CIAIAC
Comisión de Investigación
de Accidentes e Incidentes
de Aviación Civil

TECHNICAL REPORT
A-068/1999

Accident of aircraft Fokker MK-100, registration I-ALPL, at Barcelona Airport (Barcelona), on 7 November 1999

MINISTERIO
DE FOMENTO

Technical report

A-068/1999

Accident of aircraft Fokker MK-100, registration I-ALPL, at Barcelona Airport (Barcelona), on 7 November 1999

MINISTERIO DE FOMENTO

SECRETARÍA GENERAL DE TRANSPORTES

COMISIÓN DE INVESTIGACIÓN DE ACCIDENTES E INCIDENTES DE AVIACIÓN CIVIL

Edita: Centro de Publicaciones
Secretaría General Técnica
Ministerio de Fomento ©

NIPO: 161-03-011-0
Depósito legal: M. 23.129-2003
Imprime: Centro de Publicaciones

Diseño cubierta: Carmen G. Ayala

COMISIÓN DE INVESTIGACIÓN DE ACCIDENTES E INCIDENTES DE AVIACIÓN CIVIL

Tel.: +34 91 597 89 60
Fax: +34 91 463 55 35
E-mail: ciaiac@mfom.es
http://www.mfom.es/ciaiac
C/ Fruela, 6
28011 Madrid (España)

Foreword

This report is a technical document that reflects the point of view of the Civil Aviation Accident and Incident Investigation Commission (CIAIAC) regarding the circumstances of the accident and its causes and consequences.

In accordance with the provisions of Law 21/2003 and Annex 13 to the Convention on International Civil Aviation, the investigation has exclusively a technical nature, without having been targeted at the declaration or assignment of blame or liability. The investigation has been carried out without having necessarily used legal evidence procedures and with no other basic aim than preventing future accidents.

Consequently, any use of this report for purposes other than that of preventing future accidents may lead to erroneous conclusions or interpretations.

This report has originally been issued in Spanish language. This English translation is provided for information purposes only.

Table of contents

Abbreviations

°	Degree
°C	Degree Celsius
1L	Left forward door
1R	Right forward door
AFM	Aircraft Flight Manual
APP	ATC Approach Control
ATC	Air Traffic Control
ATPL	Airline Transport Pilot Licence
C	Cycles
CAS	Calibrated airspeed
CBO	Cycles between overhauls
CECOPS	Airport Operations Office
CIAIAC	«Comisión de Investigación de Accidentes e Incidentes de Aviación Civil» (Spain)
CMM	Component Maintenance Manual
CPL	Commercial Pilot License
CSN	Cycles since new
CSO	Cycles since overhaul
DFDR	Digital Flight Data Recorder
ENAC	«Ente Nazionale per l'Aviazione Civile» (Italy)
EPR	Engine Pressure Ratio
F/A1	Flight Attendant n° 1
F/A2	Flight Attendant n° 2
F/A3	Flight Attendant n° 3
g	Acceleration of gravity (9.81 m/s^2)
GND	ATC Ground Movement Control
GS	Groundspeed
Hz	Hertz
ICAO	International Civil Aviation Organisation
in	Inch
INTA	«Instituto Nacional de Técnica Aeroespacial» (Spain)
IAS	Indicated airspeed
IR	Instrument rating
kg	Kilogram
kt	Knot
lb	Pound
LDA	Landing Distance Available
LH-MLG	Left main landing gear leg
lpm	Litres per minute
m	Metre
min	Minute
mm	Milimetre
NLR	Dutch Aerospace Laboratory
PA	Public address
RAI	«Registro Aeronautico Italiano» (Italy)
RH-MLG	Right main landing gear leg
s	Second
SB	Service bulletin
SB F100	Service bulletin of Fokker 100 aircraft
TBO	Time between overhauls
TWR	ATC Tower Control
UTC	Universal Time Coordinated

Synopsis

The aircraft Fokker MK-100, registration I-ALPL, operated by Alpi Eagles on behalf of Air Dolomiti, landed in Barcelona on 7 November 1999 at 13:55 UTC. It was making a commercial flight, DLA 2708, from Venice to Barcelona with a crew of five and 39 passengers on board.

Moments after the first contact of the wheels on touchdown on runway 25, the right-hand landing gear suffered a phenomenon of shimmy vibration, of divergent amplitude, which in a few seconds caused the breakage of the main fitting of the right-hand main landing gear (RH-MLG).

The vibration was not damped, due to the low damping capacity of the shimmy damper caused by a defect of the component.

After RH-MLG failure, the aircraft leaned to the right dragging the right hand wing tip and flap over the runway surface. It run about 1,000 m over the paved surface crushing several runway edge lights, until it came to a halt in a grassy patch between two taxiways 100 m to the right of the runway centre line.

The crew and passengers evacuated the aircraft in an orderly manner via the evacuation slide of the forward right-hand service/emergency door. No fire was caused.

The aircraft suffered considerable damage to the wing and the cowlings of the right-hand engine, and also to the doors of the right-hand main landing gear leg.

1. FACTUAL INFORMATION

1.1. History of the flight

1.1.1. *Flight*

On 7 November 1999, at 13:55 hours UTC[1], the aircraft Fokker MK-100 registration I-ALPL was preparing to land at Barcelona airport. The aircraft was operated by Alpi Eagles on behalf of Air Dolomiti, under a commercial agreement. The flight, Air Dolomiti DLA-2708, had taken off from Venice at 11:31[1] with a weight of 37,427 kg. It was a commercial flight of some two hours' duration, with 39 passengers on board, two technical crew members and three flight attendants. The approximate fuel consumption on this journey was some 3,000 kg, as a result of which the landing weight was some 34,500 kg, of which 3,000 kg corresponded to the reserve fuel in the main tanks built into the wings.

That same day, at 08:26, the aircraft had already landed in Barcelona on a previous flight, with a different crew, originating from Verona.

In Barcelona the runway in service for landings was runway 25, while for take-offs runway 20 was being used.

1.1.2. *Approach*

Flight DLA-2708 had proceeded normally, the wind was calm, there was no cloud ceiling, visibility was more than 10 kilometres and the control tower (TWR) had already authorized landing. The co-pilot was acting as the flying pilot, maintaining a speed of some 140-145 kt, some 9-14 knots above the reference speed corresponding to the landing weight of 35,000 kg and the elevation of the airport at sea level. After performing the verifications included in the checklist, the landing configuration was set with 25° of flap. In the approach to runway 25 the flight was conducted manually, that is, without connecting the automatic pilot. There were other aircraft in the approach circuit to runway 25.

The next traffic in order of landing was an Iberia flight, IBE-4571, which was following at four miles but did not yet have the Fokker in sight. Flight DLA-2708, with which the Iberia aircraft was reducing the distance, announced that it would make every effort to leave the runway immediately.

1.1.3 Touchdown

The pilot in command stated that the aircraft's wheels touched down at a point some 300 m from the threshold of runway 25. The DFDR (Digital Flight Data Recorder) shows

[1] All time references are expressed in UTC. The local time, which is the same in Venice and Barcelona, is obtained by adding one hour to the UTC time.

that the maximum pitch angle in the flare, which was 4.9°, was reached six seconds before the ground mode signal was recorded.[2] The recorded ground signal coincides in time with a ground speed (GS) reading of 128 kt. Three seconds later the pitch angle decreased, permitting the contact of the nose wheel with the runway surface at a ground speed of 110 kt.

At that moment, with the aircraft now rolling along the runway, it experienced an increasing vibration which was felt both by the pilots and by the flight attendants and passengers. The flight deck door, which was open during landing as per AFM rules, closed by itself as a result of the vibrations; it was reopened by attendant F/A1. The attendant who was sitting in the rear folding seat, F/A3, stated that during landing she heard a sudden sharp impact.

The captain took control of the aircraft when he felt the vibrations. The lift dumpers opened in the normal manner. The aircraft was zigzagging, with a tendency to pull to the right, and the pilot used the brakes and applied idling reverse to attempt to brake and keep the aircraft on the runway; he increased the power asymmetrically, up to 1.18 EPR in the left-hand engine and 1.13 in the right.

Some three seconds after the nose was lowered, the right-hand main landing gear collapsed. The two wheels, together with the sliding member of the right-hand main landing gear leg, sheared off and struck the fairing of the right-hand engine. The wing leant on that side, scraping the right-hand flap, wingtip and aileron along the ground. In the wing, the MLG Bracket split. However, the fuel tanks remained intact.

The aircraft finally came to a halt at the side of the runway, outside the tarmac paved surface, in a grassy area 1,730 m from the threshold of the runway and 100 m to the right of the centre line or axis of the runway, in fast exit G-A. The right wing was resting on the ground. From the activation of the ground mode sensor until the aircraft came to a stop 36 s elapsed.

1.1.4. *Evacuation*

No fire was caused. The engines were turned off, following the normal checklist.

When the captain gave the order to evacuate, attendant F/A1 opened service/emergency door 1R, checked the deployment of the evacuation slide and helped the passengers to evacuate the aircraft. Then she opened passenger door 1L, which operated in the normal manner, although no passengers used it.

The evacuation was conducted in an orderly manner and without problems. The passenger address (PA) and intercom systems operated correctly.

[2] The landing gear legs have microswitches that are activated by the deflection of the main damper, so that it is possible to determine whether the weight of the aircraft is sustained by the wings (air mode) or is resting on the ground (ground mode). This signal is used by various automatic mechanisms.

Photo 1.1.1

There were no injuries. The medical services proceeded to the disembarkation site. The passengers were transferred to the terminal building in the normal shuttle vehicles.

Four fire-fighting vehicles reported to the site in a matter of seconds, protecting the aircraft by spraying foam over the right-hand side, since it was losing fuel from the engine zone.

1.1.5. *Notification of the accident*

The first alert signal, seconds after the accident, was given by an unidentified station. Ten seconds later, at 14:56:20, Ground Control alerted the Fire and Rescue Service of the existence of an aircraft with landing problems. The aircraft was in sight of the personnel of the Fire and Rescue Service. The alert of the aircraft itself was issued ten seconds later. This information has been extracted from the TWR recording.

1.2. Injuries to persons

Injuries	Fatal	Serious	Minor/none
Crew			5
Passengers			39
Others			

1.3. Damage to aircraft

The accident caused considerable damage to the aircraft.

1.4. Other damage

The scraping of the wing along the runway caused abrasion damage to the tarmac, leaving five holes of various dimensions and breaking some twenty marker lights on the edge of the runway and taxiways G-A and C1-3.

The aircraft in transit were redirected to waiting zones and points. After a few minutes, they began to operate on runway 02/20.

Runway 07/25 was out of service for five hours, during which time tasks of cleaning and repairing the paved surface of the runway were carried out, although the repairs to the marker lights were not concluded until 8:50 hours the following day. One hour earlier, at 7:50, the transfer of the aircraft to the hangar zone was completed.

The fuel which escaped from the right-hand engine for four hours was collected.

1.5. Personnel information

1.5.1. *Captain*

Sex:	Male
Nationality:	Italian
Title:	ATPL
Licence number:	V3665170
Issue date:	08-07-1996
Validity:	28-04-2000
Type rating:	F100, IR
Last medical examination:	31-08-1999
Flight experience last 90 days:	236 h
Flight experience last 30 days:	80:50 h
Flight experience last 24 hours:	3:30 h
Rest time before accident:	20:05 h
Duty time before accident:	2:05 h

1.5.2. *Co-pilot*

Sex:	Male
Nationality:	Italian
Title:	CPL
Licence number:	8219
Issue date:	06-10-1992
Validity:	31-12-1999
Type rating:	F100, IR
Last medical examination:	18-02-1999
Flight experience last 90 days:	175 h
Flight experience last 30 days:	64:15 h
Flight experience last 24 hours:	5:10 h
Rest time before accident:	16:10 h
Duty time before accident:	2:05 h

1.5.3. *Cabin crew*

Three flight attendants integrated the cabin crew, all of them with valid national licences. Flight experience amounted for more than 200 hours within last 90 days. Rest time before initiation of this day flight was over 24 hours.

1.6. Aircraft information

1.6.1. *History of the Fokker 100/70 models and configuration*

The aircraft

The Fokker F28 aircraft are short-range jet aircraft built to carry 65-85 passengers, depending on configuration. They are fitted with Rolls-Royce jet engines. The Fokker F28, with Spey engines, entered service in 1969.

As a development and update of the F28, the MK-100 appeared in 1986 with Tay engines. The MK-F70 model is a short-fuselage version of the MK-100. Before the collapse of the Fokker Company in 1996, 274 MK-100 aircraft and 27 MK-70 aircraft had been manufactured.

The configuration of the aircraft is cantilever wing, semi-monocoque structure, tail-mounted engines and tricycle landing gear.

The landing gear (see Figure C.1 in Appendix C)

The nose leg has two wheels mounted on the same axle with tyres of size 24 × 7.7 (measurements in inches of the outer diameter and width), ply rating 12, speed rating 225. The wheels are fitted with a small brake to stop them turning inside their retraction compartment after take-off.

The aircraft was equipped with landing gear manufactured by Messier-Dowty Rotol.

The two main legs of the landing gear, left and right, are identical. Each of them is composed of a main fitting attached to the wing MLG Bracket by means of articulated fittings and a sliding member connected to the wheels. The sliding member can move axially inside the main fitting. The interior of the two cylinders is filled with hydraulic fluid and compressed nitrogen, to perform the functions of spring action and damping. The axial movement compresses the nitrogen and forces the hydraulic fluid to pass between the chambers which an inner piston separates from the nitrogen chamber.

The main fitting is joined to the wing spars by means of a longitudinally-articulated main joint which allows the MLG to retract laterally towards the fuselage, by means of a ram. In the «landing gear down» position, an articulated side stay and a set of locks secure this in extended position. These elements are installed to the right or left of the main fitting, according to whether the leg is installed in the left- or right-hand position on the aircraft.

The twin wheels of each main leg, fitted with tyres of size H40 × 14.0–19 (ply rating 20 and speed rating 225), are mounted on a horizontal axle connected to the sliding member. The radial position between the main fitting and the sliding member is maintained by means of torque links articulated at a common apex and between the main fitting and the sliding member. The torque links permit the relative axial movement of the main fitting and sliding member and prevent rotation between them.

A shimmy damper is mounted at the common apex of the torque links.

1.6.2. *Landing performances of the Fokker MK-100*

- With a weight of 35,000 kg, flap of 25°, at sea level and with calm wind, the aircraft needs a landing runway length of 1,383 m, including a margin of 40% for possible deviations from the distance demonstrated in tests. Normal landings with this weight have a run of between 830 and 1,383 m.
- The reference speed in the approach for this weight is 131 kt IAS.
- The pre-landing checklist includes arming the lift dumpers and selecting the flap position.
- In demonstration tests of landing performance, the inverse thrust of the engines is not used, and the runway threshold is overflown at 50 ft.

1.6.3. *Aircraft identification*

Make:	Fokker
Model:	F-28 MK-0100
Serial number:	11250
Registration:	I-ALPL
Version:	89 passengers/2 flight crew members/4 flight attendants
M.T.O.W.:	44,450 kg
Operator:	Alpi Eagles
Contractor:	Air Dolomiti

The cabin version is defined by the operator as 000/012/077, indicating accommodation for 12 passengers in Business class in rows 1, 2 and 3, and 77 passengers in Economy class.

