Appendix 4 – Simulator Package

Table of Contents

1. Introduction

This document describes information and data developed for improving the realism of certain engine malfunction simulations. This work was undertaken as a follow-on to the AIA/AECMA report on Propulsion System Malfunction + Inappropriate Crew Response (PSM+ICR), published in 1998. This phase II work was sponsored and co-chaired by the ATA and FAA. Phase II activity consisted of Training Issues Group (TIG) and a Simulator Issues Group (SIG). The organizations involved in preparation and review of the material included regulatory authorities, accident investigation authorities, pilot associations, airline associations, airline operators, training companies, and airplane and engine manufacturers.

The Simulator Issues Group (SIG) subcommittee was formed to address the recommendations for simulators presented in the AIA/AECMA Project Report on Propulsion System Malfunction plus Inappropriate Crew Response (PSM+ICR). The report identified the following issues concerning simulators:

1. The simulator propulsion system malfunction models in many cases are inaccurate and/or do not have key cues of vibration and/or noise. There is also no robust process that ensures the quality and realism of simulator propulsion system malfunction models or that the malfunctions which are used in the training process are those most frequently encountered in service or those most commonly leading to inappropriate crew response.

2. The regulatory authorities should establish a means to ensure that the simulators used to support pilot training are equipped with the appropriate realistic propulsion system malfunctions for the purpose of "recognition and appropriate response training." To this end, the industry should develop specifications and standards for the simulation of propulsion system malfunctions.

This document is the end result of the SIG committee efforts.

2. Contributing Organizations and Individuals

Air Transport Association (ATA)	Jim McKee
Boeing Commercial Airplane Group (BCAG)	Bob Curnutt David Ernst John Lutch Wendell Miller Dennis Tilzey Walter Viebrock Van Winters
Delta Airlines (DAL)	Tim Hester Steve Sage Capt. John Sciera David Stewart
FAA/NSP	Ann Azevedo (FAA) Ed Cook (NSP) Karen Curtis (FAA)
General Electric (GE)	Dr. Sarah Knife
Northwest Airlines (NWA)	Antony Hunt David James Duane Sebens
Pratt & Whitney (P&W)	Dick Parker Bob Valli Charles Wright III
United Airlines (UAL)	Chuck Ferrari Steve Ferro Jason Hartmann Erwin Washington
US Airways (US)	Ron Thomas
US Department of Transportation	Judith Burki-Cohen
Others	Capt. Kip Caudrey (CAE/FSI) Dr. Hayrani Oz (Purdue)

3. Work Scope Definition

3.1 Training Group

The Training Issues Group, consisting mainly of pilots, engine manufacturers, and regulatory authorities; recommended a number of malfunction types for special emphasis for recognition training. These malfunction types were recommended as a result of a detailed analysis of 79[1] recorded serious incidents and accidents. It was found that the five types that were recommended (see Table 1 below) covered 91% of the recorded events and were therefore the highest priority for training value. The Training Group then produced a Propulsion System Malfunction Recognition document and video to supplement the training for these types of events.

3.2 Simulator Group

The Simulator Issues Group looked to the Training Issues Group to identify the malfunctions to be prioritized for Propulsion System Malfunction Training. The Simulator Issues Group's goal was to produce a document to address these malfunctions containing the following information:

1. Representative data for common propulsion system malfunction engine parameter display behavior and also the effects/cues of vibration, sound, and kinematics for which enhancements are deemed necessary.
2. Define generic tuning parameters to adequately represent engine parameter display behavior, vibration, sound, and kinematics.
3. Discussion of other simulator malfunctions currently in use which may lead to negative training concerning recognition of propulsion system malfunctions (i.e. blown tire malfunctions)

The scope of this document was to include data and tuning effects for high bypass ratio engines only.

1. AIA/AECMA Project Report on Propulsion System Malfunction Plus Inappropriate Crew Response (PSM+ICR), Volume 2, 1 November 1998.

Table 1:

