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Zusammenfassung/*Summary*:

Gulfstream G650 Aircraft Serial Number 6002 was destroyed in a take off accident. This report records the analysis of Engine Monitoring System (EMS) data recorded during this flight up to the accident and the conclusions drawn from it.

Conclusion:

Analysis of the available EMS Data from the last flight did not reveal any evidence of malfunction of the engines. Both engines followed the commands of the flight crew and behaved as intended.

Unterschrift/Signature:

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1 Introduction

Gulfstream G650 Aircraft Serial Number 6002 was destroyed in a take off accident during its flight Fx. This report records the analysis of Engine Monitoring System (EMS) data recorded during this up to the accident and the conclusions drawn from it.

2 Definitions and Abbreviations

AOA	Angle of Attack
AOS	Angle of Sideslip
BFU	Bundesstelle für Flugunfalluntersuchung – German Federal Bureau of Aircraft Accident Investigation
EHSV	Electro-Hydraulic Servo Valve
EMS	Engine Monitoring System
EPR	Engine Pressure Ratio – Primary Control Parameter for engine thrust
EPRCmd	Commanded EPR
FMV	Fuel Metering Valve
GAC	Gulfstream Aerospace Corporation
HP	High Pressure
LH	Left Hand
LHE	Left Hand Engine = Engine 1
LP	Low Pressure
MLG	Main Landing Gear
MTO	Maximum Take Off Thrust
NTSB	National Transportation Safety Board
P30	HP Compressor exit pressure
RH	Right Hand
RHE	Right Hand Engine = Engine 2
RRD	Rolls-Royce Deutschland Ltd & Co KG
TM	Telemetry
VSV	Variable Stator Vanes
WOW	Weight-On-Wheels

3 Analysis of EMS Data

3.1 Available Data – Basis of the Analysis

3.1.1 Explanation of Nomenclature “Flight Fx”

Gulfstream flight test uses a convention for the identification of Flight Test Data which consists of so called “Flight Numbers”. In this numbering convention a “Flight” does not necessarily consist of only one take off and landing but rather a of a set of experiments. The convention only requires to increment the flight number after both engines have been shut down.

For the purpose of this report, the last Flight is labeled “Fx”, the second last flight “F(x-1)” etc.

3.1.2 EMS Data

Recovery of the EMS Hard Disk allowed restoration of four EMS files, two per engine:

M123832Eng1.rdf
M123832Eng2.rdf
M190658Eng1.rdf
M190658Eng2.rdf

These files were transferred to RRD from the BFU under authority from the NTSB, for the restricted use by only those individuals explicitly authorised as part of the accident investigation team. The files contain EMS data from the beginning of Flight Fx up to just seconds before the aircraft made contact with the ground.

3.1.3 Telemetry Data

During Flight Fx, Aircraft 6002 was transmitting data via a telemetry system to a ground station. The last data was recorded by this ground station after the last data recovered from the EMS, hence the telemetry data was used to correlate the EMS data to the timeline of the accident

The National Transportation and Safety Board (NTSB) has provided a subset of this data to RRD for the purpose of supporting the investigation. The data file is named CEN11MA258_Data_Group_CSV_Export_PRELIMINARY.

3.1.9 Synchronisation of EMS- and Telemetry Data

Comparing the time when the EMS was recording transmission of an ARINC discrete to the time when the telemetry data indicates that the Aircraft has received it shows that the EMS time base was deviating from the telemetry data time base by less than one second.

3.2 Timeline of events

The table below gives a timeline of the events recorded in the EMS data from Flight Fx.

UTC	Time [s]	AbsTime [s]	Description of event	Comment
Date: 2011-04-02	**NTSB Data Group CSV Export**	**EMS Data**		
12:38:33.999	N/A	0	First sample in file M123832Eng1	95513.999s since midnight
12:38:35.209	N/A	0	First sample in file M123832Eng2	95515.209s since midnight
12:52:28.9		833.71	RH Engine Start initiation	Eng2 Time
12:53:99.3		915.32	LH Engine Start Initiation	Eng1 Time
13:17:15.7		2321.78	Weight Off Wheels –Take Off #1	Eng1 Time
13:20:38.7		2529.76	Weight On Wheels	Eng1 Time
13:29:06.2		2732.3	Weight Off Wheels – Take Off #2	Eng1 Time
13:33:09.6		3270.65	Weight On Wheels	Eng1 Time
13:97:31.6		9137.70	Weight Off Wheels – Take Off #3	Eng1 Time
13:50:09.7		9290.73	Weight On Wheels	Eng1 Time
13:52:97.2		9953.22	Weight Off Wheels – Take Off #9	Eng1 Time
13:56:00.5		9616.57	Weight On Wheels	Eng1 Time
19:06:51.263	N/A	5297.319	Last sample in file M123832Eng1	
19:06:52.375	N/A	5297.166	Last sample in file M123832Eng2	
19:06:58.339	N/A	0	First sample in file M190658Eng1	50818.339s since midnight
19:06:59.552	N/A	0	First sample in file M190658Eng2	50819.552s since midnight
19:08:52.6		113.01	Weight Off Wheels – Take Off #5	Eng2 Time
19:12:95:8		396.26	Weight On Wheels	Eng2 Time