1.6.4. *Certificate of airworthiness*

Number:	13594A issued by the «Registro Aeronautico Italiano» (RAI)
Type:	TPP/I, TPM. Passenger and cargo transport
Date of issue:	20-06-1996
Date of expiry:	15-06-2002

1.6.5. *Maintenance log*

The Alpi Eagles maintenance schedule was passed by the RAI on 28-07-1998.

Situation in regard to the maintenance programme

Total flight hours:	24,429
Total flight cycles:	22,880
Last inspection «D»:	01-04-1999
TSO. Hours since last inspection «D»:	1,428
Cycles of main left-hand landing gear leg:	18,083

Cycles of right-hand main landing gear leg:	18,306
Potential cycles between inspections of main landing gear leg:	20,000
Cycles of RH shimmy damper:	2,795
Potential CBO of cycles between inspections of shimmy damper:	12,000

- After the last flight of the day before the accident, maintenance personnel in Verona performed the daily service inspection on the aircraft. This inspection includes checking the level of hydraulic fluid in the reservoir of the shimmy damper. The tank has a red-line indicator which appears when the fluid level descends.
- No flight abnormality was recorded in the list of deferred defects.
- Two days before the date of the accident, wheel n° 3 and brake unit n° 3 were changed, due to an alert from the components workshop on observing the state of a wheel previously removed from that position. The wheel, removed by working order, did indeed show damage in the housing of the inner bearing caused by the brake unit.
- On 8-9-1999, two months before the day of the accident, brake unit n° 3 had been changed. After the landing, brake unit n° 3 jammed, preventing the wheel from rolling. The brake temperature reached 500 °C.
- On 1-9-1999 hydraulic fluid was replenished in the shimmy damper of the main right-hand leg.
- The shimmy damper installed in the aircraft, manufactured by Menasco P/N: 23700-3, S/N: MAL176, passed a general inspection or overhaul at HYDREP in February 1998. Subsequently it was repaired by the same workshop and delivered with certificate JAA Form One on 28-05-1999, with CSO: 1,979 and CSN: 16,227.
- The shimmy damper component status at the moment of the occurrence was: 2,795 CSO, 17,043 CSN, and 816 FC since last inspection.

1.6.6. *Engines*

Make:	Rolls-Royce
Model:	Tay 620-15
Potential of the engines:	«On condition»
Serial number n° 1:	17,018
Serial number n° 2:	17,007
Hours and cycles engine n° 1:	17,809 FH 16,650 C
Hours and cycles engine n° 2:	20,217 FH 19,233 C

1.6.7. *The shimmy phenomenon*

«Shimmy» is the name given to the phenomenon of torsion vibration and lateral flexing of a landing gear leg.

This vibration can be due to various causes, such as transient elastic deformations in the impact of the wheels with the runway, cyclic forces due to centrifugal forces of the rolling masses (wheels, brake disks and tyres), roughness and undulations in the runway surface, pressure oscillations in the hydraulic lines of the brake system, differential braking between the twin wheels of the same leg, partial locking of brake units, and so on.

The oscillation, once commenced, can be self-excited by the friction between tyre and surface due to the «cornering» effect,[3] the phenomenon of «hydraulic crosstalk»[4], etc. The vibrations can enter into resonance when the frequency of the excitation approaches the natural frequency of torsion vibration of the leg. The energy involved, which oscillates between the states of elastic deformation energy and kinetic energy of the vibrating masses, can reach and accumulate values high enough to cause breakage due to exceeding the elastic limits of loads and deformations of the structural elements.

In the shimmy phenomenon, a prominent role is played by the plays between the wheels and their axles and between the various joints.

The main leg unit of the Fokker MK-100 has a natural frequency of torsion vibration in the order of 16 Hz and is sensitive to the shimmy phenomenon, as are those of other aircraft of similar configuration.

Due to the impossibility of totally preventing the causes of the lateral torsion/flexion vibration, shimmy dampers were introduced, mounted in the common apex of the torque links. These elements permit a lateral play of the torque links, centred by a spring, and damping by the passage of hydraulic fluid between the left and right chambers of the damper. The use of these dampers means that small oscillations in the leg are not amplified.

1.6.8. *History of shimmy phenomena in relation to the main landing gear of the Fokker MK-100*

Since 1987, the year of the first accident of a prototype due to these causes, after which the length of the torque links was modified, other accidents and incidents have been

[3] Cornering: forces perpendicular to the direction of a wheel caused by a slip angle formed by the direction and vertical plane of the wheel.
[4] Influence of the modulation of the pressure of a hydraulic line on another line.

recorded in which the shimmy phenomenon has been present, in most cases associated with problems of assembly of the torque links, fatigue in the main fitting, and others.

In 1989 the shimmy damper was introduced by SB F100-32-34 after the investigation of the collapse of a left-hand landing gear unit. Errors of assembly of the spacers in the apex joint of the torque links were the cause of other accidents which gave rise to SB F100-32-97 and SB F100-32-113. These SB, of a recommended nature, were raised to airworthiness directives by the airworthiness authorities and were incorporated into the aircraft I-ALPL.

Shortly before the accident involving this aircraft, there was another of similar characteristics which gave rise to SB F100-32-114, published on 1 October 1999, one month before this accident, which modified the shimmy damper by removing the shims (see point 1.16.5), among other actions. This SB, of a recommended nature, which was later declared mandatory by an airworthiness directive, had not yet been incorporated into the aircraft, which was still within the compliance period of 21 months.

1.6.9. *Maintenance record of the shimmy damper*

In point 1.6.5 it has already been said that the shimmy damper, with a potential of 12,000 cycles between overhaul, had accumulated 2,795 cycles since its last overhaul and 816 since the last workshop visit for repair. Hydraulic fluid had been replenished on one occasion, in the in-line maintenance inspections, two months before the accident.

General inspection

The tasks carried out on the unit in February 1998 during its general workshop inspection included complete disassembly, cleaning and pickling, visual and geometric inspections, and the incorporation of Service Bulletins.

The actions of geometric inspection on the assembly included checking the dimension of the gap between the cap and housing sleeves, which was to be covered by shims without exceeding the thickness of the gap. In the maintenance documents this action is recorded as performed, but a single measurement of 0.95 mm is given without specifying whether this refers to the measured gap or the thickness of shims installed. Later verbal information indicated that it referred to the thickness of the shims.

The functional tests include a measurement test of the flow of hydraulic fluid, which under pressure of 50 psi must be less than 1.9 lpm (litres per minute). As a result of the test, the indication «OK» is recorded in the workshop documents without specifying the flow measured in the test. It must also be pointed out that the working document specifies that «*the flow... must at all times be less than or equal to 1.9 litres*», using the unit of measurement *litres* instead of *litres per minute* to express the requirements of the test.

Workshop repair

In May 1999 the shimmy damper unit went into the workshop for «*conditionnement*». On this occasion no disassemblies or dimensional inspections were carried out. The CMM tests of hydraulic leaks were performed, but the flow test was not.

1.7. Meteorological information

The routine meteorological reports of Barcelona airport at 13:30 and 14:00 UTC on 7-11-1998 were as follows

1330 LEBL 25004KT 190V250 CAVOK 20/06 Q1017 NOSIG
1400 LEBL 25006KT CAVOK 19/04 Q1017 NOSIG

That is to say, light winds of 4 to 6 kt from the west, which at 13:30 varied between directions 190° and 250°. Visibility was more than 10 km and there was no cloud ceiling. The temperature was between 19° and 20°. The relative humidity was low, with a dew point between 4° and 6°, and no significant changes were expected.

At the moment of the approach, TWR reported calm wind to the aircraft.

1.8. Aids to navigation

With regard to glide path aids, Barcelona's runway 25 is fitted with the PAPI visual aid of 3° glide path gradient and the ILS CAT II/III electronic aid.

1.9. Communications

VHF contacts were maintained in the frequencies 118.1 of TWR and 121.7 of Ground Control.

— The first communication from DLA-2708 in the final approach was recorded at 13:53:35.
— On receiving permission to land, DLA-2708 replied at 13:54:23 giving its indicated speed, 145 kt, at the request of TRW.

— The next and last communication from DLA at 13:56:23 is «MAYDAY MAYDAY»[5], with an acoustic alarm in the background.

Various recordings of the communications establish the times at which various rescue actions were carried out: these are included in point 1.15.

1.10. Aerodrome information

Barcelona airport has two intersecting runways in directions 07/25 and 02/20, with a surface of asphalt concrete. The two runways cross at a point 500 m from the threshold of runway 25.

Runway 07/25 has an available landing length of 3,108 m and a width of 45 m. Its magnetic orientation on the date of the accident was 247°. The elevation of threshold 25 is 2.9 m, equivalent to 9.5 ft. The final approach to runway 25 is made by over flying the Mediterranean Sea and crossing the coastline some 3,500 m before the threshold. The elevation of the terrain in the final approach areas is of the order of 9 ft (See diagram of runways in Appendix B).

1.11. Flight recorders

1.11.1. *Flight data recorder*

The aircraft carried a Sundstrand DFDR flight recorder with P/N 980-4100-DXUN and S/N 4154.

Appendix A shows a table of the DFDR data from the final approach until the moment the aircraft came to a halt. The column entitled «Space» shows an integration of the groundspeed parameter GSPD. The «Space» scale makes it possible to determine the position of the aircraft in metres from the threshold of runway 25 at each moment and correlating it with the phenomena taking place.

From the dumping of recorded data, with a timescale in seconds, with origin zero at the moment when the ground mode sensor was activated, we show below the moments when interesting changes were recorded in the flight parameters:

Time (seconds)	GSPD (kt)	Parameter and (unit)	Value
–62	133	Radio height (ft)	684
		Magnetic orientation (°)	253.4

5 «MAYDAY, MAYDAY» is the international emergency assistance call in aviation.

Time (seconds)	GSPD (kt)	Parameter and (unit)	Value
–9	134	Radio height (ft)	24
–6	134	Maximum pitch angle (°)	4,9
0	128	Ground mode signal	√
1	126	Vertical acceleration (g)	1.317
2	121	Reverse spread	√
4	117	Pitch angle (°)	–0.2
6	110	Banking. Right wing drops (°)	11.8
		Vertical acceleration (g)	1.651
10	94	Maximum longitudinal acceleration (g)	–0.353
11	87	Maximum lateral acceleration (g)	–0.493
13	78	Magnetic orientation (°)	232.1
26	33	Magnetic orientation (°)	264.4
		Power of engine n° 1 (EPR)	1.18
		Power of engine n° 2 (EPR)	1.12
31	16	Reverses stowed	√
35	3	VHF transmission	√
		Magnetic bearing (°)	285.4

Vibration

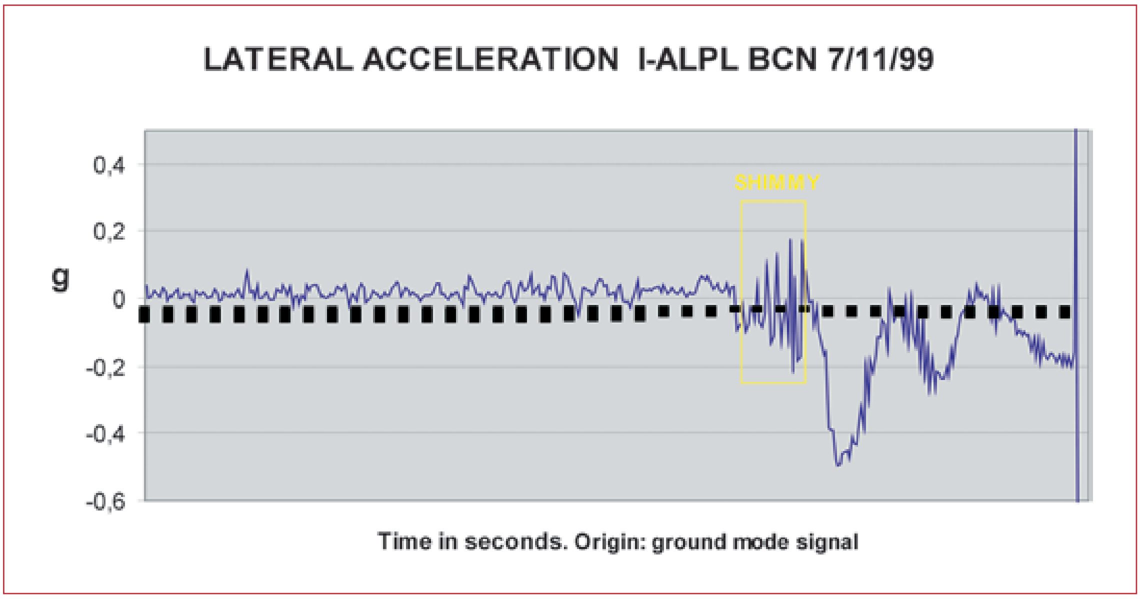

Figure 1.11.1

The installed DFDR records the parameter of lateral acceleration with a periodicity of a quarter of a second. The series of data recorded during the approach, touchdown and braking run until the aircraft came to a halt are shown in graphic form in figure 1.11.1. It can be seen that although the levels of lateral acceleration were low at all times, at touchdown they increased in absolute values and the frequency of the changes of direction of those accelerations also increased. After the breakage of the main landing gear leg, the aircraft zigzagged for several seconds, tending to pull to the right. The maximum acceleration in that direction reached almost 0.5 g, some 13 s after touchdown.

1.11.2. *Cockpit voice recorder (CVR)*

The aircraft had a Fairchild CVR recorder, model A100A. P/N: 93-A100-80 with S/N: 60711.

The poor quality of the recording made it impossible to understand the conversations and sounds recorded.

The CVR records a rhythmic knocking of a frequency between 6 and 10 Hz before the dropping of the right wing.

1.12. Wreckage and impact information

1.12.1. *Tracks in the runway of the aircraft and tyres and minor wreckage collected on the runway*

It was not possible to distinguish the tracks of the tyres in the first contact of the wheels at touchdown.

Some 760 m from the threshold of runway 25 there began some undulating tracks which denote sustained vibration of the right main leg (see photo 1.12.1), which continued for 136 m, stopping suddenly. At the beginning the traces are light and at the end they are more marked. These tracks were very clearly marked at the points of maximum elongation on both sides. However, the track was not marked at the points of zero elongation. In the vibration zone, total wave amplitudes of 9 cm were measured at the beginning and 15 cm at the end. The wavelength was 2.5 m at the beginning and 3 m at the end.

A zone of some 80 m of length of the runway was then examined, with various fragments broken off the aircraft by friction and impacts being collected.

Finally, tracks were detected of the tyres of the nose and left-hand landing gear, which had left cycloid traces which crossed on two occasions and continued until the aircraft's stopping point.

Photo 1.12.1

At almost all the times the aircraft travelled over paved surface, the greatest separations of the aircraft from the runway centre line coinciding with the confluence of taxiways. In its course the aircraft ran over some twenty marker lights and a sign. Only at the last moment did the aircraft leave the tarmac, entering a grassy area.