	PROBLEM FLIGHT PHASE	SYMPTOM	ICR	Desired Immediate Response	Next Response	Failure Mode	TRAINING ACTION
SURGE	***TAKEOFF < V1***	LOUD BANG (usually 1 or 2). N1/N2 drop, EGT increase, AIRCRAFT VIBRATION, YAW	68, 57 Shutting down good engine 54, 29 unsuccessful RTO 35, Not Completing checklist, 81 Continuing takeoff, shutting down wrong engine	RTO	Contact Maintenance	SURGE, NON-RECOVERABLE SEVERE DAMAGE	SIMULATE LOUD NOISE, SUDDEN AIRCRAFT SHUDDER, FLUCTUATION OF ENGINE PARAMETERS N1 & N2 & EPR DECREASE WHILE EGT INCREASES. TRAIN TO REJECT THE TAKEOFF
SURGE	***TAKEOFF>V1*** ***INITIAL CLIMB*** ***CRUISE*** ***GO AROUND***	LOUD BANG. (repetitive) N1/1n2 drop, EGT increase, AIRCRAFT VIBRATION. POSSIBLE YAW	8, 12, 14, 17, 28, 38 RTO 47 not stabilizing flight path 51, 58 not intervening to throttle back on dual engine event 69, 70, 72 throttle good engine. 42, 53, 71 shutting down good engine 2 Inability to identify engine involved	Continue Take-off, climb, go around to safe altitude	Accomplish stall/surge checklist	SURGE, RECOVERABLE, W/PILOT INTERVENTION	SIMULATE LOUD NOISE, SUDDEN AIRCRAFT SHUDDER, FLUCTUATION OF ENGINE PARAMETERS N1, N2, & EPR DECREASING, EGT INCREASING, TRAIN TO KEEP CONTROL OF THE AIRCRAFT, CONTINUE TAKEOFF/GO AROUND, CLIMB TO A SAFE ALTITUE THEN THROTTLE BACK TO CLEAR SURGES AND REAPPLY POWER AND TROUBLESHOOT PER CHECKLISTS
POWER LOSS single engine	***TAKEOFF>V1*** ***INITIAL CLIMB*** ***CRUISE*** ***DESCENT*** ***APPROACH***	Bang or fire warning or very severe vibration, aircraft yaw, high EGT	43, 27 Failure to stabilize flight path, Shutting down good engine 32, 1 Not taking action to secure engine. 24 Shut down good engine.	Maintain control of the aircraft, Continue takeoff or climb to achieve or maintain minimum safe altitude	Evaluate & perform appropriate checklist	SEVERE DAMAGE	SIMULATE LOUD NOISE, AIRCRAFT SHUDDER, FLUCTUATION OF ENGINE PARAMETERS N1 & N2 & EPR DECREASING WHILE EGT INCREASES. TRAIN TO CONTINUE TO CONTROL THE AIRCRAFT AND CLIMB AS NECESSARY TO A SAFE ALTITUDE BEFORE ATTEMPTING TO TROUBLESHOOT.
POWERLOSS single engine	***TAKEOFF > V1*** ***CRUISE*** ***APPROACH*** ***/LANDING***	Parameter spool down. Services (generators) drop off line	37, 6, 50, 44, 34, 30 Failing to control yaw or compensate for reduced thrust. 39 Failing to control yaw, airplane upset as result.	Continue takeoff, go around, or landing as appropriate	If go-round, evaluate and perform appropriate checklist	FLAME OUT	SIMULATE AIRCRAFT REACTION TO AND FLIGHT DECK PANEL CHANGES FOR LOSS OF SINGLE ENGINE. TRAIN TO MAINTAIN CONTROL OF THE AIRCRAFT, THEN RECOGNISE SITUATION,
Uncommanded thrust change or non-response to throttle movement	***TAKEOFF >V1*** ***INITIAL CLIMB*** ***CRUISE*** ***DESCENT***	Aircraft yaw, engine parameter difference.	74, 59, 61 Not recognizing thrust asymmetry/yaw until autopilot disconnect and aircraft upset resulted 31, 25 Shut down good engine.	Control airplane direction	Evaluate and perform appropriate checklist	No engine damage	SIMULATE THRUST INCREASE TO WARNING BAND AND APPROPRIATE AIRCRAFT REACTION. TRAIN TO CONTROL AIRCRAFT AND SECURE ENGINE BY FUEL CUTOFF. ALSO SIMULATE SLOW ROLL BACK OR NON-RESPONSE TO THROTTLE IN IFR CONDITIONS. TRAIN TO RECOGNISE AIRCRAFT SITUATION, FLY THE AIRCRAFT,

4. Evaluation of Malfunctions

The Simulator Group evaluated the malfunctions defined by the Training Group to determine which of the identified engine simulator malfunctions were capable of being improved.

The PSM+ICR malfunction matrix defined by the Training Group included a number of engine malfunctions that do not need any additional symptom cueing or model enhancement. In these cases the simulation models are usually adequate to accurately represent the airframe effects. The malfunctions grouped in this category include:

- Power loss (flameout)
- Uncommanded thrust change
- No response to PLA (throttle input)
- Fire Warnings

The malfunction matrix did show that the main contributing factor of PSM+ICR (63%) was one particular type of engine malfunction symptom, namely high power compressor surge or stall. The terms surge and stall can be used interchangeably and both are valid. However for consistency we shall use the term compressor surge from hereon.

Three types of compressor surge malfunctions were identified as having major shortfalls in cueing noise and tactile (thrust pulse and vibration) response.

- Compressor surge – self-recoverable (Type 1)
- Compressor surge – multiple, recoverable with pilot action (Type 2)
- Severe Engine Damage with compressor surge (Type 3)

A lack of realism in the simulation of high power surge malfunctions can lead to negative training and an increase in the likelihood of an inappropriate crew response. This area was therefore felt to be the main area for research and enhancement.

5. Definition of terminology

The following terms are defined to aid in the communication of these malfunctions.

Compressor Surge

The term compressor surge is used to describe the audible sound heard due to a sudden aerodynamic reversal of flow in the engine's compressor operation. A reversal of flow occurs with the downstream high-pressure air in the compressor escaping forward through the inlet. This reversal of flow is rapid and produces a very loud audible "bang", similar to an explosion, for modern high by-pass ratio engines. The intensity of the noise depends on engine power setting or pressure ratio as well as the amount of expansion permitted by the inlet. Depending on the type of the compression system instability, there may be single, multiple, or continuous multiple loud bangs, and associated engine parameter fluctuations. For a compressor surge that involves more than one audible surge event, the second bang may be muffled compared to the first since the engine may not have recovered completely to its initial conditions prior to the first surge. At high power conditions the sound from a low bypass ratio fan or turbojet engine will be a sharp "pop", while a large high-bypass engine will be a highly energetic "boom". The effects of a compressor surge result in a rapid decrease in rotor speeds, pressures, and fuel flow, and typically an increase in EGT.