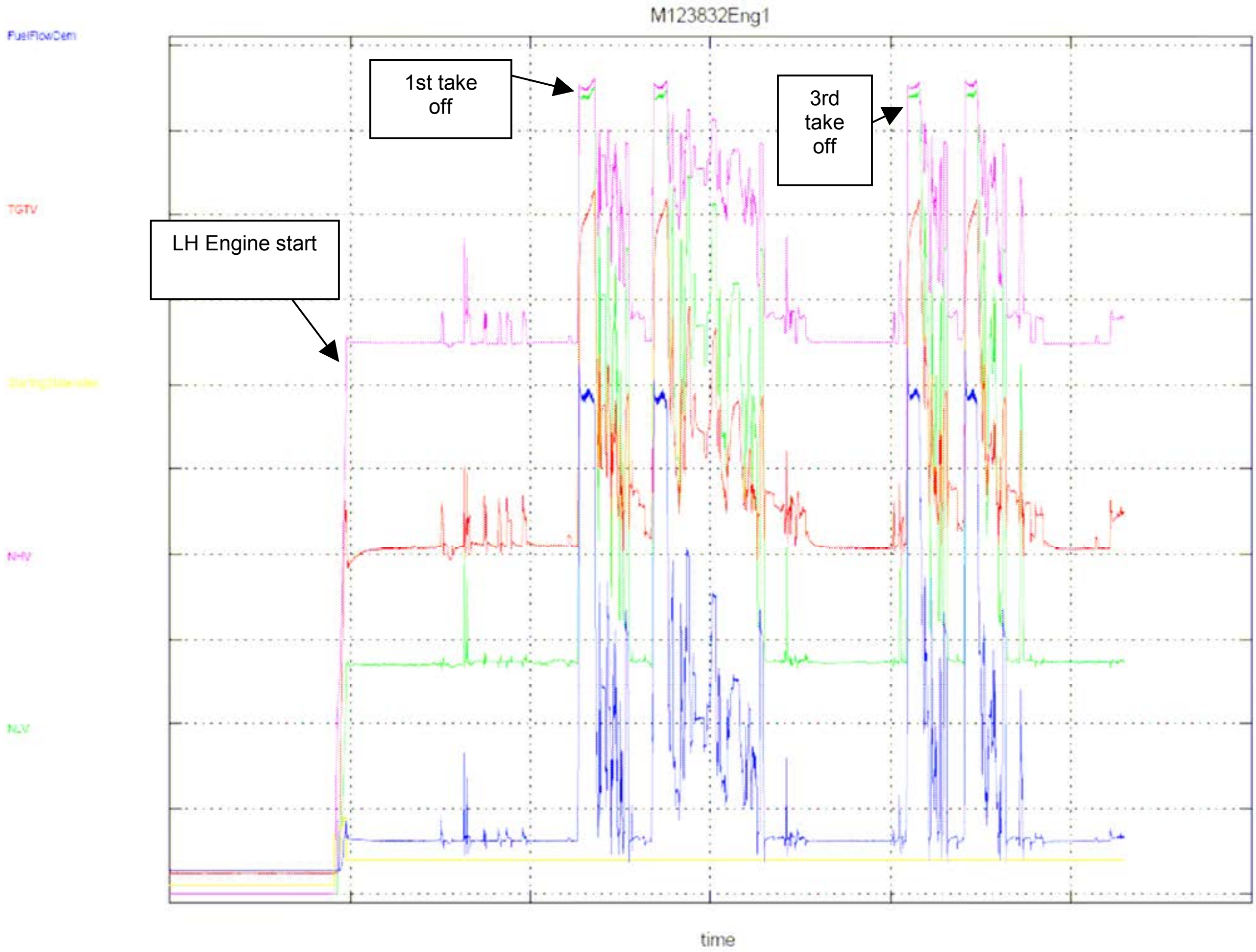
19:16:98.1		588.55	Weight Off Wheels – Take Off #6	Eng2 Time
19:29:22.1		1092.59	Weight On Wheels	Eng2 Time
19:28:03.9		1263.88	Weight Off Wheels – Take Off #7	Eng2 Time
19:31:18.7		1959.12	Weight On Wheels	Eng2 Time
19:92:51.2		2151.66	Weight Off Wheels – Take Off #8	Eng2 Time
19:95:57.0		2337.96	Weight On Wheels	Eng2 Time
15:12:52.9		3952.87	Weight Off Wheels – Take Off #9	Eng2 Time
15:15:92.1		9122.59	Weight On Wheels	Eng2 Time
15:19:55.7		9376.19	Weight Off Wheels – Take Off #10	Eng2 Time
15:22:30.1		9530.52	Weight On Wheels	Eng2 Time
15:26:25.1		9765.52	Weight Off Wheels – Take Off #11	Eng2 Time
15:30:93.5		9973.99	Weight On Wheels	Eng2 Time
15:25:00.0	0		Begin of NTSB TM-Data	
15:30:93.5		9973.99	Weight On Wheels	Eng2 Time
15:31:55.0	915.0		Both engines at reverse idle	
15:31:57.0	917.0		Both throttles moved to forward idle, engines decelerate from rev. idle to forward idle	
15:32:06.0	926.0		Both engines at stable forward idle	
15:32:29.5	999.5		Both throttles advanced to top end of throttle deadband	
15:32:56.2	976.2		Both throttles advanced to 10°	
15:32:59.2	979.2		Begin of throttle advancement (both)	
15:33:05.5	985.5		Both throttle positions above maximum thrust threshold	
15:33:06.8	986.8		Thrust of both engines reaches MTO EPR	
15:33:36.2	516.2		Begin of RH throttle chop – EPR command commences to fall	
15:33:36.7	516.7		RH throttle lever at idle	
15:33:96.9	526.9		Rotation	PITCH_IRS1_9 increases through 0°
15:33:97.1	527.1		Weight Off Nosewheel	
15:33:50.1	530.1		Weight Off left Main Landing Gear	
15:33:50.6	530.6		RHE reaches lowest idle speed	
15:33:50.7	530.7		RHE accelerates slightly to satisfy the increased minimum bleed pressure requirement in flight.	
15:33:50.0	N/A	5210.95	Weight Off Wheels in EMS Data – Take Off #12	Eng2 Time
15:33:50.8	530.8		Weight Off right MLG	
15:33:51.0	531.0		Aircraft rolls right wing down	
15:33:52.9	N/A	5219.589	End of EMS Data from LHE	Last sample in file M190658Eng1
15:33:53.3	533.3		Begin of RH throttle advancement	
15:33:53.5	533.5		RH EPR command exceeds EPR actual – engine begins to accelerate	
15:33:59.6	539.6		AOA second peak	AOS still close to zero
15:33:55.9	N/A	5215.872	End of EMS Data RHE	Last sample in file M190658Eng2
15:33:59.8	539.8		Weight On Right MLG	
15:39:00.0	590.0		Weight On Left MLG and Nose Wheel	