Taking as coordinates the runway axis and the perpendicular threshold line, we give below the position of the wreckage collected and the tracks, traces and marks left in the surface and edge of the runway:

Wreckage and tracks	Distance from threshold (m)	Distance from runway axis (m)
Start of traces of shimmy of RH-MLG [2]	760	7
End of traces of shimmy of RH-MLG [2]	896	7
Start of abrasion in asphalt by RH-MLG	1,001	7-7.5
Scraping of wingtip; loss of traces of wreckage of landing gear	1,106	17
Track of wheel carriage	1,016	7-7.5
Track of wheels of LH-MLG and NLG	1,166	–2
Final position of RH-MLG wheel carriage and stop ring	1,206	24
1st crossing of wheel tracks: nose wheel to the left	1,246	4
Maximum elongation of wheel tracks to the right	1,356	25
2nd crossing of wheel tracks to the left	1,436	17
Final position of the aircraft	1,730	100

1.12.2. *Inspection of the aircraft after the accident*

The aircraft finally came to rest at a point 100 m to the right of the centre line of runway 25 and 1,730 m from its threshold 25. The orientation of the aircraft was some 36° yawed to starboard with regard to the runway direction. The right main leg had collapsed and the aircraft, leaning to the right, was resting on the wing. The wingtip, flap and right-hand aileron were badly damaged, with loss of covering material, due to scraping against the runway, marker lights and terrain.

The right wing landing gear fixing was fractured. Of the main fitting of the right main leg, which had broken into fragments, there remained the front half-shell (Photo 1.12.2), attached to the wing structure by the extension/retraction joint.

Photo 1.12.2

The main joint was destroyed. The other fragments of the main fitting had broken off. The sliding member with wheels was separated.

The air inlet cowling and the side cowling of the right-hand engine showed damage and perforations produced by the blow from the wheel carriage, formed by the two wheels of the right-hand main leg mounted on the sliding member unit, broken off from the leg. In this engine zone a fuel leak occurred, lasting several hours (Photo 1.1.1).

The left main leg suffered damage to the bearings of the wheel axle caused by the lateral loads of the aircraft.

1.12.3. *Examination of the right-hand landing gear after the accident*

The main components of the right-hand leg of the landing gear were searched for, and almost all of them or pieces of them were found. An in-depth investigation was set in motion, organizing a working team under the direction of CIAIAC with the participation of INTA, ENAC, Alpi Eagles, Messier Dowty and Fokker Services. We describe below the findings of the preliminary inspection, and point 1.16 sets out the findings of the investigations and tests.

Some minor parts like bearings, seals and rings could not be recovered.

Main fitting (see photos in these pages and Figures in Appendix C)

This was broken into three major pieces. From the largest piece, which included a half-shell of the main fitting, the lugs of the main joint had broken off. The forward lug was split into two and its sleeves had broken off.

The lower end of the largest piece of the main fitting showed little abrasion, indicating that it had only made a short contact with the runway surface. The bottom edge of the main fitting was more abraded, indicating greater contact with the ground.

Another large piece of the main fitting included a triangular surface joined to the upper torque link (Photo 1.12.3). This arm of the torque link turned freely, and some play

Photo 1.12.3

could be appreciated in it in its connection with the main fitting. The housing of the shimmy damper was connected to the torque link.

The apex bolt of the torque links was split due to excessive flexion.

Sliding member

The sliding member showed abrasions in the upper end due to its contact with the runway. The separation piston of the nitrogen chamber was still inside it, and maintained pressure. A piece of the lower torque link connected to the sliding member offered resistance to turning and did not show any play.

The housing of the upper bearing of the sliding member was only slightly damaged. As the bearing is mounted at the upper end of the sliding member, the position of the damage inside the main fitting indicates that when the RH main landing gear collapsed it was almost completely compressed, but no signs were found of it having reached the end of its run (no bottoming).

Wheel unit

The tyres had not burst and they maintained pressure. No previous defects such as flat spots were observed. The circumferential damage they showed was due to friction with the upper torque link before shearing off.

Photo 1.12.4

The wheel units (tyres, brakes and rims) did not show any apparent anomalies or damage, apart from those mentioned in the tyres and a few small impact traces on the outer rims.

Shimmy damper

After the breakage of the apex bolt of the torque links, the shimmy damper remained connected to the upper torque link (Photos 1.12.3 and 1.16.3). Its housing showed some damage but was still intact. The reservoir, (reserve hydraulic tank) of the damper was found broken off and separated.

The description, examination and tests to which this damper was submitted are set out in point 1.16.5.

1.13. Medical and pathological information

No injuries were suffered, and the occupants of the aircraft did not require subsequent medical attention.

1.14. Fire

No fire was caused.

1.15. Survival aspects

Cabin configuration

The passenger cabin configuration admitted 89 passengers, 12 in Business Class and 77 in Economy. The cabin crew had four folding seats: one in the front of the aircraft, another alongside row 17 and two at the rear between the two rear toilets.

Layout of passengers and cabin crew

The flight was carrying 39 passengers and three attendants.

According to the load and balance sheet, the passengers occupied 15 of the 35 seats in zone A of Economy Class between rows 4 and 10, and 24 of the 42 seats in zone B of Economy Class, from row 11 to 22 (the last).

The flight attendants occupied one front folding seat (F/A1), the passenger seat in row 14 in the right-hand aisle (F/A2) and the right-hand rear folding seat (F/A3) (the figures in brackets identify each of the attendants).

Location of emergency doors

For evacuation, the aircraft has door 1L, the normal passenger door, in the front part of the left-hand side of the aircraft, and one smaller door (1R) for emergencies and galley service, at the same point in the fuselage as the passenger door but on the right-hand side of the aircraft. It also has four exits via hatches over the wings on both sides at rows 12 and 14.

Declaration of emergency and order of evacuation

The first alarm was given by an unidentified radio station (with a German accent), at 13:56:04 h. At 13:56:23 h the aircraft itself transmitted its MAYDAY message and the captain ordered the evacuation of the aircraft.

All of the passengers left the aircraft by the front right-hand door 1R, sliding down the inflatable evacuation slide. Door 1L operated in the normal manner but it was not used and the doors over the wing were not opened. It took less than three minutes to abandon the aircraft. According to the transcription of the telephone communication between GND and CECOPS, at 13:59:18 h the passengers were disembarked and a transfer vehicle had already moved into position beside them.

The evacuation was conducted in an orderly manner and without problems. The PA and intercom systems operated correctly.

There were no injuries. The medical services proceeded to the disembarkation site. The passengers were transferred to the terminal building in the normal shuttle vehicles.

Four fire-fighting vehicles reported to the site in a matter of seconds, protecting the aircraft by spraying foam over the right-hand side, since it was losing fuel from the engine zone.

1.16. Tests and research

The following actions were carried out as part of the investigation:

- Dimensional verification of the diameters of various bolts, sleeves, pins, etc., in accordance with the documentation of Dowty Rotol.

— Fractographic analysis of the main fitting of the right-hand main leg.
— Metallographic inspection and investigation of the mechanical properties of the material of the RH-MLG.
— Detailed inspection and functional tests of the shimmy damper.

These actions were carried out at INTA, Fokker Services, and NLR (Dutch Aerospace Laboratory). The results were recorded in three reports, from which we extract the following information.

1.16.1. *Plays in the main joint/support of the right-hand landing gear*

The measurement of plays in the pins of the main joint and in the lugs of the main fitting was carried out at INTA. The dimensional examination of the diameters of the sleeves of the main joint of the landing gear in the wing was carried out at Fokker Services.

In general the play levels found were within tolerances but close to the permitted upper limit. Some diameters measured at the sleeves of the forward lug of the main fitting, were out of tolerance with dimension up to 57.835 mm where the maximum wear limit stated is 57.22 mm. This was the lug which split into two halves when the landing gear collapsed (See Figure C.7 in Appendix C).

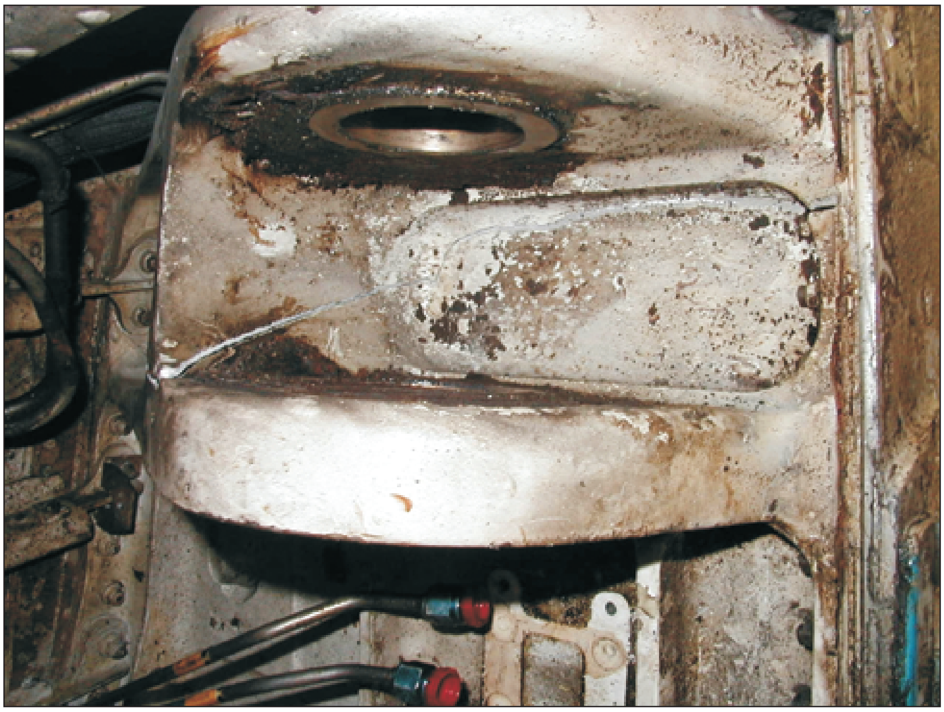

Photo 1.16.1

1.16.2. *Analysis of the fracture of the main fitting*

The fracture surfaces of the main fitting were investigated visually, using visual aids at low magnification power. And several locations of crack initiation were observed.

The crack that is expected to be the primary initial crack was located at the outer surface of the main fitting adjacent to the RH centreline of the upper main fitting torque link section. This is the location where the highest stresses occur in case of local bending due to torsion introduced by torque links. From this location the crack run upwards and downwards.

Cracking occurred exclusively in an overload mode and no evidence of pre-existing damage could be found such as fatigue, corrosion or forging damage.

A second crack initiation was observed at the LH side of the main fitting torque link lug section. The position of this initiation site was located closer to the lower end of the main fitting and started not at the outer surface but at the inner surface, suggesting that this initiation was caused by similar torsion bending loads following from the RH crack. Also from this initiation the crack ran to lower and upper direction.

Two secondary initial cracks were observed on fragmented parts of the main fitting. These cracks most likely were caused by the sliding member splitting the main fitting open during separation.

The pintle pin lugs in the main fitting also fractured due to overloading.

Apart from the separation of the pintle pin lug the type of damage observed on the main landing gear is typical for a torsion bending failure resulting from shimmy.

Photo 1.16.2 shows the fragments collected, with indication of the direction of extension of the cracks. Figures C.2 and C.3 of Appendix C show drawings of lines of cracks and fragmentation of the main fitting.

1.16.3. *Analysis of the fracture of the wing fitting*

The RH-MLG wing fitting, MLG Bracket, was inspected at Fokker Services. The cracks found in this part were caused by extremely high loads in a rearward direction.

The cracks began in the rear support hole of the bushing of the pintle pin, in its lower left-hand web. Although the hole displayed considerable corrosion, it is assumed that it did not contribute to cracks initiation.

The state of the main joint of the RH-MLG was considered satisfactory for its hours of service.

Photo 1.16.3

1.16.4. *Analysis at INTA of the material of the main fitting*

The manufacturing material of the main fitting is the light alloy DTD 5094 for forged parts according to British standards. The chemical analyses, metallographic structure suitable for T7xx treatment, electrical conductivity, Brinell hardness and traction resistance of a test piece extracted from the cylindrical zone, gave results in accordance with the standardized values in the analyses performed at INTA.

1.16.5. *Shimmy damper: disassembly and functional tests.*

The shimmy damper is composed of a housing and a cap joined by 10 bolts forming a hollow body inside which a piston moves, centred by «belleville» elastic washers which act as a compression spring on each side (see exploded diagram in Figure C.6. in Appendix C). The piston connected to the torque links by the pin in their common apex has an axial movement range of 5.89 mm in both directions. Its movement is damped by the passage of the hydraulic fluid from one end of the piston to the other, through valves and restrictors.

The gap between the surfaces of the housing and cap casings was filled with shims (see Figure C.5 in Appendix C).

The amount of hydraulic fluid contained before the accident could not be determined due to the breakage of the joint of its reservoir. It also showed other minor damage, but it was considered that this could be repaired in order to evaluate functionally its contribution to the accident. It was decided to reconstruct it in a controlled manner in order to test it in the same condition in which it was found and to compare its functioning in other conditions closer to normal design use.

Visual and dimensional inspection

An initial inspection at INTA revealed three anomalies:

— The tightening torque, measured on loosening the bolts joining the two parts of the sleeve, showed an average value 40% lower than the nominal rating specified in the CMM.
— One of the «belleville» elastic or spring washers was split due to fatigue, with no particle being separated from its surface.
— The play between housing and sleeve measured under a torque of 70-80 lb per in was found to vary between 0.75 and 0.82 mm (see Figure C.5 in Appendix C).
— The measured thickness of the shims was 0.95 to 1.06 mm.
— Therefore, the thickness of the shims of assembly between cap and housing was 0.15 to 0.20 mm greater than the gap between the casings. The component manual stipulated that this thickness must be less than the gap with a tolerance of +0/-0.076 mm, and that it must be measured with the specified tightening torque (CMM point ASSEMBLY, 2.A.(8)).

Functional hydraulic bench tests

The hydraulic bench flow test specified in CMM point TESTING 1.C.(1) was carried out on the premises of Fokker Services. The measured flow was 2.93 lpm, when the maximum permitted flow is 1.9 lpm. It was determined, by means of alternative assemblies without shims and with the correct tightening torque, that the excess flow was due to the excessive thickness of the shim pack.

Functional dynamic excitation tests

In order to make the tests possible, the joint of the damper housing with its reservoir was repaired with an oversized threaded connector.

Several series of tests were performed on the damper as it was found, (with excess shim thickness, low tightening torque and presence of a split spring washer) and with the anomalies of the spring washer and tightening torques corrected and without shims. In these tests, the amplitude of the induced vibration was 5 mm and the frequency varied between 8 and 28 Hz. A report by Fokker Services adds several graphs of the performance of the damper at frequencies of 8, 16 and 20 Hz in the condition found in the accident and in other assembly configurations for comparison purposes (see graph in Appendix D of the comparative results of the tests at 20 Hz).

The results of the tests demonstrated that:

— At frequencies of over 16 Hz the damper in the accident configuration had a much lower damping capacity, less than 50%, than the damper in the configuration complying with the requirements of the functional test CMM 1.C (1).
— The defect of one split washer had no influence on the damping capacity.
— The increase in the tightening torque did not improve the performance of the damper in the configuration of excess shim thickness.

1.17. Organisational and management information

1.17.1. *Visit to the runway of Barcelona airport*

The accident investigators requested permission to inspect the zone of the airport where the event occurred. They were not permitted to enter runway 07/25 until the early morning of 9 November, in deficient light conditions for the task they were carrying out. They did not have the opportunity to visit the zone in full daylight until four days after the accident.