Three main types of compressor surge related malfunctions were identified and addressed.

Type 1: Compressor Surge - self-recoverable. A self-recoverable compressor surge will typically have one or up to three loud bangs. The engine then self recovers to normal operation without any pilot action. Engine parameters will fluctuate quickly and may not be noticed by the crew unless they are looking at the instruments during the event. Note that after the surge(s) the engine recovers to normal operation.

Type 2: Compressor Surge - multiple, recoverable with pilot action. This will typically have multiple compressor surges which continue until the throttle is reduced to idle per flight manual procedures. Once the throttle is at or near idle the engine returns to normal operation to match thrust setting. Note that the definition of “recoverable” in this instance refers to the cessation of the engine surges only and not the self-recovery of full commanded power. The surge condition may reoccur if the throttles are subsequently advanced, as the cause of the compressor instability may still be present, depending on the desired training requirements.

Type 3: Severe Engine Damage with Compressor Surge. The non-recoverable symptoms are a single loud bang and an immediate lost of thrust (power loss) to steady state wind milling conditions. If a restart is attempted the engine will not restart as long as the engine malfunction is active.

6. Definition of Compressor Surge Parameter Effects

As part of the definition of a representative compressor surge the Simulator Group reviewed a number of compressor surge related malfunctions from in-service field events using Digital Flight Data Recordings (DFDR) and Flight Test with high resolution data recording systems.

A summary of the data and the plots are shown in section A (Surge Event Data). The range of engine effects for the compressor surges (Type 1 and Type 2) was as follows:

EPR/Burner Pressure	60% - 90% drop to coincide with bang sound
N1	15% - 40% drop to coincide with bang sound
N2 or N3	5% - 10% drop to coincide with bang sound
EGT	10 – 20 deg/sec rise

The data highlighted that no one surge will be the same as another. The objective here is to present a range of acceptable parameter effects to provide representative tuning data for a surge simulation. Note that the other engine parameters should be calculated by the engine model (i.e. the fuel flow should be a function of N2).

The Training Group determined that the training value of the surge malfunctions would be best enhanced by improving the elements that contribute to the "startle factor" of the high power surge. Analysis of in-flight events has shown that the "Inappropriate Crew Response" was often caused by the crew not interpreting the event correctly. This was linked to tactile sensory inputs such as noise (engine bang), visual disorientation (vibration), and jolts from sudden motion inputs (a lateral kick). Very little aircraft data was available for these inputs. One set of high resolution data did provide a lateral cue, and this has been used as a basis for the equivalent simulator effect. However the noise from the events often overloaded the recording devices and was not usable. Attempts to convert pressure data to a usable sound wave were not successful. The recommendation for the compressor surge sound is therefore based upon follow-up interviews with crews. Similarly for the vibration effects the recommendation for the simulator effect is based upon a subjective feedback without data support. The following items are therefore suggestions for implementation of these effects to enhance the "startle factor" for compressor surge training.

Motion effect. The available data showed a lateral sine wave input of 0.5 g for a takeoff condition. For simulation purposes it is suggested that the engine thrust for the affected engine be multiplied by a constant for one or two iterations, depending on the speed of the simulator host computer, to immediately reduce the thrust into the aerodynamic model for that time. The thrust can then be allowed to recover immediately. This type of an input into the aerodynamic model has been shown to provide the correct type of yaw effect and subsequent recovery. A multiplier of 0.5 was used by one operator to achieve this effect.

Vibration effect. Feedback from crews involved in some of the more violent compressor surge events has included comments that the vibration was so bad they could not read the instruments. This is an extreme and such an effect could cause damage to visual components and some of the electronics mounted on the simulator. The recommendation is to link the engine surge to an airframe buffet effect and to fade this effect out linearly over 3 to 5 seconds. The initial effect should be enough to shake the crew but not damage simulator components. This vibration represents airframe response to the compressor surge.

Sound effect. Despite a very intense effort to gather data for this effect the recommendation is again based on crew feedback. Historically the simulated engine surge noise is a small "pop". The response for crews involved in events compared the actual noise to a 12-gauge shotgun at 10 feet. Limitations in simulator sound generation components prevents achieving this magnitude of sound level in most cases and would also be inadvisable on a regular basis in the close confines of the simulator cockpit. However several operators have had success in disorienting crews by significantly increasing the amplitude of the sound generated for the engine surge. The use of different sound waves (i.e. noises) has also been tried with some success. In the end the conclusion reached by the group was that the sound should be as loud as is practical and safe to do so for both crews and machine.

The enhancement of the motion, vibration, and sound cues as a complete package has been shown to significantly increase the initial confusion and disorientation of crews in the cockpit. This overall effect closer represents the situations reported in accident and incident reports. It must be repeated however that no two events will be the same, and the intent here is to improve the realism of the training by adding the "startle factor" and hopefully reducing "Inappropriate Crew Response" by reinforcing training to crews to "fly the plane" in these situations.