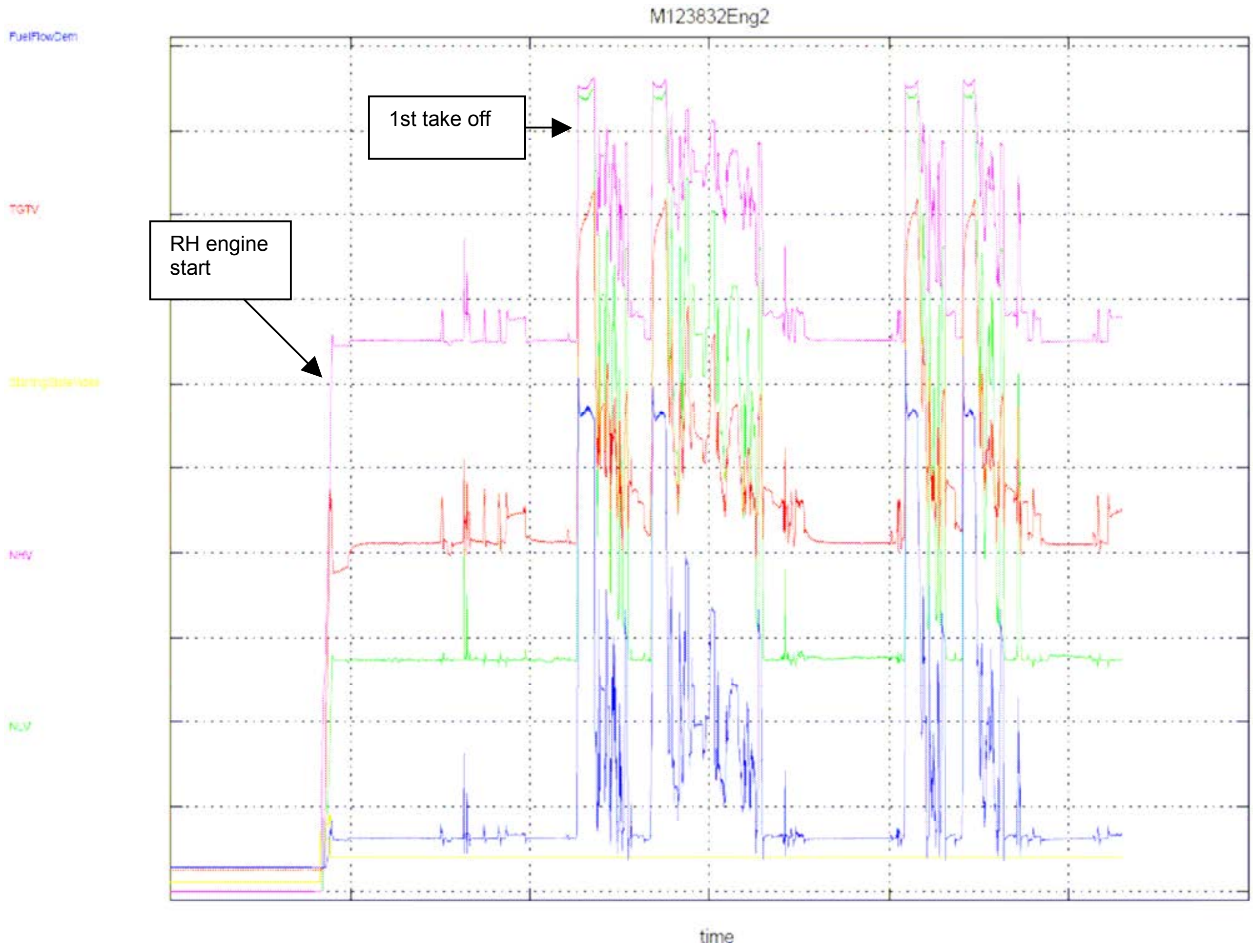
3.3 Graphical Overview of EMS Data

The plots shown in this section give a graphical overview of the events contained in the EMS data. The plotted parameters are:

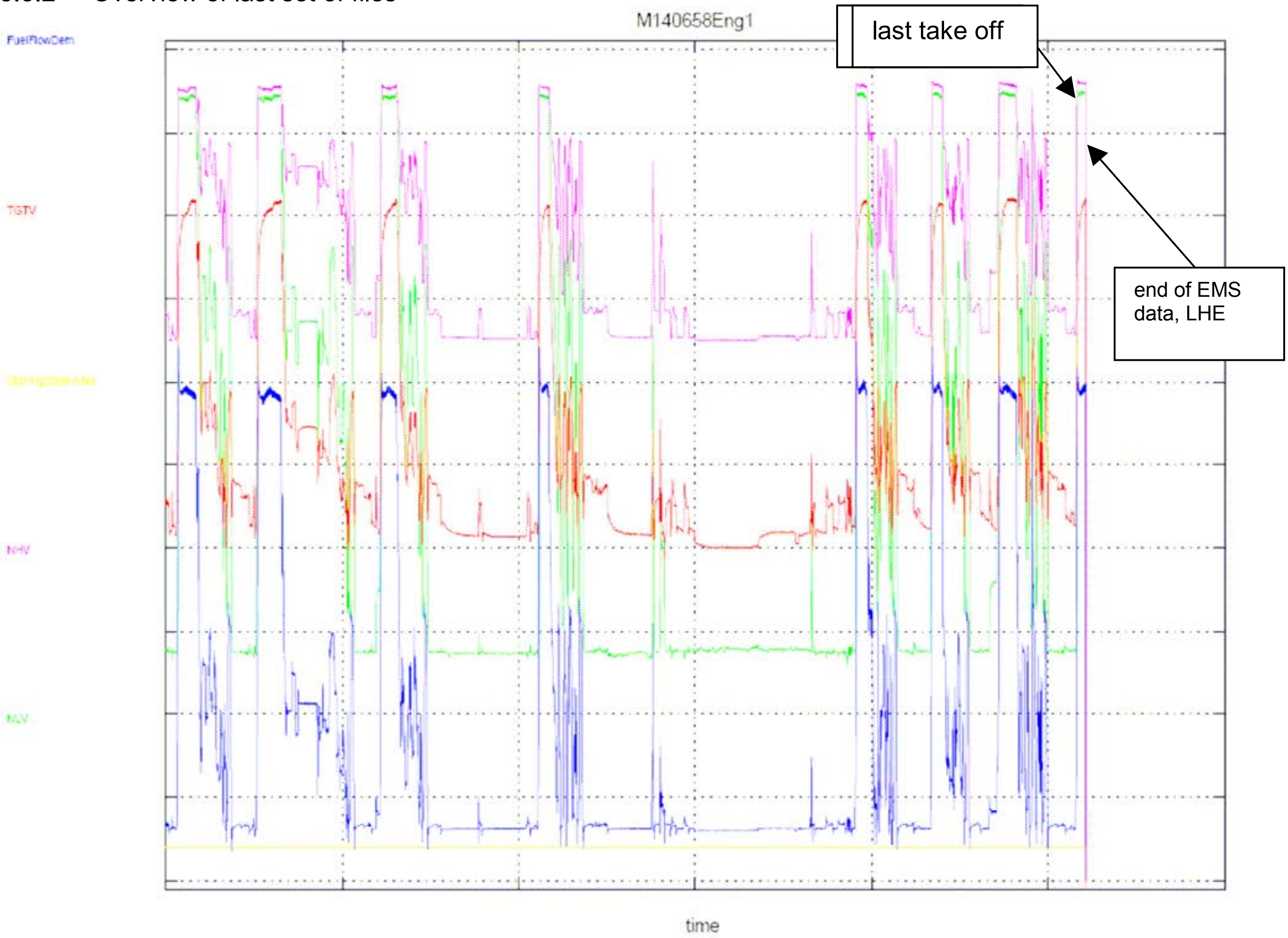
- FuelFlowDem: the fuel flow demanded by the EEC's control laws. The FMV position is controlled closed loop to realise this fuel flow.
- TGTV: Turbine Gas Temperature. Measured between the HP turbine and the LP turbine.
- StartingStateIndex: enumerated parameter indicating the active phase of the EEC state machine controlling engine starts and relights.
- NHV: High Pressure spool speed.
- NLV: Low Pressure spool speed.