1.17.2. *ICAO Regulations on aerodrome planning*

As a reference regarding possible conditions of aerodrome runway surfaces which could be related with the phenomenon of shimmy, we highlight the following:

In the ICAO Aerodrome Planning Manual, Part 1, Runways, (2nd edition, 1984), paragraph 5.1.14 reads: «*... The finish of the runway surface must have a regularity such that, when verified with a 3-metre rule placed on any part and in any direction of the surface there is no point, except across the drainage ridge or channels, with a separation of 3 mm between the edge of the rule and the runway surface*».

In addition, paragraph 5.1.16 states: «*The movements of the aircraft and the differences of settling of the cements tend in time to increase the irregularities of the surface... A sequence of superficial undulations in the runway, each one of which may be considered acceptable in isolation, could induce substantial dynamic loads in the landing gear of the aircraft, or intense vibrations which could affect the readings of the flight deck instruments*».

2. ANALYSIS

2.1. Flight, approach and touchdown

- The flight had proceeded normally at all times. The operation in Barcelona was habitual for the airline and all conditions that day were favourable. It may be that the pilots felt pressured by the traffic following them in the landing path, probably at a greater speed than their own aircraft, and they consequently increased its gliding speed slightly over the reference speed for its weight in order to facilitate the operation of the other flight. From the difference between the CAS and GS speeds, it is possible to assume a headwind component of 4 kt. The resulting angle of yaw from the magnetic orientation (253°) which is observed in the DFDR with regard to the orientation of the runway (247°) may imply a small component of wind from the right-hand side. Both deviations of speed and orientation are slight and normal in an approach, which in this case was made with stabilized speed and following the normal glide path gradient. Corroborating this, 3,736 m before the threshold the aircraft was at a height of 684 ft above sea level, and approximately 674 above the head of the runway. From these data we can calculate a true glide path of 3.1° and it can be assumed that the PAPI3 and ILS visual aids were followed.
- From the DFDR recordings and the integration of the speeds, we can calculate that the aircraft overflew the runway threshold at a height of 18 ft.
- The flare was gentle. During five seconds before touchdown, zero values of radio height were recorded.
- At the moment of touchdown there was a maximum vertical acceleration recorded of 1.317 g for two-eighths of a second, which can be classified as gentle and slight acceleration in this phase of the operation.
- From the DFDR data, it is calculated that the first point of wheel contact with the runway was 560 m from the threshold, instead of the approximately 300 m estimated by the pilot.
- On contact with the ground, the aircraft was perfectly oriented with the runway.

2.2. Braking and control of the aircraft in the landing run

After the first contact, and on lowering the nose, the pilot felt vibrations during a few seconds and zigzags which complicated the lateral control of the aircraft on the ground. Then the collapse of the right-hand landing gear imposed a strong tendency to pull to the right. At the beginning of the run, with sufficient speed and aerodynamic control, it was possible to maintain the aircraft within the 45 m width of the runway, and the pilots were able to turn the aircraft more than 15° to the left in an attempt to return to the centre of the runway. The braking was relatively poor, with idling reverse deployed in the early seconds of touchdown. Later, with speeds of the order of 30 kt (GS), the pilot used asymmetric thrust, increasing that of the left-hand engine in reverse, but he could not prevent the aircraft from pulling to the right. The aircraft left the runway and entered a grassy area. Its orientation at the end of the run was some 36° to the right with regard to the orientation of the runway axis.

The mean longitudinal acceleration in braking was of the order of –0,187, calculated as the uniform acceleration which can nullify a speed of 128 kt in approximately 1,730 m, or rather, nullify that speed in 36 s. This acceleration value is low compared with normal values, but it must be taken into account that the wing/asphalt friction is less than that of the tyre, and that the modulation of the power in reverse was used more for lateral control of the aircraft than for bringing it to a halt.

Corroborating this, the normal lengths of 830-1,383 m were exceeded in this landing, which overflew the threshold at a height of only 18 ft instead of the 50 ft taken in the theoretical calculation of the necessary length in accordance with the regulations. In contrast, the greater approach speed would slightly increase the run.

2.3. Evacuation of the aircraft and rescue

It must be pointed out that only door 1R was used, of lower size than door 1L. No doubt its lower sill height from the ground and the lateral inclination of the floor of the cabin, due to the aircraft leaning towards that right-hand side, led the occupants to evacuate the aircraft by the lower side, apparently making for an easier exit.

The flight attendant F/A2 was sitting, as is normally recommended, close to the wing exits, taking advantage of the fact that the aircraft had passenger seats available. In contrast, in other flights, with the aircraft full of passengers, the configuration version 000/012/77 would situate this attendant in the rear folding seat.

The small number of passengers, the integrity of the fuselage, the absence of fire and the final position of the aircraft in the centre of the airport facilitated the rescue operations.

Control rescheduled the traffic and in a few minutes was able to start authorizing both landings and takeoffs by runway 02/20, after it was verified that the crossing-point of the runways was free of wreckage and obstacles detached from the aircraft: the crossing-point of the runways is some 500 m from head 25 and the aircraft touched down beyond this point.

However, it is observed that criteria of complete operability normally predominate in air traffic services, hampering the performance of other activities. In this case, in order for the operability of the airport to be maintained, the accident investigators were not permitted to enter the runway in full daylight until 4 days later. This delay in starting the investigations may have caused the disappearance of traces due to the use of the runway and the maintenance actions performed on it.

2.4. State of maintenance

2.4.1. *Programmed maintenance*

The aircraft had passed the programmed inspections, had incorporated the mandatory SB relating to the landing gear, and in its daily routine had undergone the compulsory transit and service inspections.

2.4.2. *In-line maintenance*

The dossier of flight reports shows some entries concerning possible shimmy-related defects found and corrected:

- The recharging of hydraulic fluid in the shimmy damper, performed the previous September, may suggest that the damper was dry again. This supposition is not corroborated by the first inspection of the damper, since it may have lost the fluid after the accident when its reservoir sheared away. One point of the daily service inspection requires the verification of the level of shimmy damper hydraulic fluid. This simple inspection was performed at various maintenance bases in the preceding days by several technicians. It is believed highly improbable that the fluid could have been consumed in a few days' operation and that the inspection could have been performed incorrectly for several days in succession. Moreover, as the tests on the damper found a deficiency in its configuration, there is no reason for assuming any other anomaly.
- The recent changes of brake units may have altered the balancing conditions of the right-hand main landing gear wheels. However, no specific anomalies were found in these elements to suggest a direct relationship between those changes and the appearance of the shimmy vibration.

2.4.3. *Play and wear in main joints*

The proximity of the limit of cycles for the general inspection of the landing gear is observed in the wear of the main joints measured in the RH-MLG. Some measurements at the limit of the tolerances were in fact found.

As for the excess plays found in the sleeve of the forward lug of the main fitting, these may be the effect and consequence of the high loads and the breakage of the lug in the accident; because of this breakage, the sleeves would lose their support and would expand. The play felt by touch in the upper torque link with the main fitting may also have been a consequence of its impacts with the wheel and the runway.

2.4.4. *Workshop maintenance of the shimmy damper*

Apparently, on examination of the documentation supplied, during the workshop visit for general inspection, the measurements, assemblies and functional tests stipulated in the CMM were performed on the shimmy damper.

In the assembly procedure, it was specified that the gap in the casing of the sleeves must be measured and that a pack of shims of thickness equal to that gap with a tolerance of +0/-0.076 must be installed. However, the workshop measurements record only one value, corresponding either to the play or to the thickness of the shim pack, although subsequent clarifications confirmed that they referred to the shim thickness installed. It has also been observed that the measurements of the shim thickness after the accident coincide with the only measurement recorded during the general inspection.

The dimensional measurements of the shim pack taken after the accident showed a shim thickness of 0.15 to 0.20 mm, outside of the tolerance (+0/-0.076 mm), greater than the measured play.

Similarly, no reason has been found for the discrepancy between the result of the workshop flow test performed after the overhaul and that of the post-accident investigation test.

This test must obtain a flow equal to or less than 1.9 lpm. In the test performed after the accident the measured flow was 2.93 lpm. In the workshop test performed after the repair, no quantitative result was recorded, only the description «OK».

As for the use in the working document of the measurement unit *litres* to express a flow, instead of *litres per minute,* it is not believed, in principle, that this could give rise to confusion for technical personnel familiar with the component.

The repair report does not indicate the anomaly or defect which caused its premature removal, probably, from another aircraft. The workshop maintenance actions did not discover the internal discrepancies of its configuration.

Based on the assertions in this point, two Safety Recommendations are issued addressed to the Maintenance Organization which took care of maintenance of the shimmy damper unit involved.

2.5. Shimmy vibration

The marks of the tyres on the runway make it clear that the right-hand landing gear suffered shimmy vibrations. This is reaffirmed by similar previous cases suffered by this type of aircraft. The aircraft's lateral acceleration graph (see graph in point 1.11.1) shows that vibration occurred from the first contact of the wheels with the runway, although the initial amplitude was almost imperceptible. This vibration gradually amplified and lasted at least 6 s until the main leg collapsed. The shimmy marks on the runway extend for only 136 m, that is, little more than the last two seconds at the speed at which the aircraft was moving.

We do not know if shimmy occurred in previous flights. Having determined that the cause of breakage of the spring washer was fatigue, it can be taken as an indication that in its 816 previous cycles fitted to aircraft I-ALPL or the 1,979 cycles flown in its previous position after the general inspection, maximum deformations repeatedly occurred in it.

The speed of the aircraft when the first traces of shimmy were left on the runway was 120 kt. When the last tracks of shimmy were left, the speed was 110 kt. At these moments the wavelengths left on the ground were 2.5 m and 3 m, respectively. The frequency of the vibration can be calculated as speed/wavelength. It can then be estimated that the frequency of the shimmy vibration, when its amplitude was large enough to leave slip marks on the asphalt, was 25 Hz. When the amplitude of the vibration caused the main fitting to break due to overload, the frequency was 19 Hz.

The total amplitude of the wave left on the ground of up to 15 cm, that is, 7.5 cm on each side, would correspond to the sum total of deformation of the tyre, flexion and torsion of the main leg and lateral movement of the entire aircraft.

The lateral acceleration recorded in the DFDR is that of the aircraft as a whole. Four values per second are taken of this parameter, while the vibration is repeated some 20 times per second. The maximum acceleration recorded was 0.21 g, but undoubtedly the recorded sample did not capture the maximum level generated in the mass of the aircraft as a whole. In any case, it can be estimated that in the tyres of the right-hand landing gear lateral forces of the order of 7,500 kg were generated, to the right and the left alternately, due to high slip angles. The pivoting of the tyres with regard to the trajectory, which originates the slip angle, is due to the elastic torsion deformations in the main leg and the tyres and to the plays of the axles and joints.

The origin or trigger factor of the vibration is not clear. The tyres showed no localized defects in their perimeters, such as flat spots, which could destabilize the wheel. However, the wavelength left on the ground, of 2.5 to 3 m, is close enough to the perimeter length of the wheel to suggest a cyclic origin of the vibration. The outer diameter of the Fokker 100's main landing gear wheel is 40 inches, equivalent to 1,016 mm, and its perimeter is therefore 3.18 m.

The action of the brakes and antiskid device can be discarded as the cause of the initial vibration. The first shimmy marks show a slippage of the wheels when the slip angle is large, and there are no such marks when the angle is nil, because the wheel is rolling freely. This indicates that the wheels were not braked at the initial moments of touchdown.

It seems that the plays were normal. However, the piston run of the shimmy damper, insufficiently limited due to its internal deficiencies, acted as an added play.

There is no evidence to suspect the existence of undulations of the Barcelona runway itself. It is assumed in general that the criteria of construction and maintenance of aerodromes are correct; even so, it is surprising that three metres is chosen as the length of the rule for checking for defects in the runway surface, since this value is close to the length which can produce dangerous vibrations at high speed.

2.6. Sequence of breakages

We describe below, in chronological order, what is assumed to be the sequence of the appearance of the shimmy phenomenon and the breakages caused in the right-hand main landing gear leg:

— At touchdown, the wheels of the right-hand main leg begin to spin and to vibrate due to torsion.
— The small slip angle to one side and the other induces lateral forces with high friction coefficients between tyres and runway, due to the runway being dry.
— The gentleness of the touchdown, in a long flare, prevents the weight of the aircraft itself from acting on the joints of the landing gear assemblies. The internal frictions in the joints are low, as is the natural damping of the unit as a whole.
— The vibration amplifies as the main leg unit accumulates deformation energy with each vibration cycle, due to the impulse of the lateral forces appearing in the tyres, alternatively to one side and the other.
— The torque links transmit the loads corresponding to the elastic deformations to the lugs of the main fitting. These loads, combined with the local flexion loads, exceed the elastic limit of the material at a lateral point of this fitting, in the outer surface, close to the right-hand lug of the upper torque link.
— The crack which originates from this point instantaneously extends up and down the right-hand side of the fitting.
— When the crack reaches the lower edge of the fitting, the flexion and torsion cause another crack in the left-hand side, in the inner surface. As this crack extends and joints the crack on the right-hand side, a piece of the fitting with the upper torque link breaks away, and the sliding member loses its support. The hydraulic fluid escapes from the main fitting and sliding member cylinders.
— The unit formed by the sliding member and the wheels is split by the opening caused in the main fitting, breaking the apex pin of the torque links.

— The compression of the wheels against the ground causes them to rebound and shear away upwards, striking the cowlings of the right-hand engine situated in the tail of the aircraft.
— The aircraft, without its right-hand wheels, banks to the right, and the stub of the outer half- of the main fitting, which remains fixed in place, strikes the ground. This impact breaks the lugs of the main joint and those of the retraction ram, and other pieces of the latter break off.
— What remains of the main fitting, the front half-shell, hangs down from the side stay and the retraction mechanism, and scrapes along the ground without resistance.
— In its run, the aircraft rests on the left-hand landing gear and the tip of the right-hand wing, which scrapes along the runway and runs over a series of closely-aligned marker lights at the confluence of the runway with exit C-A. Incidentally, the rhythmic signal of 6 to 10 Hz recorded by the CVR may have been the recording of the right wing impacts with the runway edge lights.

2.7. Analysis of the causes

2.7.1. *Origin of the vibration*

The start of shimmy vibration can be due to many and various causes. Of the ones analysed in relation with this case, none seems to have had a conclusive contribution. It must be taken into consideration that shimmy is a random phenomenon of greater or lesser severity depending on the causes and circumstances involved.

2.7.2. *Functional failure of the shimmy damper*

However, it has been possible to ascertain that the shimmy damper did not serve its purpose satisfactorily. The function of this damper is to restrict the amplitude of the inevitable vibrations to a supportable level. The unit fitted to the right-hand main leg of the aircraft still retained some damping capacity, which explains how it could withstand 816 cycles since the workshop repair of the damper, but in this case it was incapable of effectively limiting the intensity of the vibrations.

Subsequent investigation has determined that the cause of the malfunctioning was the existence of a derivation of the flow of hydraulic fluid inside the damper, caused by an excess of shims in the coupling of the housing and cap sleeves (see Figure C.5 in Appendix C). The solution of eliminating these shims, already proposed by the manufacturer in a recent SB, is appropriate according to the results of these tests.