Type 1: This is a single or multiple self-recoverable compressor surge type malfunction. The single surge will surge once and then return to normal operation. Multiple surges should occur at a rate of one surge every 2 to 4 seconds with a maximum of three surge cycles. This is to allow the engine model a chance to recover close to normal conditions and to prevent a flameout or sub-idle condition. No crew or instructor action is required.

Type 2: This is a multiple surge that is recoverable with pilot action. The surges should occur at a rate of one surge every 2 to 4 seconds. This is to allow the engine model a chance to recover close to normal conditions and to prevent a flameout or sub-idle condition. Engine parameters should return to normal as the throttle is retarded to or near idle setting. If the pilot then chooses to re-advance the thrust lever above idle setting the compressor surge effects will return. The malfunction can be modeled so that either it is cleared by the instructor or by the crew action.

Type 3: This is a Severe Engine Damage event and involves elements of the non-recoverable compressor surge malfunction symptom combined with a complete power loss (flameout). A single bang and subsequent flameout of the engine characterize this event. Training can be modified to include a fire warning with this event.

7. Simulation Requirements

7.1 Type 1: Compressor Surge - self recoverable

Possible Causes

A self-recoverable surge event can be caused by a momentary internal airflow disruption possibly due to internal rotor to case clearance changes, a bird strike, or an engine controls malfunction.

Effects

The crew would hear one or more loud bangs, each coupled with a momentary lateral impulse kick, vibration, and a rapid decrease in EPR and rotor speeds. EGT should show an increase of 10 to 20 deg C per second and then decrease to normal. Fuel flow would essentially follow the effects of N2. Multiple surges would not result in a sub-idle or flameout situation. After the surge event(s) the engine will return to normal operation.

Simulation Requirements

Engine Effects:	EPR, N1 and possibly Burner Pressure. Large reduction.
	N2/N3. Small reduction effect.
	EGT. Slight increase during multiple events.
	Engine parameters should return to normal 5 seconds after final event.
Motion:	Lateral impulse kick associated with each surge pulse. Caused by momentary thrust reduction. Yaw due to aerodynamic model effect
Sound:	Single or multiple loud bang
Vibration:	Buffeting type fading linearly within 2 to 4 seconds after each surge.
Timing:	Surge cycle of one every 2 to 4 seconds for multiple surge (max. of 3)
Instructor:	No action required. Self clearing malfunction.
References:	Events 1, 2, 3

7.2 Type 2: Compressor Surge- multiple, recoverable w. pilot action

Possible Causes

A multiple compressor surge that is recoverable with pilot action can be caused by a stuck vane actuator, off-schedule stator vane system, bird strike, or compressor operating line deterioration.

Effects

The crew would hear multiple loud bangs, each coupled with a momentary lateral impulse kick, vibration, and a rapid decrease in rotor speed and EPR. EGT should show an increase of 10 to 20 deg C per second with a maximum increase not to exceed the display limits. There would not be a fire warning. Fuel flow is a function of N2 speed. The surge condition would not result in a sub-idle or flameout situation. The engine would continue to surge until the throttle is reduced to idle. Once the throttle is brought to idle the engine, including the EGT, will recover to idle power settings. Depending on the desired training requirements the surge condition could reoccur if the throttle is advanced.

Simulation requirements

Engine Effects:	EPR, N1 and possibly Burner Pressure. Large reduction. N2/N3. Small reduction effect. EGT. Increase of 10-20 deg C until throttle reduction. Engine parameters should return to normal at idle.
Motion:	Lateral impulse kick associated with each surge pulse. Caused by momentary thrust reduction. Yaw due to aerodynamic model effect
Sound:	Multiple loud bangs
Vibration:	Buffeting type fading linearly within 2 to 4 seconds after each surge.
Timing:	Surge cycle of one every 2 to 4 seconds for multiple surge (max. of 3)
Instructor:	Self-clearing at idle or can be cleared by Instructor as required.
References:	Events 4, 5, 6, 7, 8

7.3 Type 3: Severe Engine Damage with Compressor Surge

Possible Causes

Severe damage is a failure of the engine turbo-machinery resulting in an immediate loss of thrust. This can be caused either by compressor/turbine blade(s) or rotor disk failure resulting in a failure of the engine's ability sustains a combustion cycle.

Effects

The crew would hear a single loud bang, feel a momentary lateral impulse kick, momentary vibration, and see the engine parameters decreasing towards zero similar to a fuel cutoff. EGT may rise momentarily and then decrease. Depending on the desired training requirements a fire warning may occur due to the escape of hot gases if an engine casing is opened. The engine cannot be restarted while the malfunction is active.

Simulation requirements

Engine Effects:	EPR, N1, N2/N3 and possibly Burner Pressure. Spools down similar to flameout.
	EGT. Momentary increase of 10-20 deg C per second then decay to flame out value.
	Steady state windmilling parameters established.
Motion:	Lateral impulse kick associated with surge pulse. Caused by momentary thrust reduction and subsequent flameout. Yaw due to aerodynamic model effect.
Sound:	Single Loud Bang
Vibration:	Buffeting type fading linearly within 2 to 4 seconds after surge.
Timing:	Single surge event
Instructor:	Cleared by Instructor or self-clearing on shutdown as required.
References:	Events 9, 10, 11

Vibration:	Some vibration on spool down.