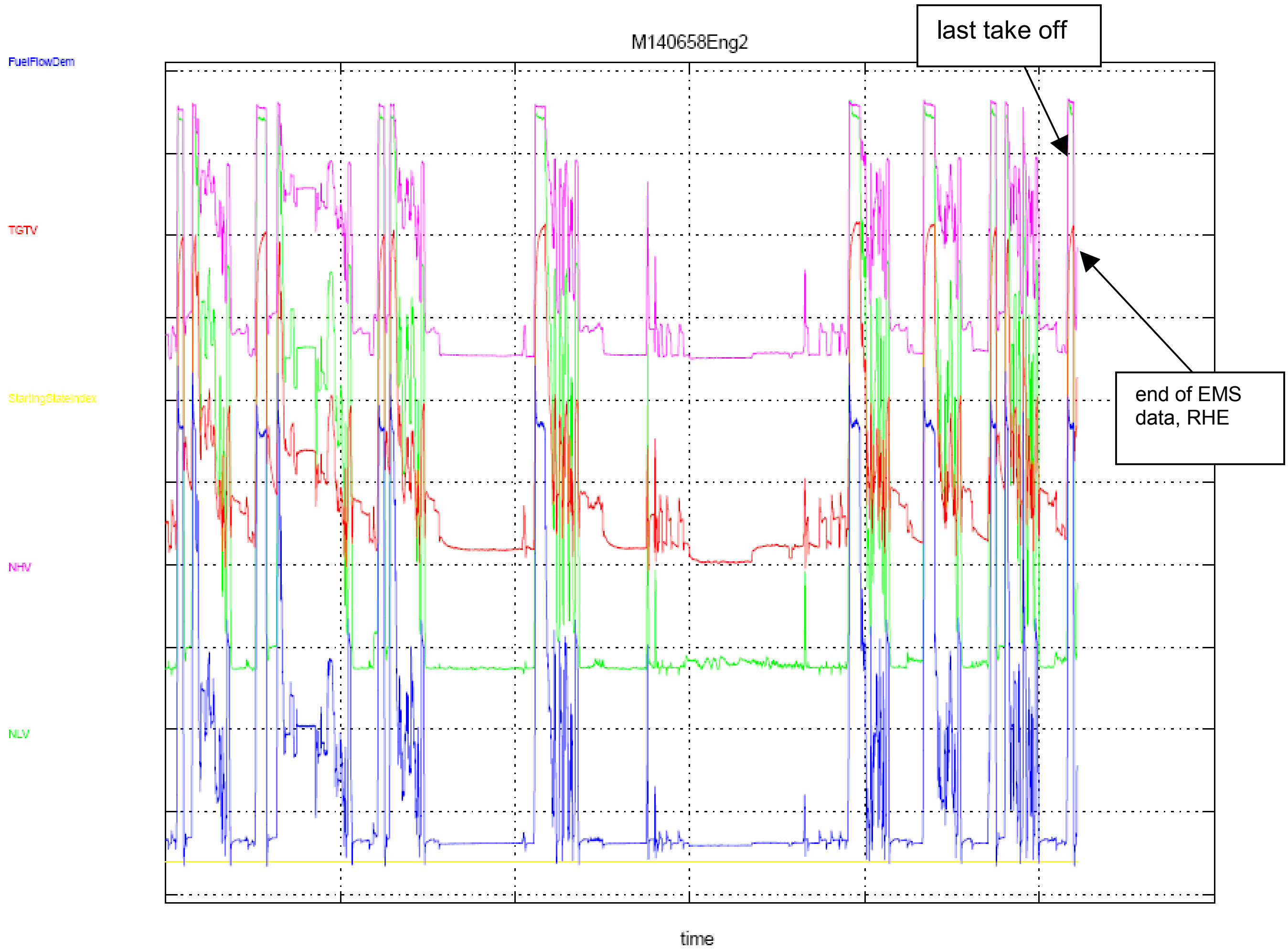
3.3.1 Overview of first set of files



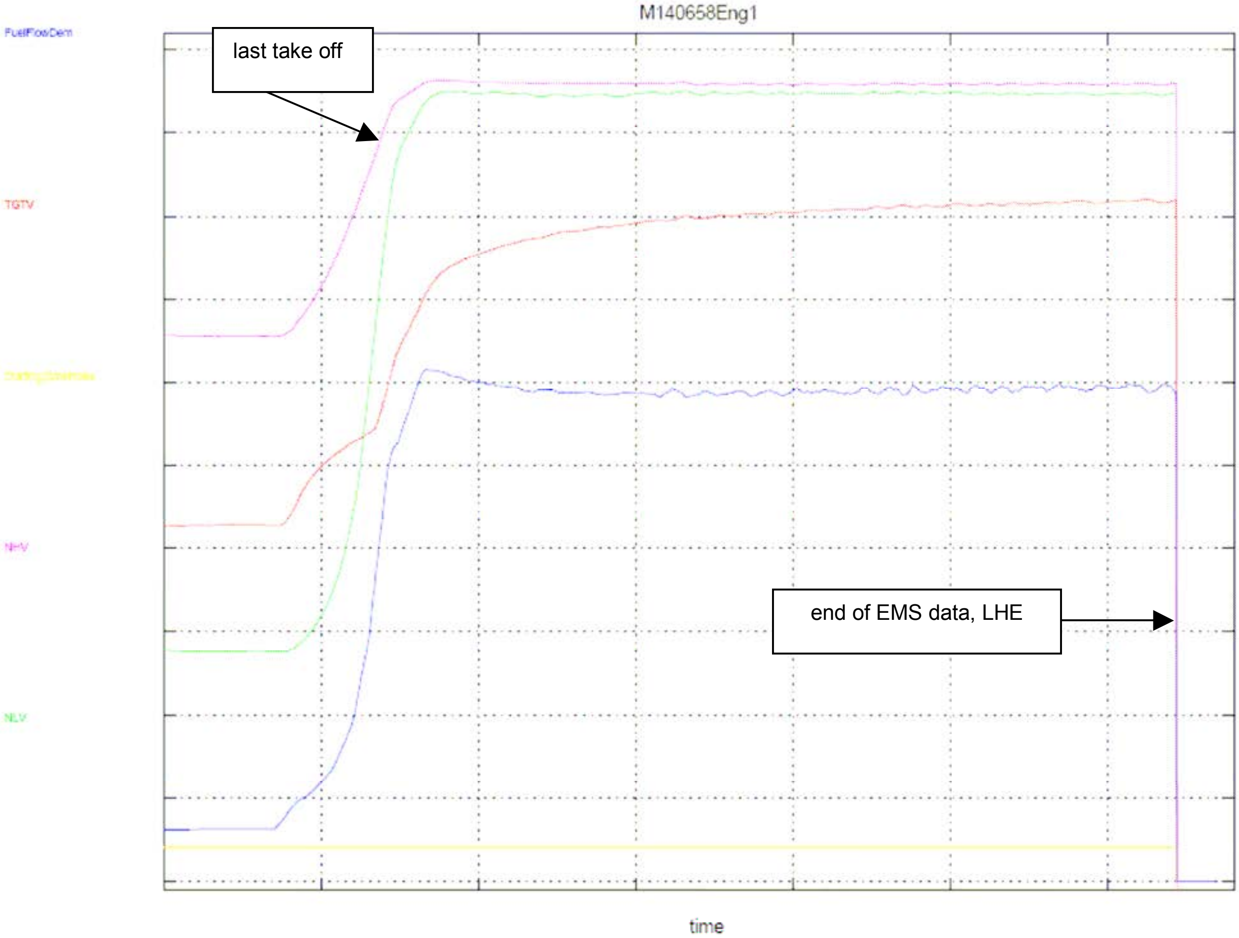

M123832Eng2
FuelFlowDem
TGTV
NHV
NLV
1st take off
RH engine start
time

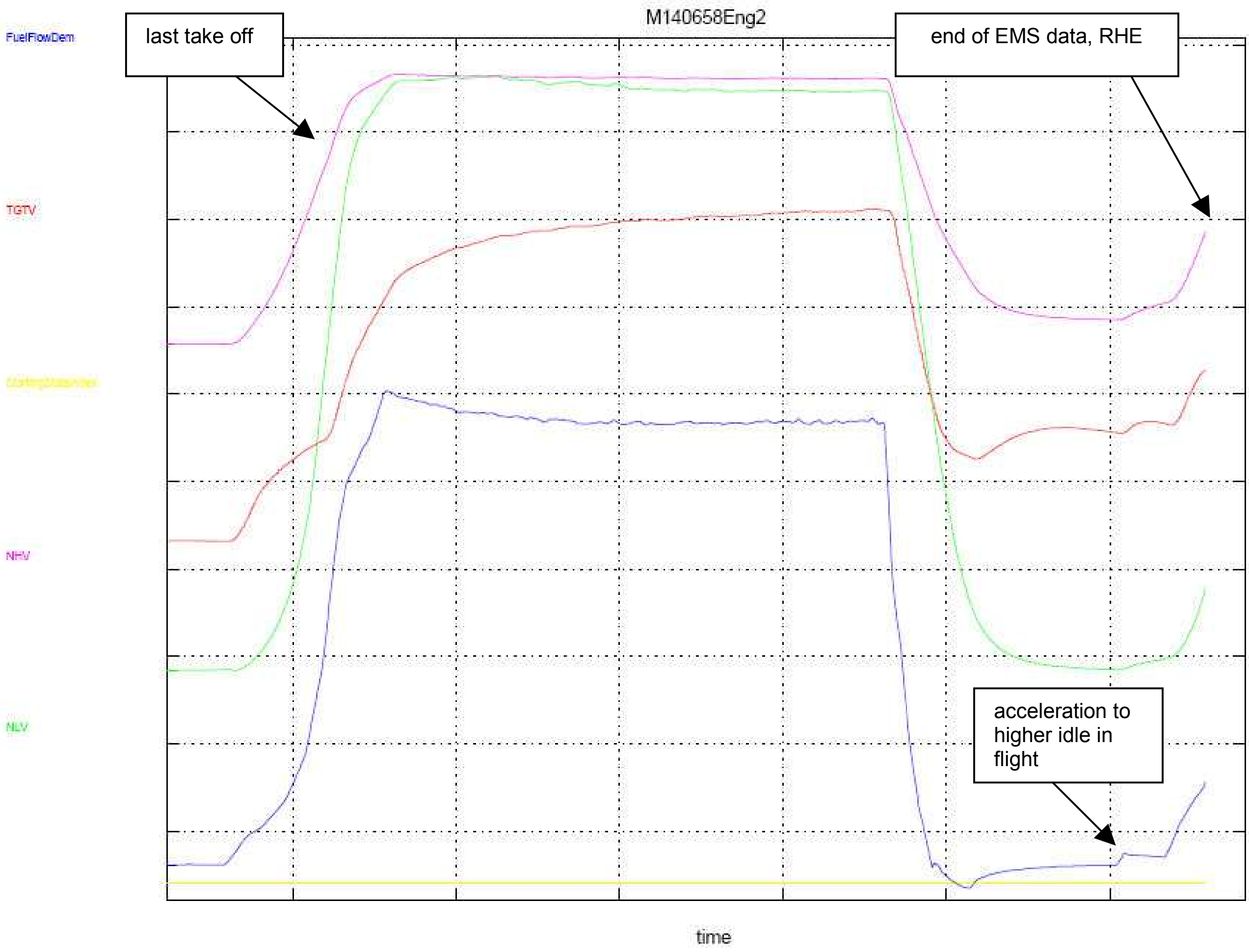
3.3.2 Overview of last set of files




M140658Eng2
last take off
end of EMS data, RHE
FuelFlowDem
TGTV
StartingStateIndex
NHV
NLV
time

3.3.3 Overview of the period from last take off to the end of EMS data




FuelFlowDem
TGTV
NHV
NLV
last take off
M140658Eng2
end of EMS data, RHE
acceleration to higher idle in flight
time

3.4 Analysis of EEC Status- and Maintenance Bits

The BR725 EEC sends discrete engine status information and fault messages to the aircraft on ARINC 929 buses. These “Status Bits” and “Maintenance Bits” are also recorded through the EMS and hence available in the available EMS files.