Another anomaly detected was the insufficient tightening torque of the bolts connecting the sleeves. Although the functional tests have not confirmed the contribution of this discrepancy in the damping capacity, attention has been paid to this characteristic because it influences the interior measurement of the housing and the integrity of the whole. On the other hand, it must not be forgotten that the tightening torque was measured by loosening the nuts; obviously, the torquemeter reading can be different when tightening and loosening a nut.

A report by Fokker Services adds a graph of the excitation tests to which the damper was subjected, in the accident configuration at frequencies of 8, 16 and 20 Hz. Although it is mentioned that other tests were performed at frequencies of up to 28 Hz, the results have not been published in this report. It must be taken into consideration that the frequency at which shimmy began was greater than 25 Hz and that energy must be dissipated and the vibration damped as soon as possible. The increase in amplitude of the vibration is an accumulative process which must be neutralized as soon as possible in order not to reach a situation of dynamic divergence.

The hydraulic bench functional tests also confirmed that in the accident configuration the damper did not comply with the flow requirements specified in the CMM. When the component was inspected in the workshop and was assembled and tested, it must be assumed that it likewise did not pass the flow test, since it had the same shim configuration used in the test subsequent to the accident. Once the shims were eliminated in the complementary tests, the damper complied with the flow requirements. Consequently, it is believed that no degradation occurred in the internal valves and passages of the hydraulic fluid to which the high flow can be attributed.

2.7.3. *Flight techniques*

The flight procedures and techniques were correct and normal at all times. The flotation on the runway in the flare may have led to a lower natural damping of the shimmy phenomenon. The weight of the aircraft on the elements of the landing gear main leg and between the tyres and the ground increases the internal frictions and limits the amplitudes of the torsion oscillation. At the same time, friction increases the dissipation of energy which must damp all oscillatory movement before wide amplitude of vibration is reached, making the movement unstable.

3. CONCLUSIONS

3.1. Findings

1. The metallurgical, metallographic and fractographic examination of the main fitting of the RH-MLG ascertained that there were no pre-existing defects in the material (chemical composition, structure, hardness, mechanical properties, corrosion, fatigue, etc.) which could have weakened the part.
2. The MK-100 aircraft type has a record of events involving shimmy, and several manufacturer's service bulletins and airworthiness directives have been published.
3. The latest SB published referring to shimmy, one month before the date of the accident, was not complied with. Its compliance period was 21 months.
4. The weather was good; the meteorological conditions had no influence on the accident. Barcelona's runway 25 was dry.
5. The approach flight and landing proceeded normally until the moment the aircraft's wheels touched the ground.
6. The aircraft followed the standard aids glide path, with a gradient of 3°, with an indicated air speed (IAS) equal to the reference speed plus 9-14 kt, and it crossed the runway threshold at a height of approximately 18 ft.
7. The aircraft touched down some 560 m from the threshold, after a gentle flare of 5 s duration. The orientation was exactly that of the runway. The ground speed (GS) at that moment was 128 kt.
8. The pilot flying was the co-pilot and he was flying manually, without connecting the automatic pilot.
9. Moments after the first contact of the wheels, a vibration commenced, the right-hand main leg of the main landing gear collapsed. The right-hand wing dropped and the aircraft began to zigzag, pulling to the right. At that moment the captain took control of the aircraft. The aircraft dragged its right wing along the runway, running over several runway edge and taxiway marker lights.
10. The lift dumpers deployed normally.
11. Idling reverse thrust was used to brake, and asymmetric reverse thrust was used, increasing the EPR of the left-hand engine to 1,183, to attempt to steer the aircraft in its landing run.
12. The aircraft came to a halt 1,730 m from the head of the runway, (1,170 m from the estimated point of first contact), and 100 m to the right of the runway axis, with an orientation of 36° to the right of its direction, and leaning to the right. The right wing was resting on the ground.
13. The cowlings of the right-hand engine received the impact of the landing gear wheels which sheared away.
14. A small fuel leak started in the engine zone, but there was no fire.
15. The 39 passengers and five crew members evacuated the aircraft via door 1R in a couple of minutes.
16. The RH-MLG experienced a shimmy phenomenon which started the moment the aircraft touched the ground and left its imprint marked on the surface of the runway for 136 m.

17. The shimmy vibration gradually amplified until the main fitting of the right-hand landing gear main leg collapsed.
18. It is estimated that the frequency of the vibration was some 25 Hz at the start of the imprint of the shimmy marks on the runway and 19 Hz when the main leg collapsed.
19. It was found that the shimmy damper did not operate correctly and therefore could not damp the vibration that occurred.
20. During the investigation it has been observed that the shimmy damper is very sensitive to the dimension of the inner length of its chamber.
21. The manufacturer had experience of other shimmy phenomena in this type of aircraft and had published several SB. The latest SB, issued shortly before this accident occurred, was also published as an airworthiness directive by the airworthiness authorities.

3.2. Causes

1. The aircraft suffered the accident due to the breakage of the main fitting of the RH-MLG.
2. The cause of the failure of the main fitting was exposure to mechanical loads, greater than the loads this part was designed for. The loads were due to a shimmy vibration
3. The vibration became unstable due to a functional failure of the shimmy damper.
4. The low damping capacity of the shimmy damper was due to the excessive thickness of a pack of shims between the housing and the cap which form the sleeve of the damper.
5. The defective assembly was not detected in a mandatory flow test on a hydraulic bench.
6. The existence of the shims themselves could have contributed to the assembly defect; it has been demonstrated that they have no functionality in the design.
7. Another possible contribution to the deficient operation of the damper could have been low tightening torque in the bolts connecting the two sleeves forming the damper housing.
8. A possible contributing factor to the shimmy phenomenon initiation could have been the gentle touchdown made by the aircraft combined with a high coefficient of friction corresponding to the dry runway.

4. SAFETY RECOMMENDATIONS

REC 38/04. It is recommended that the Hydrep Maintenance Workshop reinforce the internal quality control and the quality inspections and/or audits, in order to ensure the suitability of the maintenance methodology and procedures of the tasks carried out in the workshop, with a view to guaranteeing the correct performance of the measurements and tests stipulated by the manufacturer's CMM (Component Maintenance Manual).

REC 39/04. It is recommended that the Hydrep Maintenance Workshop upgrade the training of its technical personnel for the performance of the CMM tests of the MAIN LANDING GEAR DAMPER ASSEMBLY, P/N 237001/3, points ASSEMBLY 2.A.(8) and TESTING AND TROUBLESHOOTING 1.C.(1), in order to guarantee the correct annotation of results, including the units of the values.

APPENDICES

APPENDIX A
DFDR Parameters

Tiempo	GMT	ALTC	RALC	CAS	GSPD	Espacio (metros)	MHDG	PITCH	ROLL	VERG	VERA	VERB	VERC	VERD	VERE	VERF	VERH	LATG	LATA	LATB	LATC	LONG	LONA	LONB	LONC	EPR1	EPR2	RD1	RD2	VHF	AIR
-62	13:54	576	684	142	133	-3737	253,4	2,1	1,1	0,987	0,976	0,999	1,033	1,042	1,049	1,07	1,065	0,04	0,001	0,005	0,021	0,015	0,04	0,056	0,05	1,17	1,17	0	0	0	1
-61	13:54	576	672	140	133	-3668	253,4	1,8	0,6	1,012	0,974	0,971	0,969	0,983	0,996	0,985	0,987	0,017	0,011	0,005	0,029	0,038	0,038	0,046	0,042	1,19	1,19	0	0	0	1
-60	13:54	512	668	140	133	-3600	253,4	1,5	0,2	0,967	0,939	0,935	0,944	0,946	0,953	0,957	0,971	0,017	-0,009	0,007	0,003	0,042	0,036	0,034	0,05	1,19	1,19	0	0	0	1
-59	13:54	512	656	140	133	-3531	253,4	1,5	0,5	0,976	0,994	1,001	1,008	0,999	0,992	0,987	0,999	0,019	0,025	0,001	0,001	0,038	0,042	0,04	0,05	1,19	1,2	0	0	0	1
-58	13:54	512	640	140	133	-3463	253,4	1,4	0,3	0,994	0,987	0,98	0,969	0,957	0,953	0,939	0,946	0,013	0,009	0,013	-0,003	0,044	0,04	0,027	0,04	1,19	1,2	0	0	0	1
-57	13:54	512	628	138	133	-3395	253,3	1,4	0	0,941	0,937	0,951	0,967	0,932	0,93	0,944	0,955	-0,011	0,021	0,015	0,007	0,036	0,034	0,027	0,036	1,19	1,19	0	0	0	1
-56	13:54	512	612	140	133	-3326	253,5	1,8	0,4	0,974	1,008	1,015	1,035	1,04	1,038	1,01	1,044	0,019	0,007	0,001	0,005	0,044	0,048	0,05	0,058	1,19	1,19	0	0	0	1
-55	13:54	448	600	138	133	-3258	253,5	2,4	0,5	1,035	1,044	1,056	1,077	1,086	1,083	1,077	1,077	0,005	0,027	0,015	-0,007	0,052	0,052	0,052	0,062	1,19	1,2	0	0	0	1
-54	13:54	448	580	138	133	-3189	253,6	2,5	0,6	1,06	1,026	0,992	0,992	0,967	0,98	0,974	0,994	-0,003	0,019	0,009	0,003	0,046	0,038	0,032	0,042	1,2	1,2	0	0	0	1
-53	13:54	448	552	140	133	-3121	253,8	2,5	1,2	1,003	1,015	1,026	1,047	1,063	1,072	1,06	1,067	0,013	0,005	0,015	0,025	0,042	0,048	0,056	0,06	1,2	1,21	0	0	0	1
-52	13:54	448	520	139	133	-3053	254,0	2,5	1,2	1,044	1,067	1,095	1,09	1,081	1,12	1,081	1,074	0,003	0,001	0,06	0,078	0,06	0,05	0,058	0,056	1,21	1,22	0	0	0	1
-51	13:54	448	516	133	133	-2984	254,4	1,9	1,8	1,07	1,031	1,017	1,01	1,015	1,015	1,022	1,015	0,019	0,023	-0,001	0,042	0,048	0,036	0,044	0,046	1,21	1,22	0	0	0	1
-50	13:54	448	524	138	134	-2915	254,0	1,1	1,4	1,019	0,994	0,96	0,928	0,912	0,912	0,905	0,882	0,001	0,001	0,013	0,019	0,046	0,029	0,038	0,027	1,21	1,22	0	0	0	1
-49	13:54	384	524	139	134	-2846	253,8	0,5	-0,6	0,893	0,877	0,907	0,9	0,916	0,925	0,944	0,93	-0,005	-0,005	-0,003	0,025	0,036	0,032	0,034	0,019	1,2	1,2	0	0	0	1
-48	13:54	384	520	140	134	-2778	254,0	0,6	-0,2	0,937	0,935	0,953	0,951	0,969	0,955	0,974	0,976	0,023	0,019	0,04	0,023	0,029	0,034	0,036	0,027	1,19	1,19	0	0	0	1
-47	13:54	384	504	140	134	-2709	253,9	1	-0,2	0,994	1,006	0,999	0,987	0,987	0,974	0,99	0,948	0,009	0,036	-0,021	0,005	0,038	0,032	0,025	0,017	1,18	1,18	0	0	0	1
-46	13:54	384	488	139	135	-2639	253,3	1,2	-0,2	0,937	0,916	0,903	0,964	1,047	1,06	1,072	1,024	0,009	-0,015	0,007	-0,003	0,021	0,021	0,04	0,032	1,18	1,18	0	0	0	1
-45	13:54	384	476	140	135	-2570	253,3	1,8	1,5	1,022	1,058	1,095	1,083	1,093	1,109	1,131	1,095	0,042	0,021	0,034	0,04	0,036	0,046	0,054	0,048	1,18	1,18	0	0	0	1
-44	13:54	320	464	139	135	-2501	253,6	1,8	1,3	1,09	1,081	1,067	1,049	1,044	1,031	1,04	0,999	0,04	0,027	0,003	0,009	0,052	0,046	0,052	0,034	1,17	1,18	0	0	0	1
-43	13:54	320	456	142	135	-2431	253,4	1,2	0,3	1,012	1,001	1,006	0,992	0,996	1,012	0,992	0,953	0,001	0,005	0,013	0,011	0,044	0,044	0,04	0,025	1,17	1,17	0	0	0	1
-42	13:54	320	448	139	135	-2362	253,2	0,8	-0,4	0,919	0,93	0,955	0,974	0,992	0,983	0,951	0,921	0,015	0,036	0,025	0,021	0,023	0,032	0,036	0,021	1,17	1,17	0	0	0	1
-41	13:54	320	436	138	135	-2292	253,1	0,9	0,5	0,909	0,916	0,935	0,948	0,928	0,903	0,875	0,88	0,04	0,021	-0,023	0,013	0,029	0,034	0,029	0,017	1,17	1,18	0	0	0	1
-40	13:54	320	424	137	135	-2223	252,8	1,4	0,8	0,907	0,939	0,978	1,015	1,047	1,047	1,063	1,038	0,011	-0,009	0,021	0,046	0,027	0,046	0,064	0,05	1,17	1,18	0	0	0	1
-39	13:54	320	408	138	135	-2153	252,9	2,1	0,4	1,079	1,09	1,095	1,09	1,079	1,049	1,038	1,015	0,029	-0,011	-0,003	-0,001	0,068	0,066	0,066	0,054	1,18	1,18	0	0	0	1
-38	13:54	256	400	140	136	-2084	252,6	1,8	0,5	1,028	0,978	0,957	0,96	0,983	1,031	1,047	1,033	0,023	0,013	0,013	-0,001	0,056	0,048	0,054	0,05	1,19	1,19	0	0	0	1
-37	13:54	256	384	137	136	-2014	252,7	1,6	0,2	1,017	1,006	0,987	0,978	0,955	0,957	0,964	0,985	0,003	0,019	0,009	0,011	0,05	0,05	0,05	0,048	1,2	1,2	0	0	0	1
-36	13:54	256	380	139	136	-1944	252,9	1,8	0,7	1,015	1,01	1,042	1,047	1,04	1,012	1,026	1,01	0,032	0,034	0,05	0,046	0,042	0,048	0,056	0,06	1,2	1,21	0	0	0	1
-35	13:54	256	372	137	136	-1874	252,8	1,6	0,6	1,017	1,008	1,035	1,047	1,031	0,992	1,006	1,006	0,005	0,021	0,029	0,021	0,052	0,064	0,07	0,064	1,21	1,21	0	0	0	1
-34	13:54	256	360	137	137	-1803	251,9	1,2	0,1	0,992	0,98	0,971	0,971	0,946	0,919	0,882	0,951	0,011	0,019	0,011	0,009	0,048	0,048	0,04	0,048	1,21	1,21	0	0	0	1
-33	13:54	192	340	140	137	-1733	251,1	1,2	-2,1	0,992	0,999	0,969	0,971	0,967	0,955	0,953	0,983	-0,007	0,001	0,009	0,009	0,054	0,04	0,032	0,042	1,2	1,21	0	0	0	1
-32	13:54	192	328	142	137	-1663	251,0	1,6	-1,1	0,96	0,957	0,98	0,994	1,035	1,088	1,095	1,159	0,009	0,013	0,021	0,044	0,034	0,038	0,04	0,07	1,2	1,2	0	0	0	1
-31	13:54	192	320	139	138	-1592	251,2	1,8	0,3	1,131	1,086	1,031	1,04	1,031	1,015	1,026	1,026	0,044	0,015	0,015	0,003	0,056	0,046	0,034	0,04	1,2	1,2	0	0	0	1
-30	13:54	192	304	142	138	-1521	251,0	1,4	-0,4	1,015	1,017	1,019	1,019	1,015	1,01	0,978	0,967	-0,003	0,015	0,007	0,017	0,034	0,034	0,021	0,027	1,19	1,19	0	0	0	1
-29	13:54	192	288	143	138	-1450	251,0	0,9	-1	0,96	0,992	0,987	0,983	0,985	0,962	0,962	0,957	0,017	-0,003	-0,023	0,036	0,038	0,025	0,021	0,025	1,19	1,19	0	0	0	1
-28	13:54	192	284	141	138	-1379	251,4	0,9	1,8	0,941	0,985	1,012	1,019	1,026	1,022	0,996	0,994	0,025	0,068	0,048	0,025	0,042	0,027	0,023	0,032	1,18	1,18	0	0	0	1
-27	13:54	128	272	141	138	-1308	251,4	0,4	0,1	0,994	0,983	0,957	0,948	0,951	0,96	0,941	0,916	0,015	0,011	0,013	-0,011	0,019	0,017	0,013	0,019	1,17	1,17	0	0	0	1
-26	13:54	128	260	139	138	-1237	251,0	0	-0,8	0,916	0,925	0,951	0,971	0,976	0,978	0,964	0,971	0,011	0,019	0,011	0,011	0,005	0,011	0,011	0,013	1,16	1,15	0	0	0	1
-25	13:54	128	244	142	138	-1166	251,2	-0,1	-1,2	0,994	0,978	1,001	1,008	1,038	0,996	0,99	0,996	0,017	0,007	0,001	0,015	0,007	0,009	0,007	0,013	1,15	1,13	0	0	0	1
-24	13:54	128	228	144	138	-1095	251,7	-0,2	1,7	1,008	1,003	1,022	1,003	0,999	0,976	0,96	0,944	0,038	0,048	0,048	0,003	-0,01	-0,01	-0,01	-0,01	1,13	1,11	0	0	0	1
-23	13:54	64	212	143	138	-1024	251,9	0,2	0,4	0,919	0,907	0,905	0,912	0,946	0,985	0,99	1,028	-0,013	-0,003	0,042	0,048	-0,02	-0,02	-0,02	-0,01	1,11	1,09	0	0	0	1
-22	13:54	64	200	144	138	-953	252,4	1,4	1,1	1,047	1,095	1,145	1,161	1,18	1,189	1,198	1,191	0,021	0,027	0,036	0,072	-0,01	0,001	0,009	0,015	1,1	1,08	0	0	0	1
-21	13:54	64	184	141	137	-882	252,8	1,5	1,4	1,141	1,127	1,095	1,083	1,04	0,996	0,987	0,951	0,015	0,025	0,038	0,007	0,023	-0	-0,01	-0,01	1,09	1,08	0	0	0	1
-20	13:54	64	172	142	137	-812	252,3	0,9	0,4	0,944	0,962	0,953	0,99	1,024	1,01	1,042	1,104	0,015	-0,005	0,034	0,027	-0,01	-0,02	-0,01	0,005	1,09	1,08	0	0	0	1
-19	13:54	64	164	146	136	-741	252,1	1,1	0	1,095	1,113	1,136	1,159	1,152	1,049	0,974	1,008	0,066	0,062	0,025	-0,005	0,009	0,009	-0,02	-0,02	1,09	1,07	0	0	0	1
-18	13:54	64	148	144	135	-672	251,5	0,7	2	1,003	1,006	0,987	0,944	0,957	0,944	0,941	0,944	0,017	0,076	0,064	0,052	-0,03	-0,03	-0,02	-0,03	1,09	1,07	0	0	0	1
-17	13:54	0	144	147	135	-602	251,1	0,5	1,5	0,971	0,953	0,946	0,941	0,955	0,907	0,843	0,85	0,023	0,003	-0,011	-0,046	-0,03	-0,03	-0,03	-0,04	1,1	1,07	0	0	0	1
-16	13:54	0	128	138	134	-533	250,0	0,6	2,6	0,861	0,834	0,854	0,854	0,852	0,88	0,916	0,919	-0,027	0,032	0,029	0,023	-0,04	-0,02	-0,02	-0,01	1,1	1,07	0	0	0	1
-15	13:54	0	112	137	133	-464	250,2	1,2	-0,7	0,951	0,974	0,967	0,971	0,98	1,017	1,012	1,008	0,021	0,011	0,017	0,042	-0	-0,01	0,007	0,015	1,11	1,08	0	0	0	1
-14	13:54	0	92	135	133	-396	250,6	1,8	1,3	1,028	1,038	1,056	1,054	1,072	1,111	1,077	1,067	0,056	0,052	0,036	0,038	0,023	0,023	0,042	0,036	1,13	1,12	0	0	0	1
-13	13:54	-64	80	138	133	-328	249,9	2	1,3	1,079	1,079	1,083	1,09	1,109	1,077	1,051	1,035	0,009	0,013	0,019	-0,005	0,046	0,056	0,064	0,05	1,17	1,16	0	0	0	1
-12	13:54	-64	68	137	133	-259	249,2	1,9	1,7	1,028	1,012	0,985	1,028	1,026	0,992	0,992	0,962	0,036	0,042	-0,007	-0,013	0,048	0,064	0,062	0,052	1,18	1,18	0	0	0	1
-11	13:54	-64	56	135	133	-191	248,8	1,6	-0,3	0,996	1,008	0,978	0,978	0,941	0,928	0,969	0,996	-0,007	-0,027	-0,009	0,019	0,054	0,056	0,046	0,064	1,19	1,19	0	0	0	1
-10	13:55	-64	40	135	133	-122	249,3	1,5	-0,1	1,04	0,994	0,98	0,953	0,946	0,932	0,939	0,967	0,054	0,001	0,025	0,025	0,052	0,052	0,048	0,06	1,19	1,19	0	0	0	1
-12	13:54	-64	68	137	133	-259	249,2	1,9	1,7	1,028	1,012	0,985	1,028	1,026	0,992	0,992	0,962	0,036	0,042	-0,007	-0,013	0,048	0,064	0,062	0,052	1,18	1,18	0	0	0	1
-11	13:54	-64	56	135	133	-191	248,8	1,6	-0,3	0,996	1,008	0,978	0,978	0,941	0,928	0,969	0,996	-0,007	-0,027	-0,009	0,019	0,054	0,056	0,046	0,064	1,19	1,19	0	0	0	1