8. Modeling a surge malfunction

8.1 Introduction

The common way of simulating a engine surge malfunction in simulation is the use of tuning effects applied to individual engine parameters. Usually this tuning effect involves a negative force on the rotor speeds known as delta torques to match the requirements of the customer. The engine model will calculate the other engine effects with the exception of EGT as a result of the delta torque effects on the engine model. The sound effect is triggered to match the engine model and other effects, such as vibration, are added for "realism".

8.2 Trigger

After a malfunction is activated a logical "trigger" label is set to co-ordinate all the effects such as the motion cues, sound(s), engine parameters, and aerodynamics. In the case of a single engine surge malfunction, this label is reset immediately and the malfunction may be automatically removed. For multiple surges, a timer is used to reset and re-activate the "trigger" label on a regular or random basis. The malfunction may also be cleared if the crew responds to the effect in the correct manner, usually by retarding the throttle to idle. For the severe engine damage the malfunction can either be cleared by the Instructor or automatically when the crew follows the procedure and places the fuel switch to off.

8.3 Engine effects

As mentioned above, the engine surge is simulated using gain terms (delta torque) applied directly to the engine rotor speed equations (N1/N2/N3). Based on the available data from high-resolution flight test data and in-service engine surge events it is suggested that the engine parameters be tuned to match the reductions listed in section 6.

EPR and burner pressure are generally functions of the rotor speed so these parameters do not always require additional tuning but this is not always the case.

The fuel flow usually has a direct relationship to the engine parameters and should not require any additional tuning. This would not provide any additional training benefit.

The Exhaust Gas Temperature (EGT) effect will need an additional gain tuning term. This is done with a simple ramp term (rate of change) that is added to the base temperature calculations from the engine model to get the desired rate of increase and final temperature. Once the surge condition has cleared the ramp term is faded out.

Secondary parameters should not require any additional work with the possible exception of vibration indication.

8.4 Motion Effects

One of the high resolution data plots (Event 4) shows a lateral kick during the surge events. Depending on how well the aerodynamic effects are simulated there may be a requirement to add motion effect to enhance this. However, one operator found it was sufficient to reduce the engine thrust with a simple multiplier for the affected engine for a very short period of time, such as one or two iterations of the engine model. This caused the required "kick" in the motion as well as the representative yaw effect visible from the cockpit. As the aerodynamics dampened out the "kick" there was a slight overshoot before stabilizing. This response worked as per the data.

8.5 Vibration Effects

Several events have resulted in a pronounced airframe buffeting (shuddering effect) vibration caused by the multiple surges and this is considered an appropriate cue for training simulation. In one particular case it was reported that the crew had difficulty reading the flight deck instruments. When the operator for one of these events attempted to duplicate this vibration effect in their simulator it was found that the level of vibration needed for duplication caused simulator electronics to work loose. While the exact response is preferred, the effects sometimes need to be limited to maintain simulator reliability. The vibration and motion effects are two such cases where this applies.

The same operator subsequently detuned the vibration effect to a lower level to preserve simulator equipment reliability. Another operator found that using the simulated buffeting effect allowed a sufficient effect to be mildly disorienting without causing undue stress on the simulator electronics and visual system.

The vibration modeling may require adjustment in two areas.

First, the indications on the engine instruments need to reflect this higher vibration value. No good data exists for the values to be indicated but there is expected to be a significant increase from normal. The vibration effect should fade out as the surge ends.

Second, the motion effects should also provide a vibration cue. Two operators found that they had to either modify an existing, or add a new, effect to do this. The vibration should become apparent at the onset of the surge and then fade out as the engine stabilizes. A subsequent surge causes the vibration to reoccur.

8.6 Sound effects

One of the major shortfalls observed in many surge malfunction simulations is the unrealistic sound accompanying the engine surge. There has been considerable difficulty in obtaining a realistic recording of an actual engine surge sound in the flight deck. Areas of difficulty have been in defining the amplitude of the sound recorded in the flight deck either from in-service events or flight test recordings. Additionally, the high cost of forcing an engine to surge for a dedicated test has not been shown to be practical.

In spite of some hopeful leads on getting an accurate surge sound we were unable to get any recordings of suitable quality. The group reviewed CVR recordings as well as videos of surge events in test cells. For the CVR recordings it was found that the sound often saturates the microphone and the sound is clipped due to recording device fidelity and the structural borne vibration that accompanies a surge, which affects the sound recording. During a recent developmental flight test of a new engine, a surge was recorded but calibration signal was not considered accurate to calibrate the noise signal to a db level and was found to be inconclusive. The video sound tracks tended to have too much distortion of the sound caused by echoes from the surrounding test cell and ground. Current tools used by noise engineering groups are not capable of relating outside noises of this magnitude through the airframe structure to the flight deck for representative effects.

However, we did get several first-hand accounts, from pilot experiences, of the surge sound resembling a “shotgun blast” at close range but the group was not comfortable is proposing this as a sound form to be reproduced.