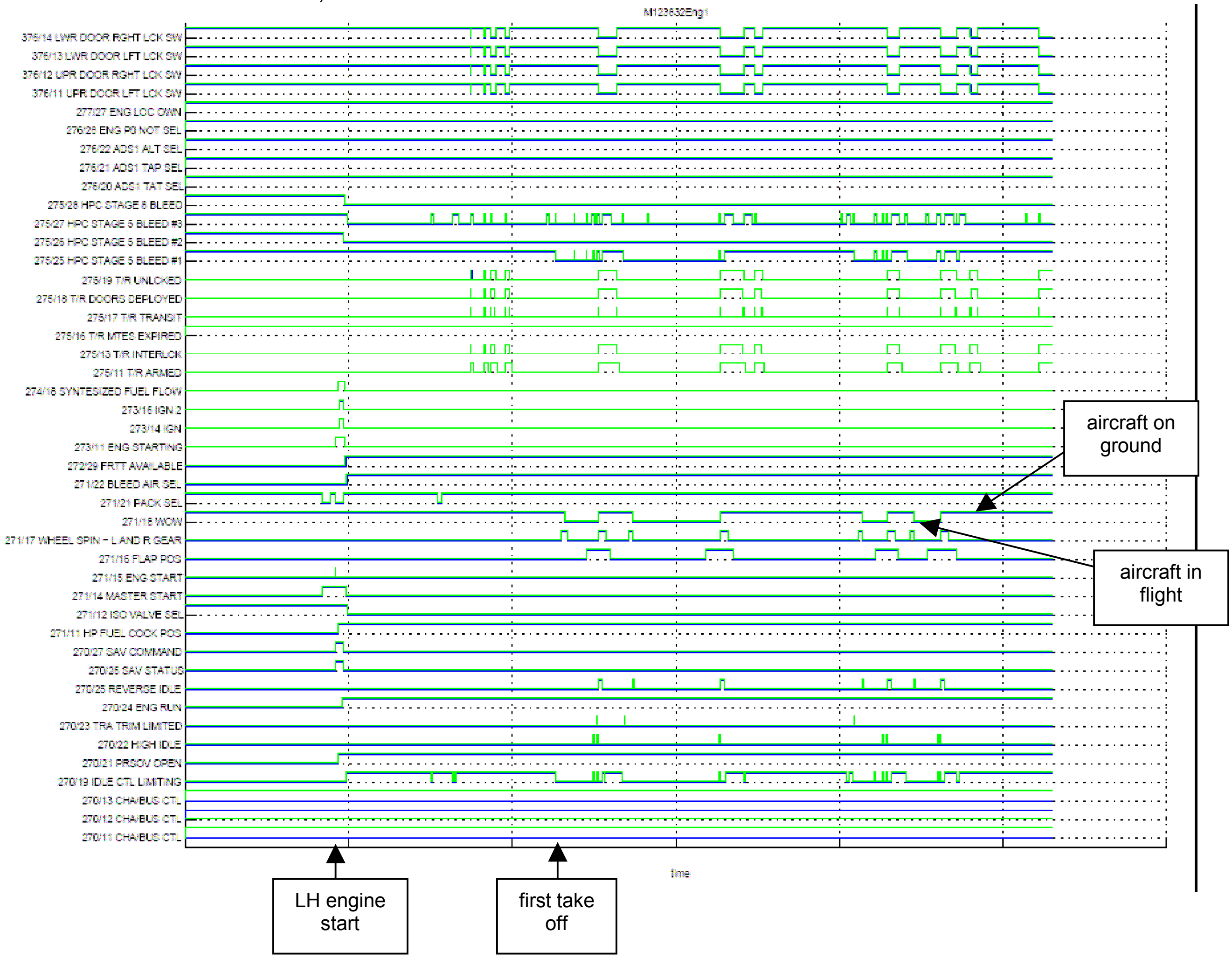
3.9.1 Status Bits

The status bits have been decoded and processed into a graphical representation. The resulting plots are included below. Out of the large number of status bits transmitted to the aircraft, these plots contain only those bits which were set to true at least once per data file. In other words, bits which were never set are omitted from the plots to increase clarity.

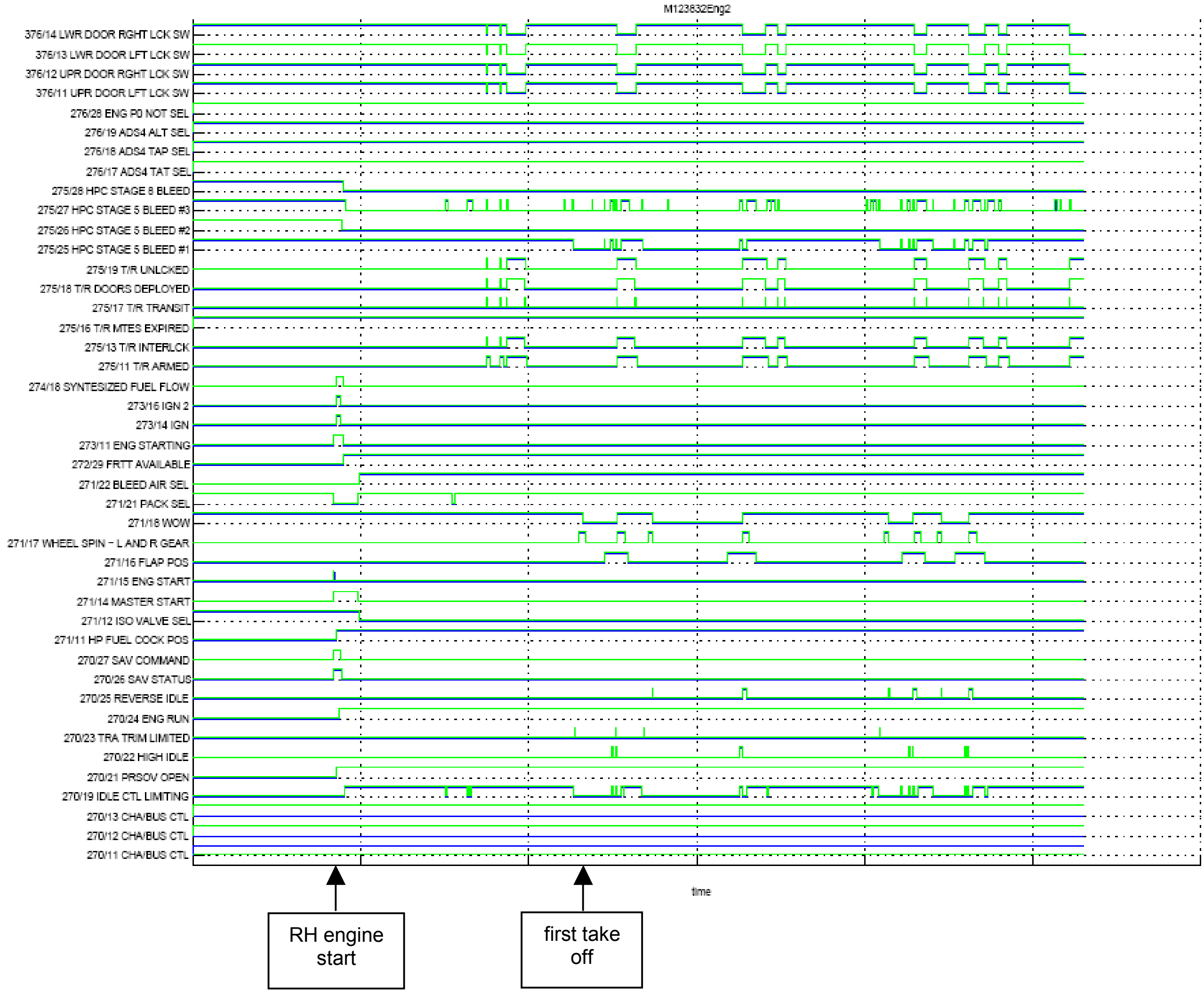
The outputs of both lanes of each EEC are represented as blue lines for the controlling lane and green lines for the non-controlling lane. The text-labels on the left side of the plots consist of the ARINC 929 label- and bit numbers in the form “label/bit” and a short descriptive text.