tpo	GMT	ALTC	RALC	CAS	GSPD	Espacio (metros)	MHDG	PITCH	ROLL	VERG	VERA	VERB	VERC	VERD	VERE	VERF	VERH	LATG	LATA	LATB	LATC	LONG	LONA	LONB	LONC	EPR1	EPR2	RD1	RD2	VHF	AIR
-10	13:55	-64	40	135	133	-122	249,3	1,5	-0,1	1,04	0,994	0,98	0,953	0,946	0,932	0,939	0,967	0,054	0,001	0,025	0,025	0,052	0,052	0,048	0,06	1,19	1,19	0	0	0	1
-9	13:55	-64	24	135	134	-54 Thrshld	249,6	1,8	-0,6	0,98	0,99	1,012	1,031	1,035	1,047	1,063	1,106	0,023	0,025	0,021	0,032	0,058	0,062	0,06	0,082	1,19	1,19	0	0	0	1
-8	13:55	-128	16	134	134	15 Thrshld	249,2	2,5	-0,8	1,074	1,088	1,095	1,111	1,097	1,111	1,093	1,109	0,032	0,034	0,019	0,038	0,066	0,068	0,066	0,076	1,18	1,17	0	0	0	1
-7	13:55	-128	4	134	134	84	248,9	3,5	-1	1,088	1,074	1,083	1,104	1,106	1,111	1,109	1,145	0,023	0,015	0,021	0,029	0,07	0,062	0,066	0,091	1,17	1,16	0	0	0	1
-6	13:55	-128	0	135	134	153 Max pitch	248,5	4,9	-1,4	1,163	1,202	1,225	1,228	1,198	1,157	1,145	1,113	0,017	0,013	0,017	0,029	0,084	0,074	0,062	0,064	1,14	1,13	0	0	0	1
-5	13:55	-128	0	130	134	222 flare	248,6	4,7	-0,4	1,088	1,111	1,074	1,067	1,06	1,038	1,017	1,008	0,017	0,003	0,017	0,015	0,06	0,042	0,042	0,029	1,11	1,1	0	0	0	1
-4	13:55	-128	0	133	133	291	249,2	3,7	0,4	1,003	0,996	0,996	0,976	0,967	0,978	0,978	0,962	0,013	0,017	0,048	0,064	0,027	0,017	0,013	0,013	1,08	1,08	0	0	0	1
-3	13:55	-128	0	133	132	359	249,9	2,9	2,1	0,962	0,967	0,941	0,953	0,953	0,935	0,953	0,994	0,062	0,054	0,068	0,05	0,007	0,009	0,001	0,009	1,07	1,07	0	0	0	1
-2	13:55	-128	0	133	131	427	249,5	3	1,7	0,962	0,967	0,969	0,983	0,98	1,008	1,003	1,019	0,027	0,032	0,044	0,027	-0	0,011	0,007	0,023	1,07	1,07	0	0	0	1
-1	13:55	-128	0	132	130	494	248,5	4,1	1	1,022	1,028	1,042	1,056	1,191	1,248	1,058	0,999	0,019	0,027	0,046	0,011	0,029	0,032	-0	0,001	1,07	1,07	0	0	0	1
0	13:55	-128	-4	130	128	560 ground	247,8	3,4	-0,4	0,983	0,941	0,889	0,802	0,754	0,857	1,006	1,01	0,029	0,034	-0,093	-0,084	0,007	-0,02	-0,05	-0,12	1,07	1,06	0	0	0	0
1	13:55	-128	-4	124	126	625	247,3	2	1,7	1,244	1,317	1,312	1,109	0,937	0,843	0,841	0,88	-0,068	-0,023	-0,095	-0,074	-0,03	-0,06	-0,08	-0,11	1,07	1,07	0	0	0	0
2	13:55	-128	-4	121	124	690 revers	247,4	1,3	1,2	0,994	1,07	1,166	1,163	1,102	1,01	0,962	0,914	-0,025	-0,04	-0,066	0,038	-0,13	-0,17	-0,15	-0,17	1,08	1,07	1	1	0	0
3	13:55	-128	-4	120	120	753 shimmy	247,9	0,7	1,1	1,003	0,96	1,019	1,083	1,07	1,035	1,022	0,944	-0,064	-0,082	-0,04	0,097	-0,18	-0,19	-0,18	-0,21	1,08	1,07	1	1	0	0
4	13:55	-128	-4	117	117	814 shimmy	248,4	-0,2	1,1	1,111	0,951	1,033	0,935	1,031	1,058	1,09	1,035	-0,015	-0,129	-0,111	0,123	-0,21	-0,2	-0,19	-0,22	1,08	1,07	1	1	0	0
5	13:55	-128	-4	113	113	873 shimmy	248,6	0,3	1,1	1,028	0,916	0,974	0,992	0,877	0,74	0,697	0,877	0,007	-0,127	-0,072	-0,015	-0,22	-0,21	-0,21	-0,14	1,08	1,07	1	1	0	0
6	13:55	-128	-4	108	110	930 wing dwn	249,1	2,8	11,8	0,957	0,852	1,475	1,516	1,651	1,218	0,735	0,603	-0,125	0,172	-0,213	0,056	-0,12	-0,22	-0,15	-0,09	1,07	1,04	1	1	0	0
7	13:55	-128	-4	107	106	986	251,2	1,4	11,2	0,598	1,113	0,953	1,115	1,15	1,196	1,015	1,095	-0,182	-0,172	0,164	-0,038	-0,1	-0,05	-0,03	-0,1	1,06	1,05	1	1	0	0
8	13:55	-128	-4	106	103	1039	254,4	1,9	11,5	0,932	0,909	0,962	1,042	1,056	1,012	0,971	0,992	0,066	-0,013	-0,009	-0,08	-0,09	-0,07	-0,05	-0,08	1,05	1,05	1	1	0	0
9	13:55	-128	-4	103	100	1092	254,9	1,9	12	0,992	1,051	1,06	1,022	0,985	0,99	0,978	0,962	-0,027	-0,093	-0,127	-0,164	-0,33	-0,31	-0,3	-0,28	1,05	1,04	1	1	0	0
10	13:55	-128	-4	94	94	1141	249,2	1,8	11,8	0,946	0,999	1,106	1,12	0,962	0,813	0,774	0,852	-0,158	-0,381	-0,388	-0,388	-0,3	-0,34	-0,35	-0,19	1,04	1,04	1	1	0	0
11	13:55	-64	-4	93	87	1188	239,3	1,8	11,5	0,912	0,994	1,047	1,042	0,99	0,925	0,877	0,884	-0,477	-0,493	-0,491	-0,459	-0,1	-0,12	-0,15	-0,15	1,04	1,04	1	1	0	0
12	13:55	-64	-4	89	82	1232	233,4	1,7	12,1	0,871	0,866	0,962	0,96	1,001	0,967	0,875	0,905	-0,457	-0,451	-0,475	-0,41	-0,12	-0,12	-0,16	-0,14	1,04	1,04	1	1	0	0
13	13:55	-128	-4	72	78	1273 LH yaw	232,1	1,8	12,5	0,916	0,9	0,994	0,999	1,008	0,985	0,971	0,93	-0,43	-0,432	-0,388	-0,318	-0,11	-0,14	-0,24	-0,24	1,04	1,03	1	1	0	0
14	13:55	-128	-4	78	74	1312	234,9	1,7	12,7	0,937	0,971	0,951	0,951	0,967	0,99	0,99	0,994	-0,386	-0,192	-0,302	-0,18	-0,23	-0,27	-0,12	-0,12	1,04	1,03	1	1	0	0
15	13:55	-128	-4	73	69	1349	239,1	1,7	12,9	1,001	0,985	0,992	0,99	0,996	0,967	0,96	0,999	-0,219	-0,166	-0,115	-0,113	-0,1	-0,15	-0,11	-0,1	1,04	1,03	1	1	0	0
16	13:55	-128	-4	68	66	1383	244,9	1,6	12,7	1,012	1,024	1,088	1,07	0,969	0,994	0,962	1,028	-0,062	-0,074	-0,152	0,017	-0,14	-0,11	-0,12	-0,1	1,04	1,03	1	1	0	0
17	13:55	-128	-4	67	63	1416	250,3	1,3	11,6	1,159	1,09	1,012	0,971	0,919	0,957	0,985	1,111	-0,036	-0,066	-0,046	-0,034	-0,11	-0,13	-0,12	-0,1	1,04	1,03	1	1	0	0
18	13:55	-128	-4	63	61	1448	253,0	1,2	11,2	1,099	0,971	0,912	0,96	1,012	0,992	1,022	1,102	-0,038	-0,107	-0,005	-0,137	-0,14	-0,11	-0,14	-0,13	1,04	1,03	1	1	0	0
19	13:55	-128	-4	61	58	1479	253,5	1,2	11,8	0,994	1,024	0,976	1,024	1,118	1,051	0,96	0,994	0,005	-0,099	-0,139	-0,04	-0,13	-0,08	-0,13	-0,14	1,04	1,03	1	1	0	0
20	13:55	-128	-4	56	55	1508	252,3	1,1	11,9	1,067	1,06	0,939	0,903	0,967	1,056	0,983	0,946	-0,204	-0,05	-0,237	-0,141	-0,15	-0,12	-0,1	-0,14	1,04	1,03	1	1	0	0
21	13:55	-128	-4	57	52	1536	249,8	1,4	11,5	1,07	1,077	1,001	0,937	0,937	0,946	0,985	1,072	-0,272	-0,176	-0,268	-0,213	-0,16	-0,16	-0,12	-0,15	1,05	1,04	1	1	0	0
22	13:55	-128	-4	51	49	1562	246,7	1,6	11,2	1,044	1,024	0,948	0,919	0,941	1,056	1,047	0,971	-0,223	-0,237	-0,237	-0,2	-0,19	-0,15	-0,15	-0,16	1,06	1,05	1	1	0	0
23	13:55	-128	-4	49	45	1586	246,3	1,4	11,3	0,905	1,022	1,047	1,019	1,003	0,98	0,903	1,04	-0,227	-0,148	-0,192	-0,117	-0,2	-0,2	-0,15	-0,13	1,08	1,06	1	1	0	0
24	13:55	-128	-4	41	42	1608	250,4	1,8	10,8	1,12	1,063	0,941	0,914	0,996	1,06	1,086	0,976	-0,111	-0,054	-0,034	-0,032	-0,26	-0,21	-0,18	-0,15	1,11	1,09	1	1	0	0
25	13:55	-128	-4	38	37	1628	257,6	2	10,5	0,887	0,914	1,033	1,12	1,159	1,102	0,941	0,884	-0,015	0,017	-0,021	-0,001	-0,1	-0,14	-0,23	-0,15	1,15	1,13	1	1	0	0
26	13:55	-128	-4	34	33	1646 Max EPR	264,4	1	10,9	0,912	0,948	0,971	1,028	1,131	1,051	0,969	0,967	0,04	0,005	0,017	-0,003	-0,1	-0,13	-0,16	-0,13	1,18	1,13	1	1	0	0
27	13:55	-128	-4	33	30	1663	270,2	1,9	10,4	1,038	1,104	1,086	0,971	1,01	1,134	1,086	1,031	0,011	-0,007	-0,062	0,019	-0,13	-0,16	-0,14	-0,17	1,17	1,13	1	1	0	0
28	13:55	-128	-4	0	27	1677	274,8	1,6	10,6	1,044	0,974	0,983	0,983	1,06	1,051	0,928	1,001	-0,089	0,023	-0,056	-0,032	-0,17	-0,15	-0,08	-0,16	1,17	1,16	1	1	0	0
29	13:55	-128	-4	0	23	1690	279,0	1,1	10,4	1,063	1,017	0,974	0,971	1,022	1,006	0,969	1,003	-0,042	-0,048	-0,064	-0,05	-0,18	-0,11	-0,16	-0,17	1,16	1,14	1	1	0	0
30	13:55	-128	-4	384	20	1701	282,6	1,1	10,2	0,971	0,948	0,969	1,022	1,065	0,967	0,983	0,999	-0,064	-0,105	-0,093	-0,109	-0,16	-0,15	-0,16	-0,15	1,11	1,1	1	1	0	0
31	13:55	-128	-4	384	16	1710 No revers	284,9	1,1	10,4	1,026	0,994	0,957	0,974	0,946	0,964	0,98	0,978	-0,095	-0,107	-0,103	-0,154	-0,19	-0,13	-0,16	-0,17	1,08	1,08	1	1	0	0
32	13:55	-128	-4	384	12	1718 RH yaw	285,9	1,1	10,6	1,012	1,006	0,976	0,983	0,999	1,003	0,978	0,96	-0,113	-0,174	-0,117	-0,19	-0,17	-0,15	-0,15	-0,14	1,07	1,07	0	0	0	0
33	13:55	-128	-4	384	9	1723	286,4	1,1	10,9	0,967	0,987	0,996	1,042	1,022	0,964	0,909	0,941	-0,129	-0,164	-0,18	-0,16	-0,14	-0,14	-0,14	-0,1	1,06	1,06	0	0	0	0
34	13:55	-128	-4	0	6	1727	286,4	0,9	10,7	1,012	1,024	0,985	0,957	0,946	0,985	1,012	1,01	-0,162	-0,176	-0,188	-0,166	-0,12	-0,14	-0,13	-0,14	1,05	1,05	0	0	0	0
35	13:55	-128	-4	0	3	1729	285,4	0,8	10,5	0,953	0,953	0,992	1,006	1,008	0,976	0,964	0,996	-0,198	-0,164	-0,196	-0,172	-0,13	-0,15	-0,17	-0,18	1,05	1,05	0	0	1	0
36	13:55	-128	7564	0	0	1730 Halt	284,4	0,7	10,5	0,992	0,996	0,992	1,008	0,992	0,795	1,729	0,822	-0,2	-0,158	0,512	-1,055	-0,23	-0,17	0,05	-1,08	1,04	0	1	1	0	0