The only data that we could justify was that the sound was very loud at high power engine operation. This loud noise is part of the “startle factor” that seems to be a major reason crews respond inappropriately to such events. A couple of operators have tried to reproduce this by taking the existing surge sound and increasing the sound level to the maximum available from the amplifiers with some account taken of the speaker capability and crew discomfort. While this cannot be said to accurately reproduce the sound itself, it does provide the “startle” that is important in this event.

8.7 Aerodynamic Effects

No additional aerodynamic effects were required beyond those listed above. All aerodynamic effects will result from the engine model thrust changes therefore no additional aerodynamic effects are added to the simulation.

A. Surge Event Data

Data for a total of 11 surge events was obtained to determine parameter effects (i.e., percent drop and rate of change). The original data is converted into a standard format to allow ease of comparison and to prevent identification of the aircraft and power plants involved.

The events used were as follows:

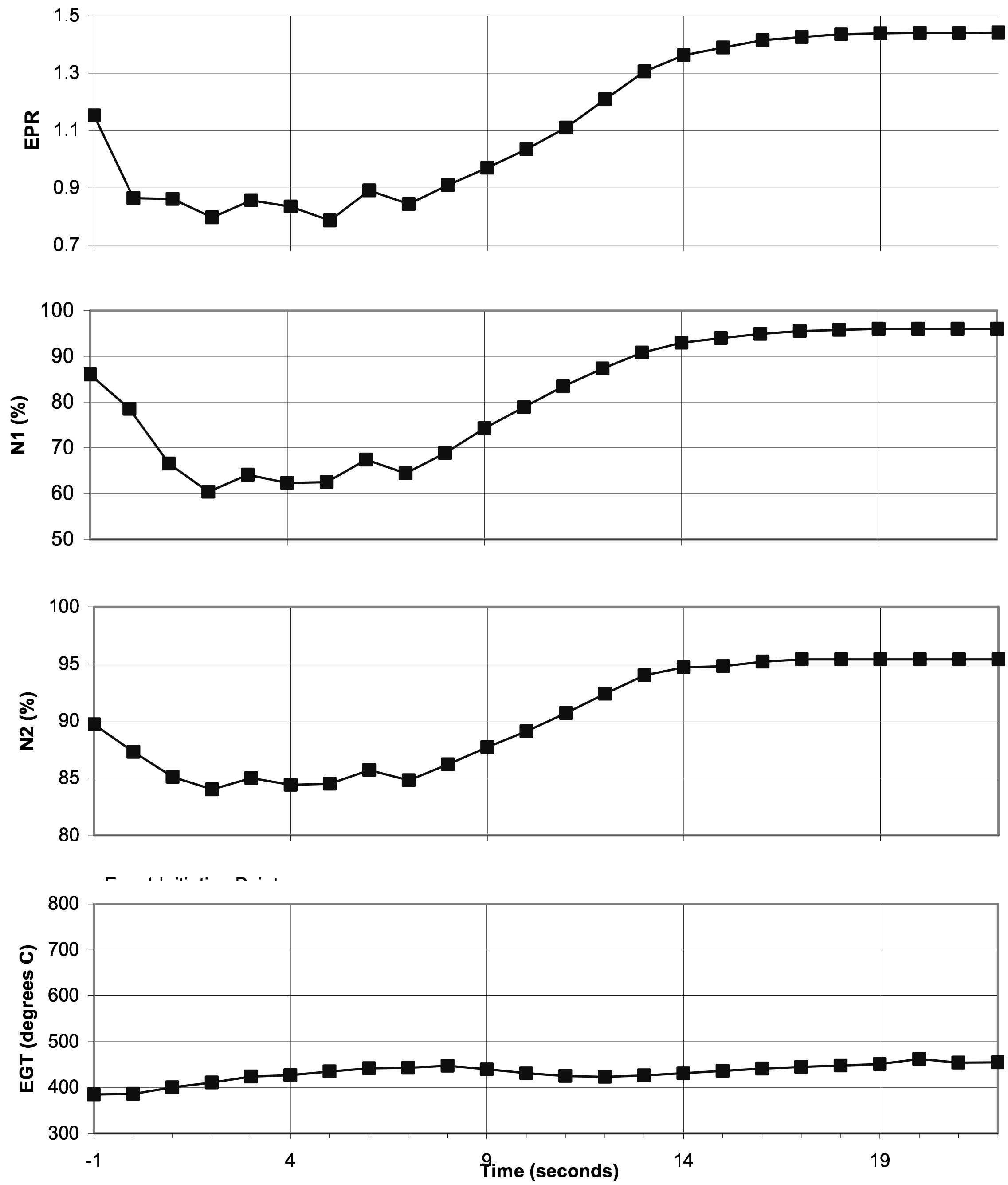
Event	Type	Alt	Speed	EPR	N1	N2	EGT
1	1	FL310	308	80%	25%	6%	10 deg/s
2	1	1800	185	60%	N/A	N/A	N/A
3	1	T/O Rt	180	N/A	40%	N/A	12 deg/s
4 †	2	500	160	60%	17%	N/A	N/A
5	2	10	182	82%	42%	10%	20 deg/s
6 †	2	160	173	75%	15%	7%	15 deg/s
7	2	330	192	90%	38%	10%	20 deg/s
8	2	500	190	90%	38%	N/A	N/A
9	3	210	180	N/A	80%	N/A	N/A
10	3	FL350	286	N/A	45%	67%	N/A
11	3	T/O	136	80%	40%	29%	100 deg/s

