gear. A check of the twisting clearance on the gear's components, which was within the manufacturer's specifications, discounted that as a possible cause or origin of the vibration.

Upon disassembling and inspecting the nose gear steering system regulating valve, however, it was found to be malfunctioning: after being actuated to the left or right, the control stick did not return to the neutral position. The valve was dismounted and disassembled at the operator's workshop, where one of the internal centering springs was found to be displaced beyond the stop.

To investigate the relationship between this defect and the vibration in question, the component was sent to the manufacturer, where it was subjected to various operational tests.

The tests on the valve made it clear that:

1. Adjustment defects in the valve's components, such as internal scratches, led to excessive friction when the control stick was moved.
2. It was impossible to induce a self-sustained vibration in the control stick by submitting the valve to operating pressures and mechanical excitation.
3. A historical review of other regulating valves like the one involved in this incident that were returned to the manufacturer only revealed one similar case of a valve

with a displaced centering spring, which vibrated at a rate of one or two cycles per second.

In this case, it is estimated that the vibrating frequency was also on the order of 1.5 cycles per second as observed by the -1 g, +1 g, -1 g successive readings spaced a quarter of a second apart. Friction within the valve due to scratches possibly produced during the incident itself prevented the vibration from being duplicated during the tests.

The investigation established as an objective to determine whether the vibration occurred prior to the displacement of one of the centering springs out of its retainer or if, on the contrary, the movement of the spring beyond the retainer was the root cause behind the vibration.

The initial vibrations observed in the DFDR data while the aircraft taxied from the parking stand to the head of runway 36L indicate that the vibration preceded the displacement of the centering spring beyond the retainer. Then, during the takeoff run, when the vibration became more violent, the spring may have moved out of the retainer.

Assuming this to be the case, then the cause of the initial vibration would have to be attributed not to the displaced spring, but to the effect of the hydraulic liquid resulting from the extreme tolerances of the regulating and bypass fluids, as well as from the extent of the friction within the valve.

Given that the aircraft and component manufacturers are only aware of one other case similar to this one in the 30-year life of this regulating valve design, it would appear that both events should be considered as isolated cases which do not warrant any further investigation into the phenomenon.

3. CONCLUSION

3.1. Findings

- The aircraft crew was properly qualified, experienced and in good physical condition. Every member was licensed in accordance with existing regulations.
- The aircraft had been maintained in accordance with the established Maintenance Program and had valid Airworthiness and Registration Certificates.
- The aircraft's weight and balance were within prescribed limits.
- The nose gear steering mechanism entered into a self-sustained vibration during the takeoff run that made the entire aircraft shudder violently. Said shaking was especially noticeable in the cockpit.
- One of the centering springs in the nose gear steering system's regulating valve was found displaced due to its displacement beyond its retainer.

3.2. Causes

The aircraft crew decided to abort the takeoff due to strong vibrations which were produced as a result of a self-sustained oscillation in the nose gear steering due to a malfunction in the steering system's regulating valve.

After the incident, one of the internal centering springs of said valve was found displaced. It has not been possible to determine whether the vibration resulted from the abnormal position of that spring, or from the regulation and bypass flow conditions within the valve and the level of friction between the piston and its housing.

4. SAFETY RECOMMENDATIONS

The malfunction history of this valve worldwide only records one similar prior case; hence, this case is regarded as one more isolated event that does not call into question the component's reliability. As such, issuing a relevant safety recommendation is considered unwarranted.