APPENDIX B
Drawing of Barcelona Airport

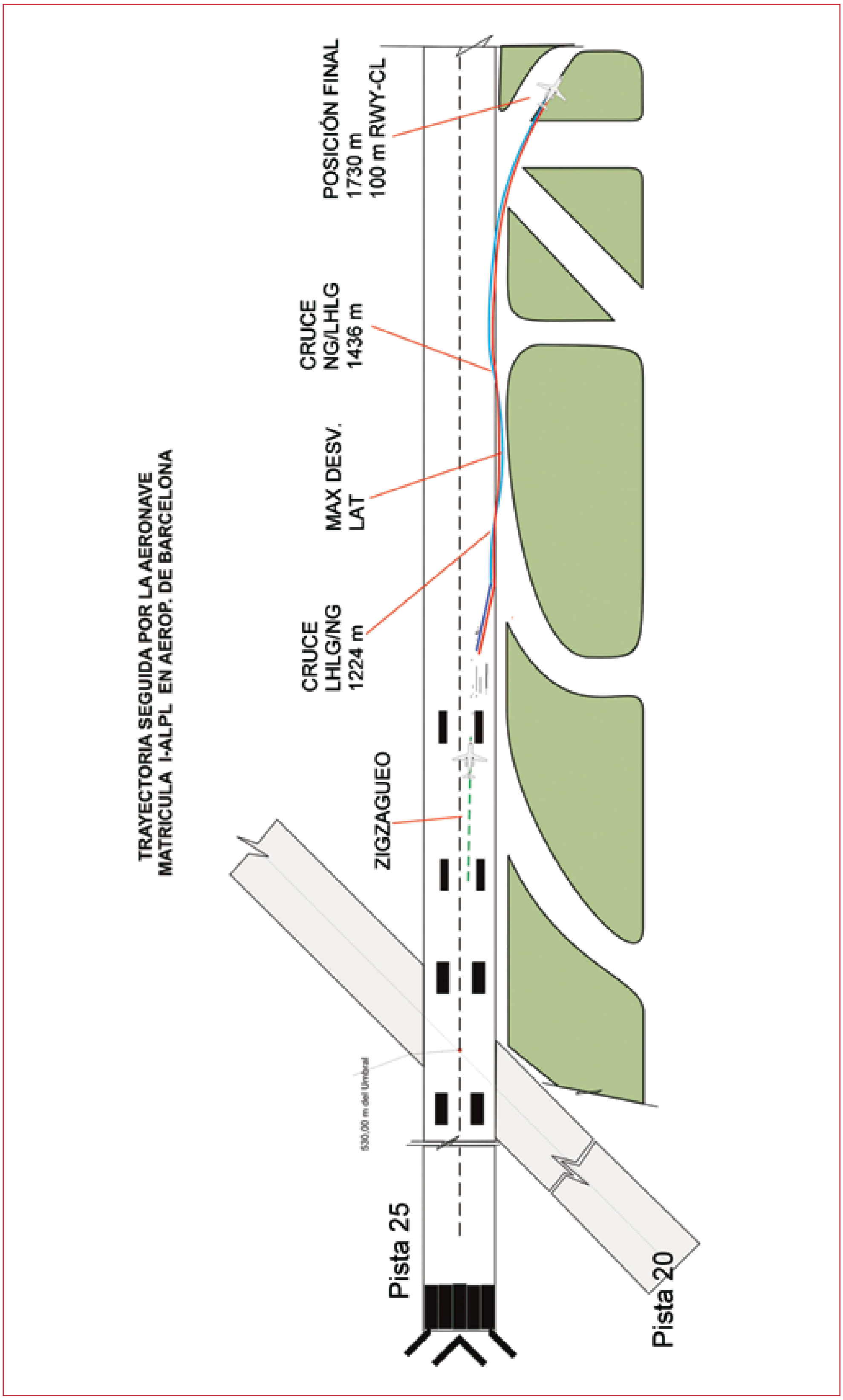

Diagram B.1. *Trajectory and tracks of the wheels in the landing run*

APPENDIX C
Drawing of the landing gear and diagram of the lines of cracks and fractures in the main fitting

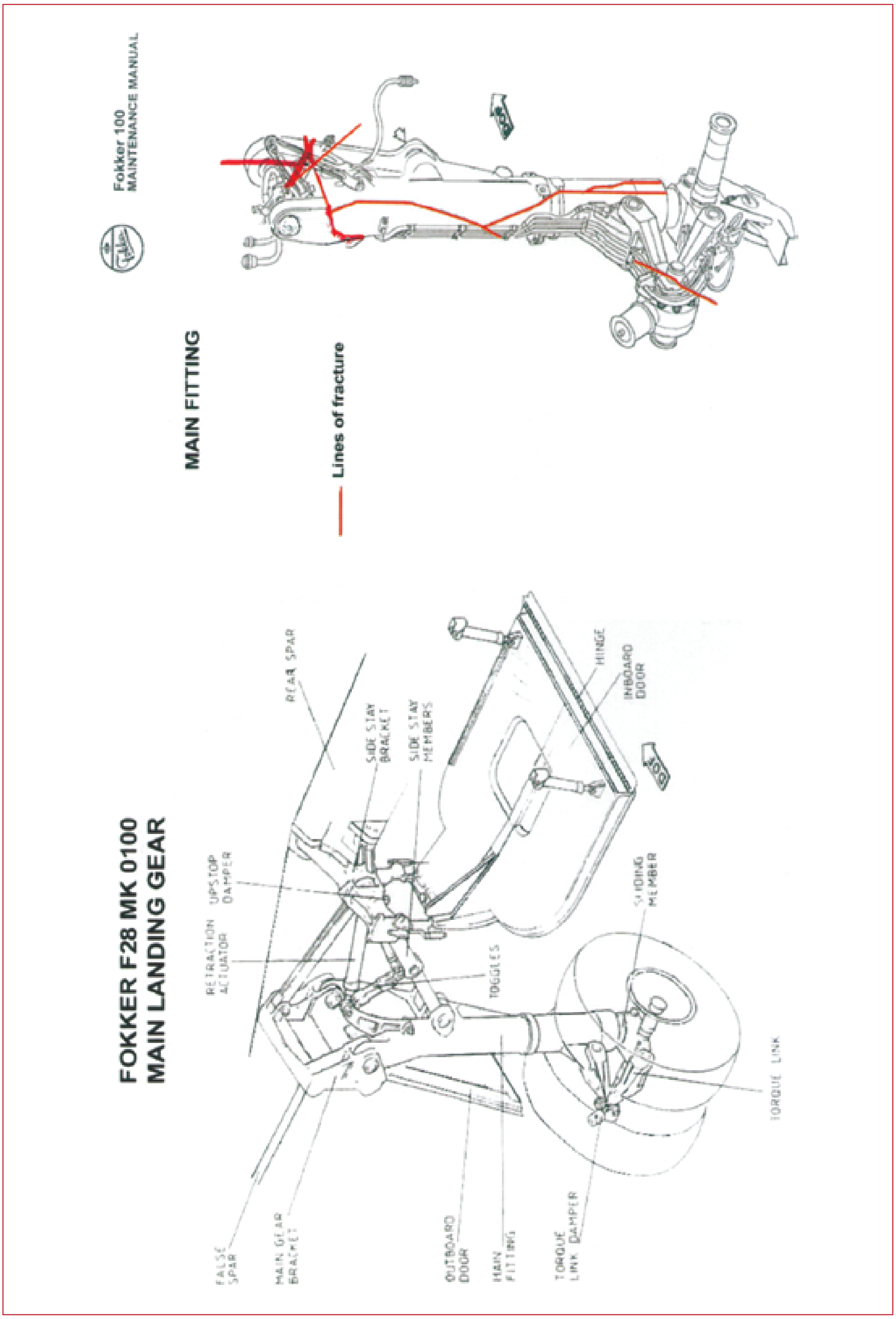

Figure C.1. *Left leg of main landing gear. The right-hand leg has the side stay fitted on the left-hand side of the leg. The fracture lines of the main fitting are marked in red*

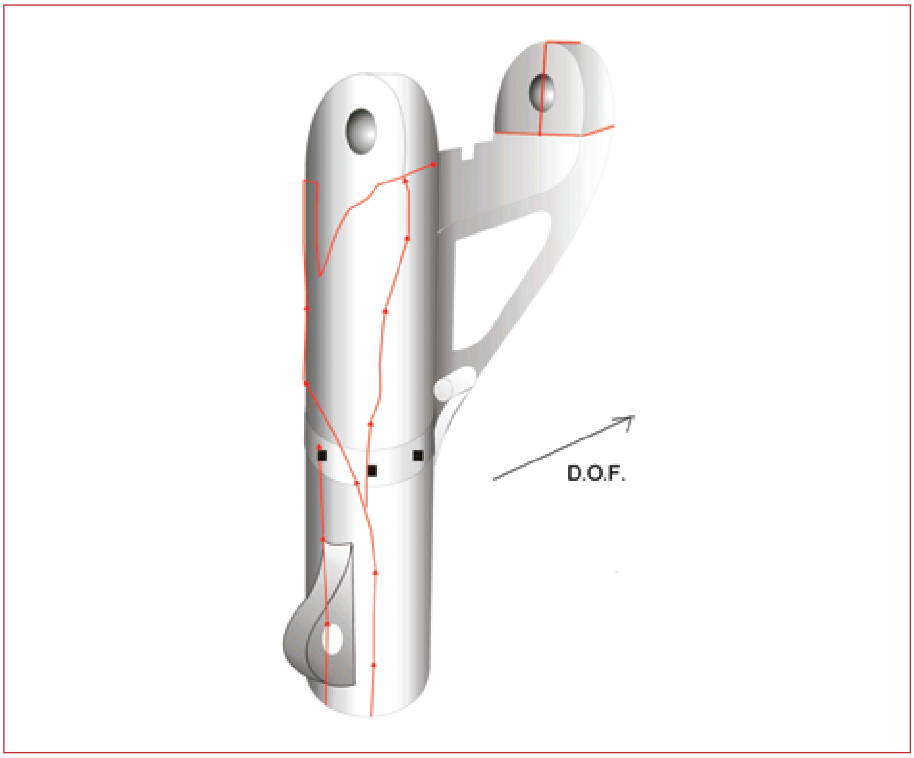

Figure C.2. *Extension lines of the cracks in the collapse of the right-hand main fitting*