† High resolution data

T/O Rt: Takeoff Rotation
T/O: Takeoff

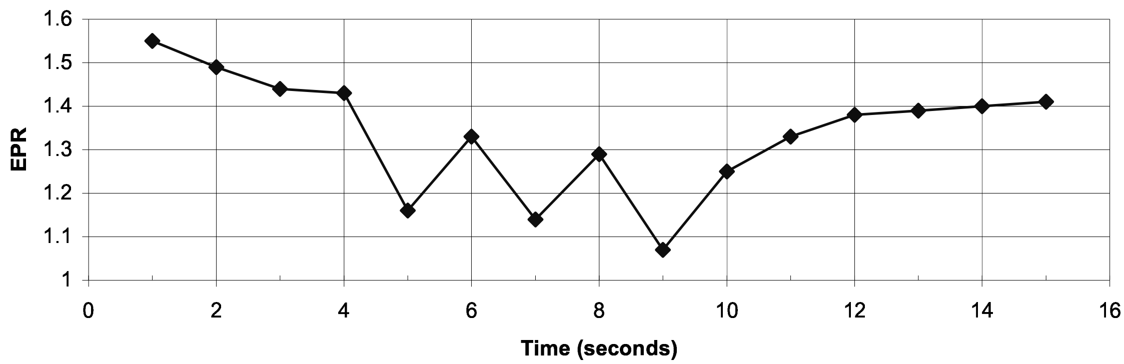
Event No. 1

Type 1: Self-Recoverable Surge (Multiple Bangs)
Engine Thrust Class: > 50,000 lbs-thrust turbofan
Airplane Phase/Altitude: Cruise / FL310
Airplane Speed: 308 knots (CAS)
Thrust Lever Action: None, then advanced to setting above original setting
Data Sample Rate: 1 per second



Event No. 2

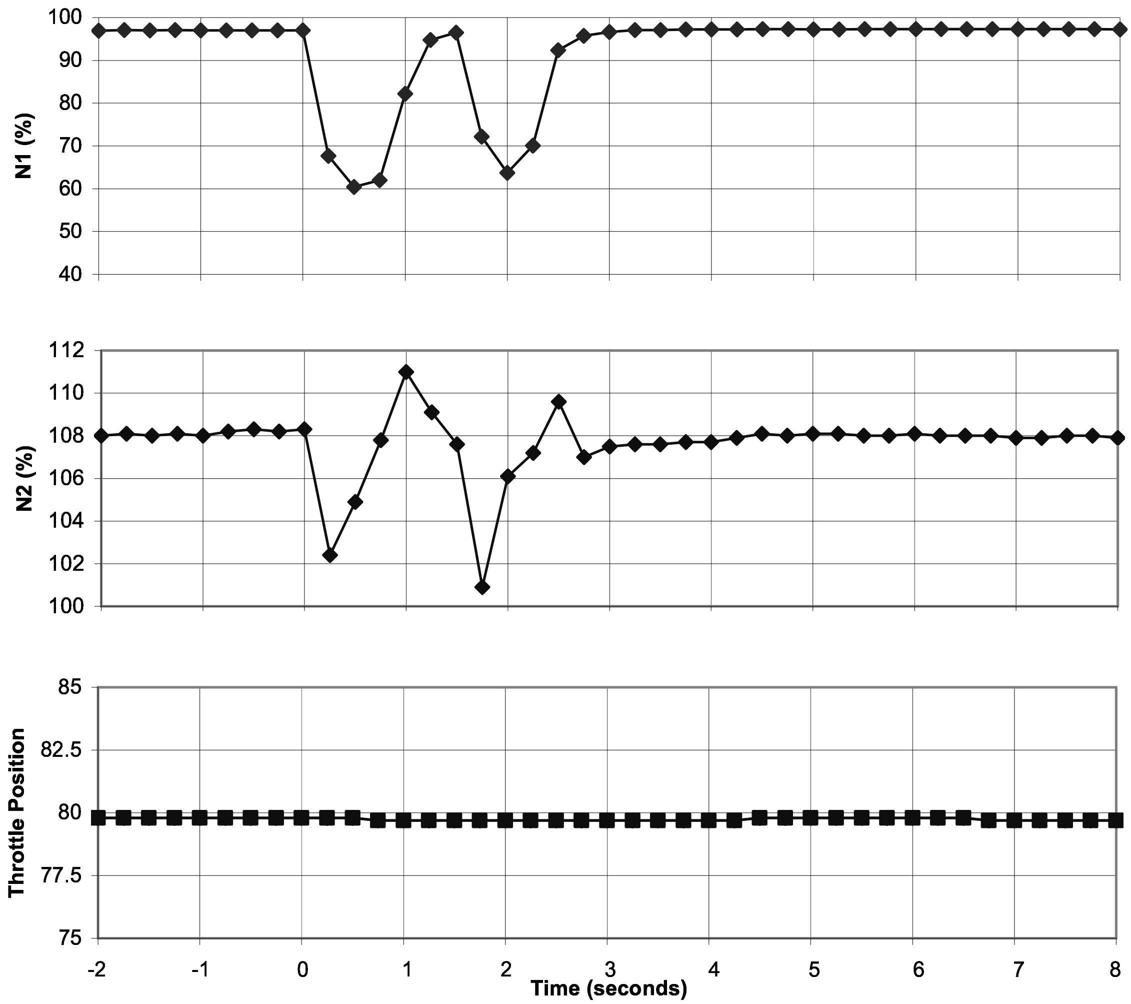
Type 1: Self-Recoverable Surge (Multiple Loud Bangs)
Engine Thrust Class: > 50,000 lbs-thrust turbofan
Airplane Phase/Altitude: Takeoff-Climb / 1800 feet above ground level
Airplane Speed: 185 Kts
Thrust Lever Action: During power reduction to climb power engine surged, then self recovered
Data Sample Rate: 1 per second