The Matlab-Scripts which have been used for this data processing have a legacy of 19 years and the current versions are in daily use by the BR725 Flight Test team. Consequently, they are deemed fully reliable and qualified for the purpose of this analysis.

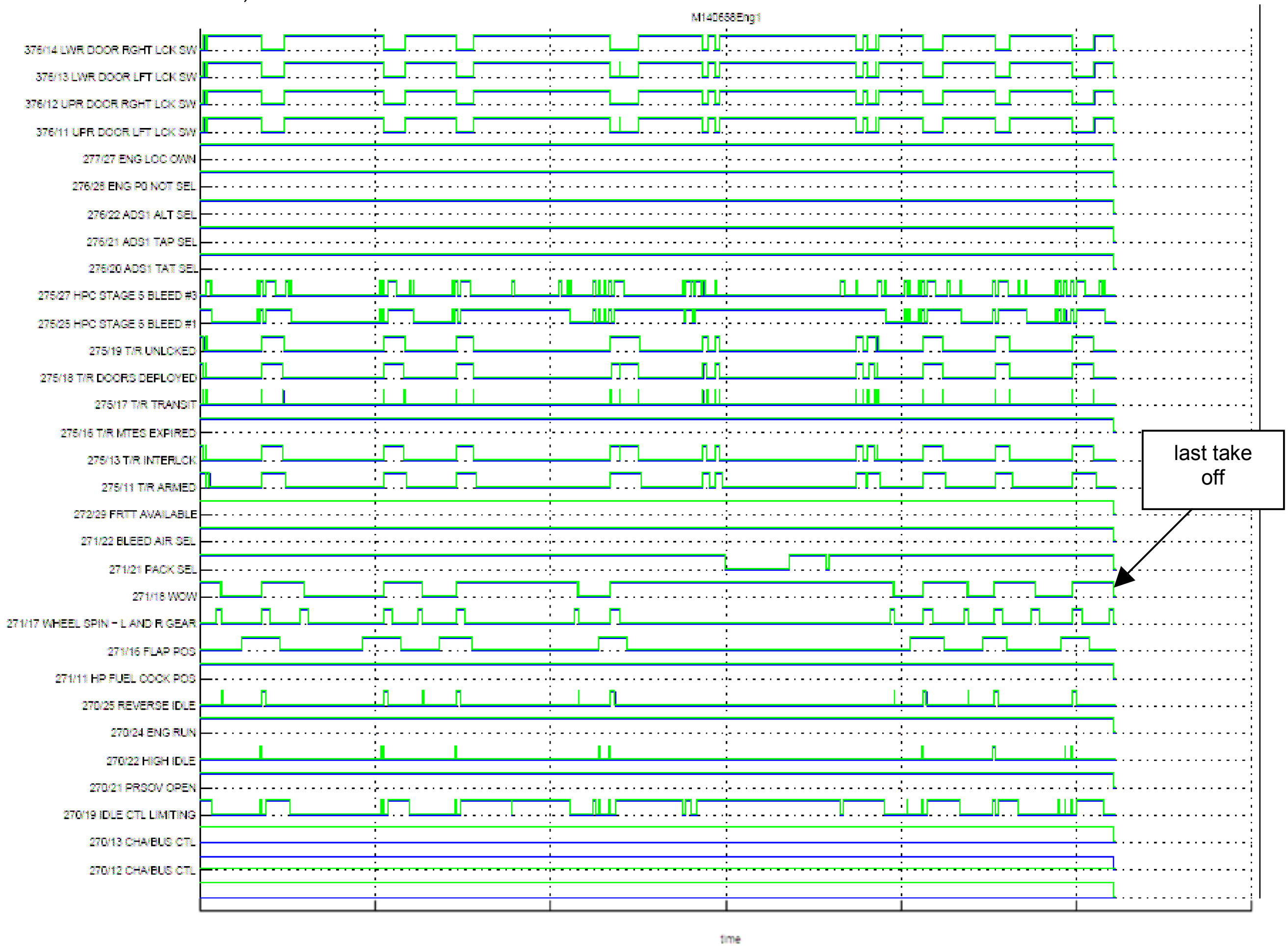
Status Bits from LHE, first File:



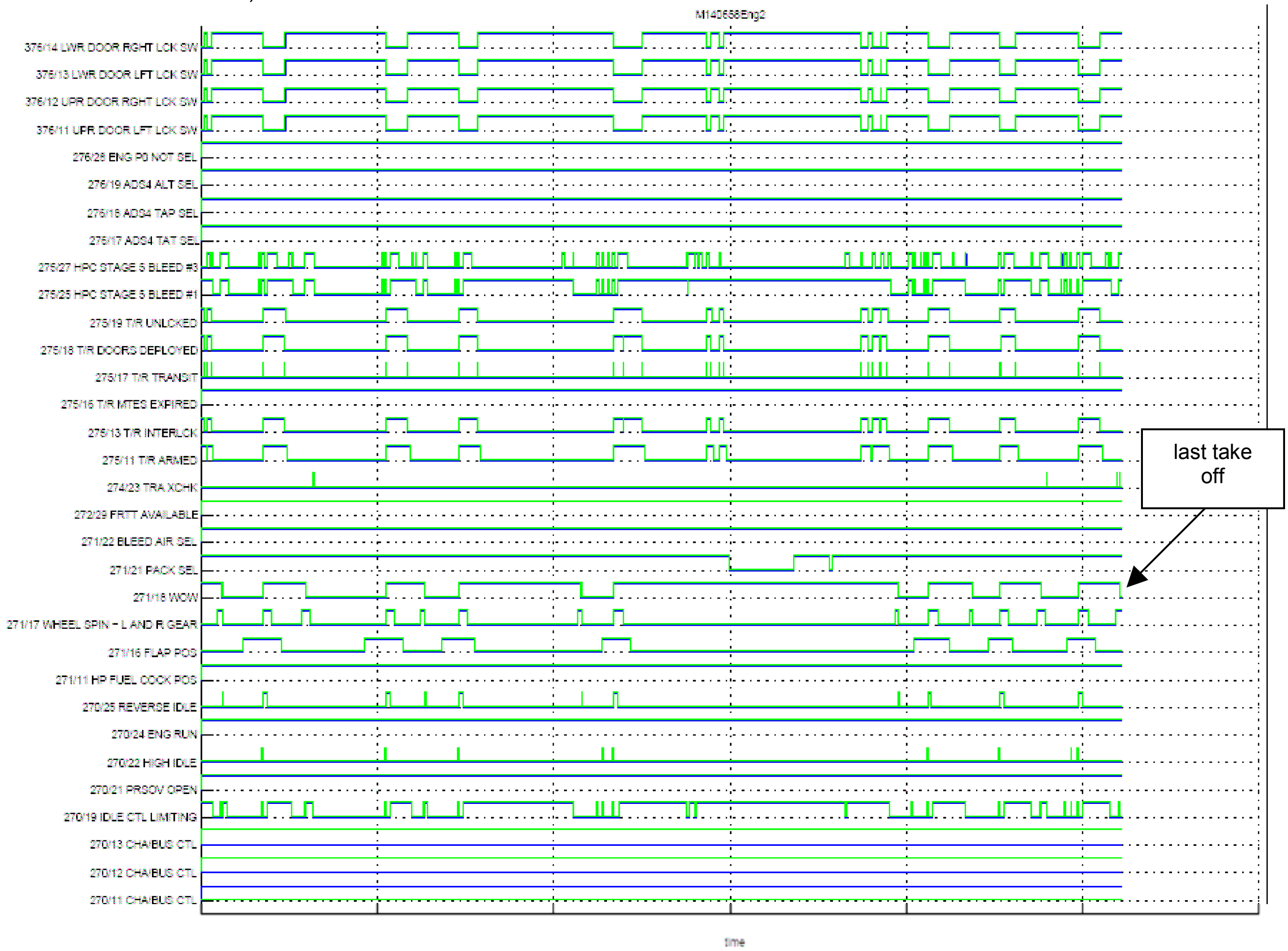
Status bits from RHE, first file:



Status Bits from LHE, second file:



Status Bits from RHE, second file:



<u>Conclusion:</u>

All of the bits which were set true report only normal system status. None of the bits which would report anomalies (for example a surge detection) were set true. This shows that the engines performed nominally throughout the period for which EMS data is available.

3.9.2 Maintenance Bits:

Not a single maintenance bit was set true throughout the period for which EMS data is available. This shows that the EECs did not detect any problems with the engines, the engines can be considered to have been perfectly healthy.

3.5 Analysis of Fuel Metering Unit Actuator Performance

The core components controlling engine performance are

- the Fuel Metering Valve (FMV), the position of which controls the amount of fuel being injected into the combustor
- the Variable Stator Vanes (VSV), the position of which control the perfomance of the high pressure compressor
- handling bleed valves – which are two position valves.

The EEC controls the FMV and VSV positions via fuel pressure electro-hydraulic servo valves (EHSV), whose first stage is a Torque Motor. The amount of Torque Motor current necessary to drive the valves to their commanded position is indicative of the health of the overall system.

Even minor changes to the above result in a shift of the torque motor current. The shift in torque motor current is noticeable in the analog data recorded by the EMS well before the fault detection thresholds of the EEC software are breached.

Consequently, the torque motor currents are useful indicators for fuel system health and allow detection of potential long term trends caused by deterioration. The torque motor currents in four key situations have been reviewed for three flights spanning a period of thirty flights, the results are listed below:

Flight	Filename	Engine	FMV Torque Motor	FMV Torque Motor	VSV Torque Motor	VSV Torque Motor
			low fuel flow holding current	high fuel flow holding current	steady state holding current	lowest transient current
Fx-31	M135020	LH	11mA .. 12mA	7.5mA	16mA	2mA
Fx-1	M125319	LH	11mA .. 12mA	7.5mA	16mA	1mA
Fx	M190658	LH	11mA .. 12mA	7.5mA	16mA	3mA
Fx-31	M135020	RH	10mA	9mA	13mA	0mA
Fx-1	M125319	RH	10mA	8mA	13mA	-1mA
Fx	M190658	RH	10mA	8mA	19mA	-1mA

Conclusion:

Individual engines differ in torque motor currents by several mA, this is a consequence of normal build tolerances. Here, the difference between LHE and RHE is far greater than any change between flights Fx-31 and Fx, evidence for the absence of deterioration and change to fuel system performance. Up to the end of available EMS data, the fuel systems of both engines performed normally.

3.6 Analysis of transient Engine Performance

3.6.1 Acceleration times during first and last take off during Flight Fx

	LHE	RHE
First Take Off	10.59s	10.19s
Last Take Off	10.85s	10.85s

The definition of acceleration time for this analysis is: period between commanded EPR exceeding actual EPR for the first time and actual EPR reaching commanded EPR for the first time during the acceleration.

Conclusion:

No significant change in acceleration time between the first and the last take off, the difference between LHE and RHE during the first take off is in the order of magnitude which is expected due to non-identical movements of the Throttle Levers and differences in the engine’s air data sources.

3.6.2 Fuel Control Loop transitions during engine acceleration for first and last takeoff in Fx

The fact that there is no change in the sequence of active control loops during the first and last takeoff indicates that the transient engine behaviour remained unchanged also.

4 Overall Conclusion

Analysis of the available EMS Data from flight Fx did not reveal any evidence of malfunction of the engines. Both engines followed the commands of the flight crew and behaved as intended.