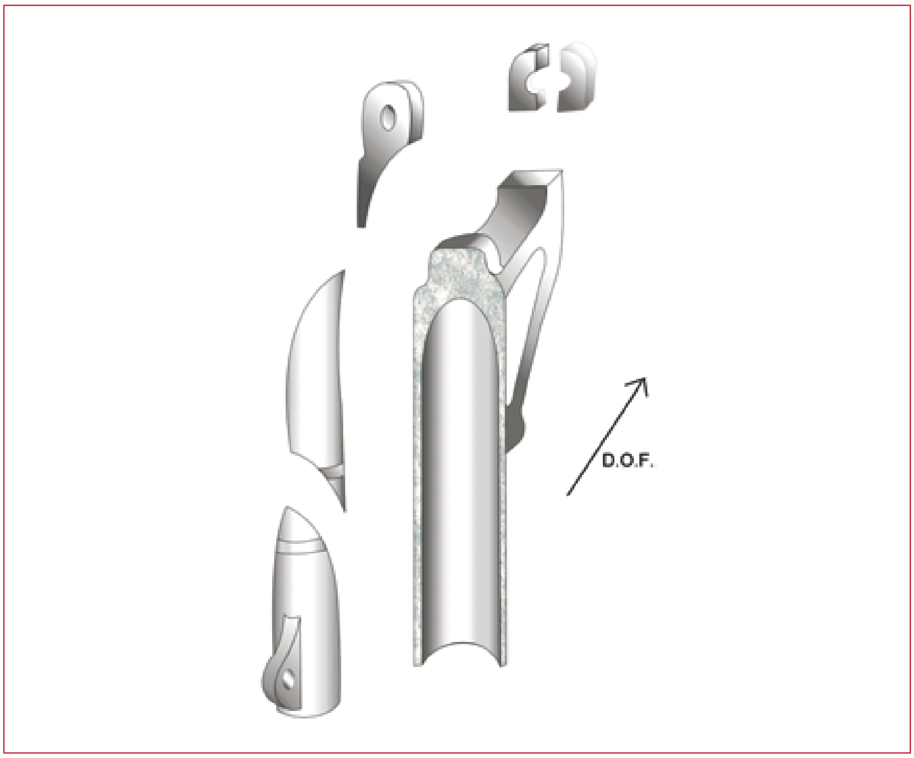

Figure C.3. *Principal fragments of the right-hand main fitting*

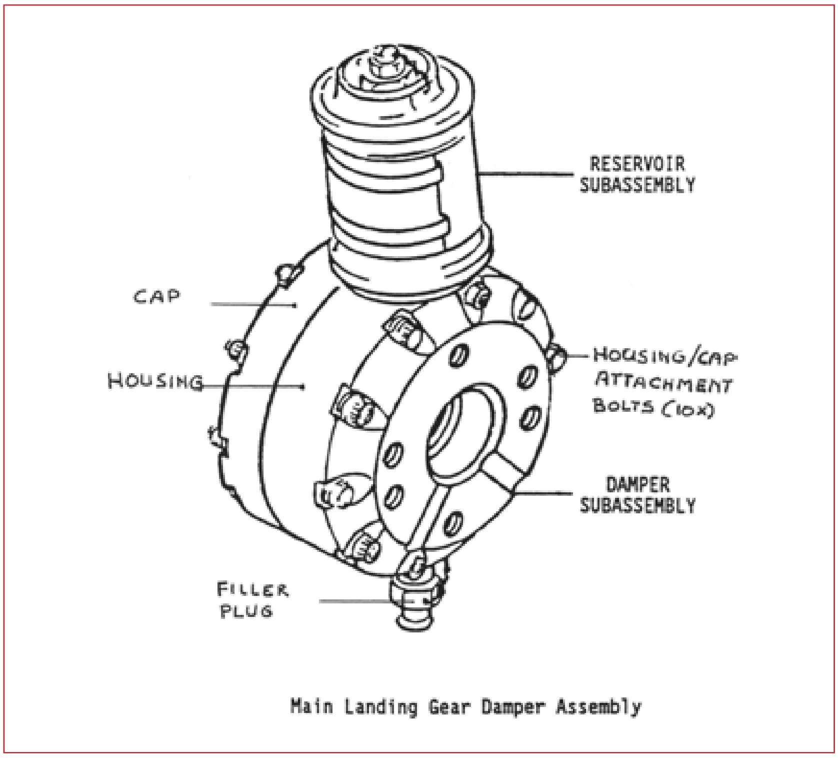

Figure C.4. *Shimmy damper*

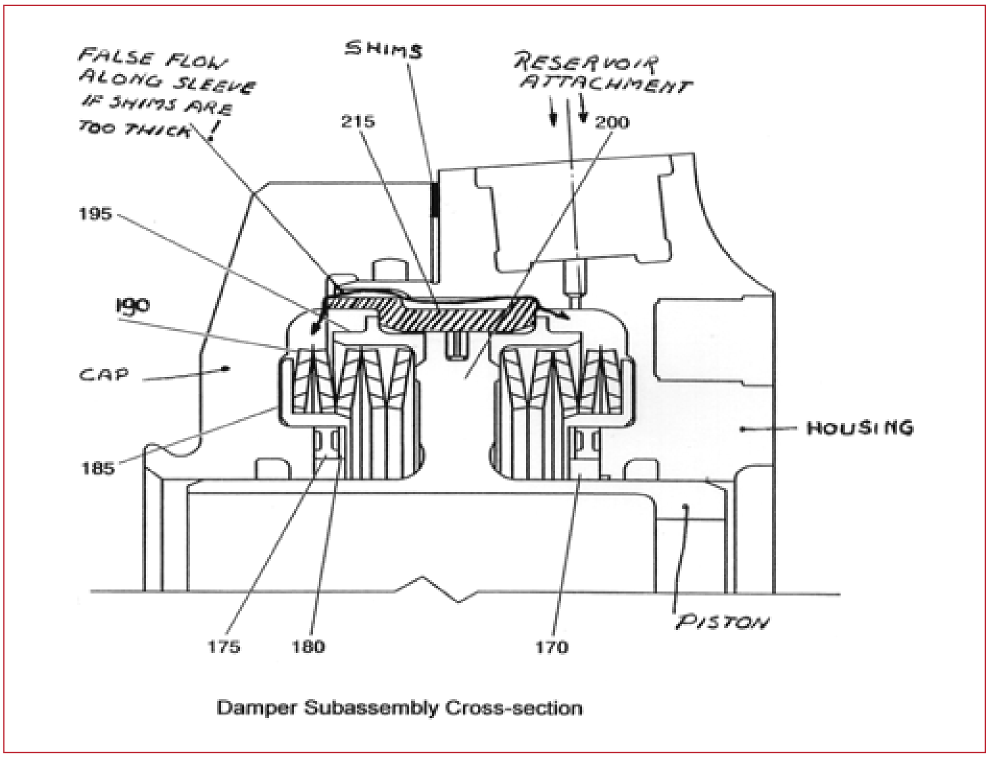

Figure C.5. *Cross-section of the damper (observe the shim pack and route of the false inner flow in the damper)*

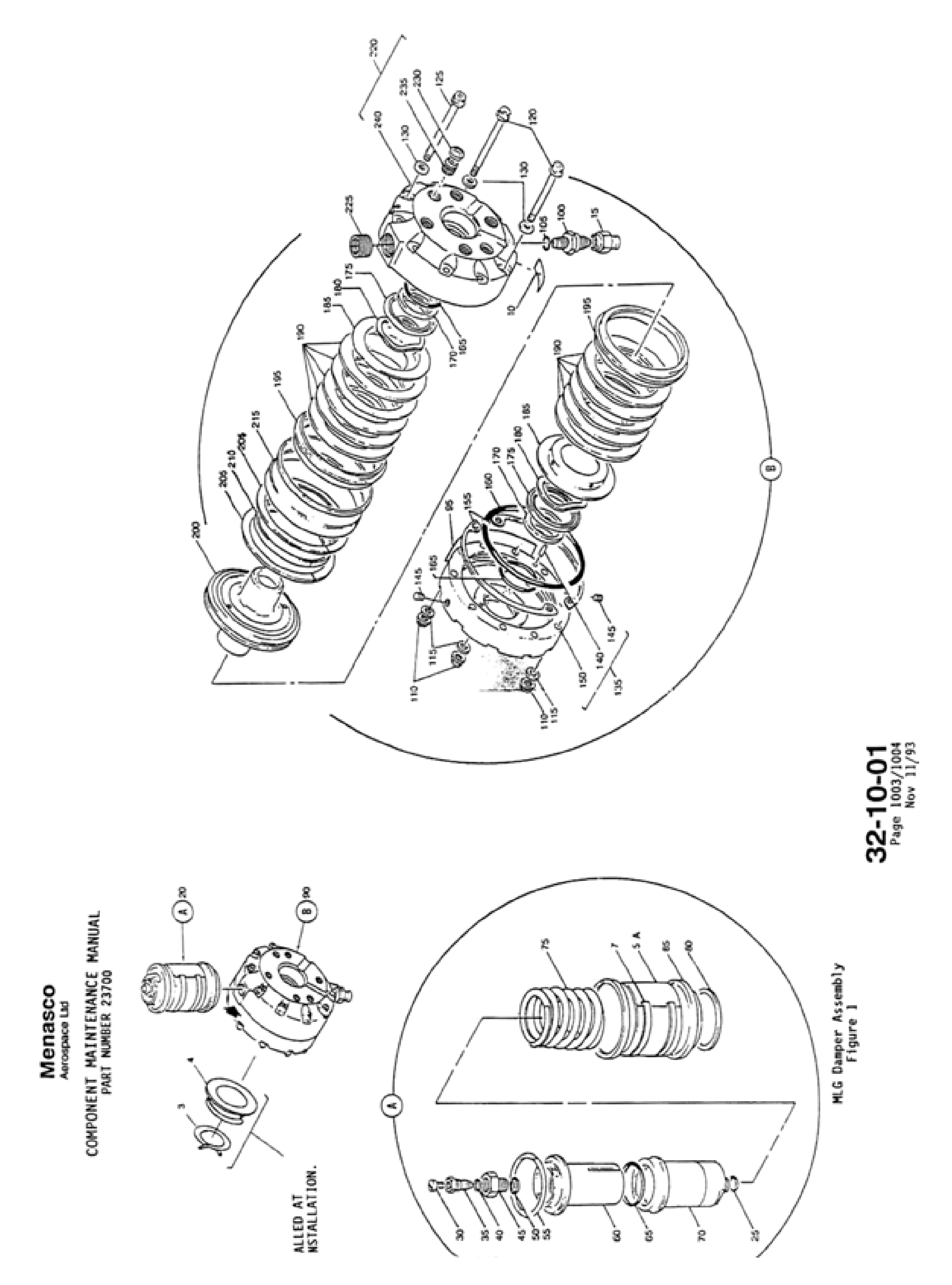

Figure C.6. *Exploded diagram of the shimmy damper*

APPENDIX D
Shimmy damping capacity in different conditions

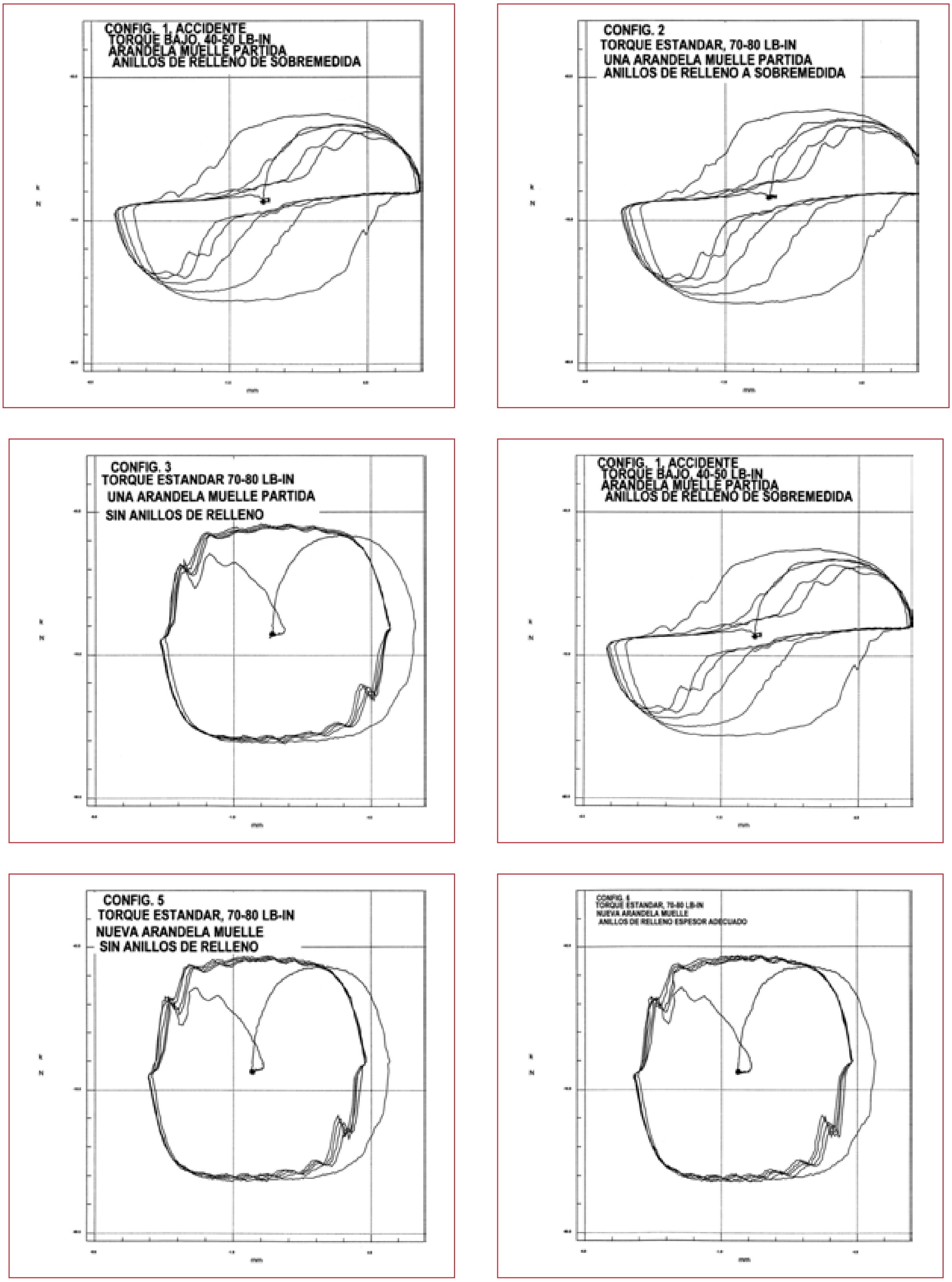

Figure D.1. *Comparison of the results of dynamic excitation tests on the shimmy damper s/n MAL176*