Note: No data for EGT, N1, N2 engine parameters

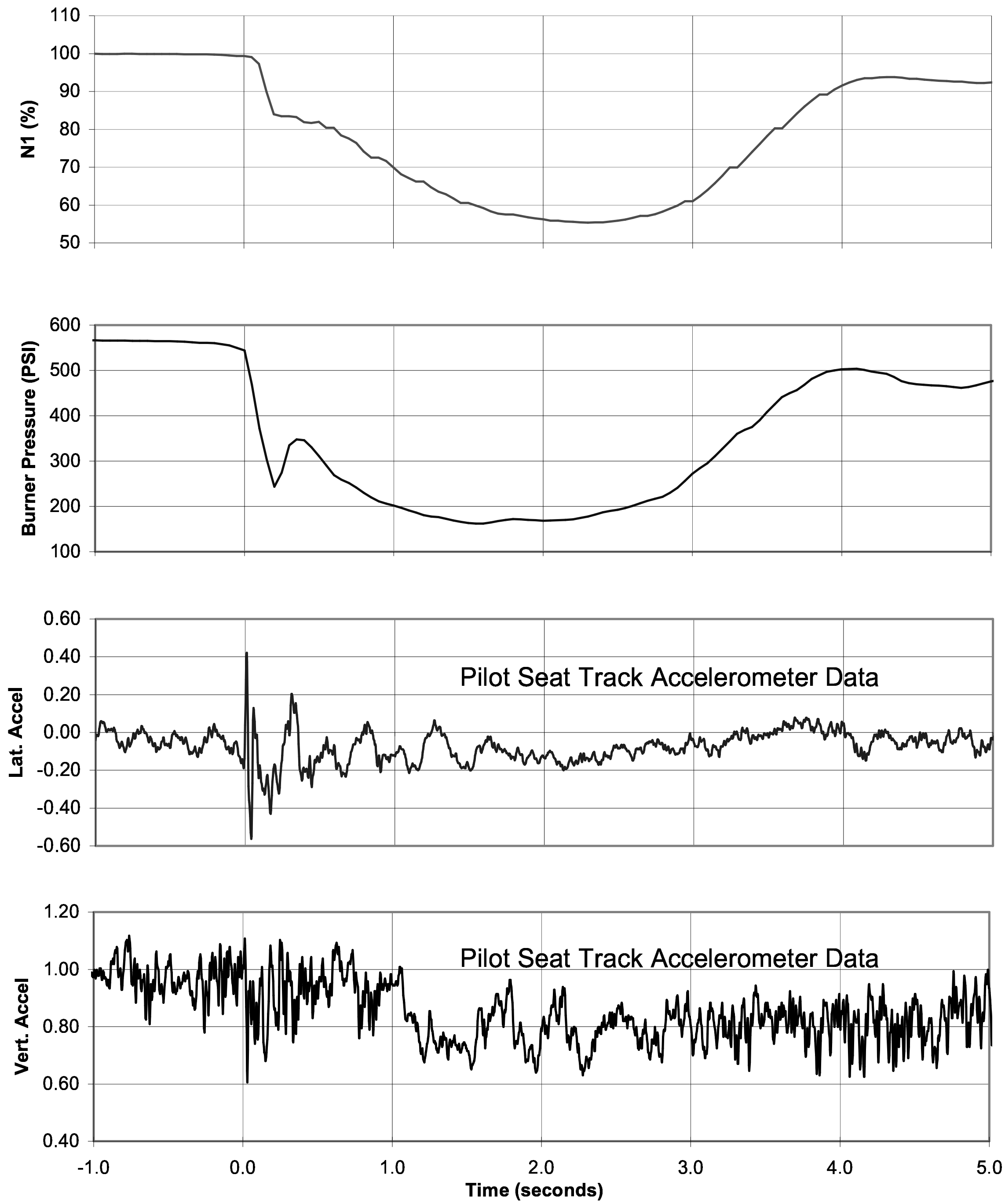
Event No. 3

Type 1: Self-Recoverable Surge (Multiple bangs)
Engine Thrust Class: > 50,000 lbs-thrust turbofan
Airplane Phase/Altitude: Takeoff/Rotation
Airplane Speed: 180 kts
Thrust Lever Action: None
Data Sample Rate: 4 samples/second



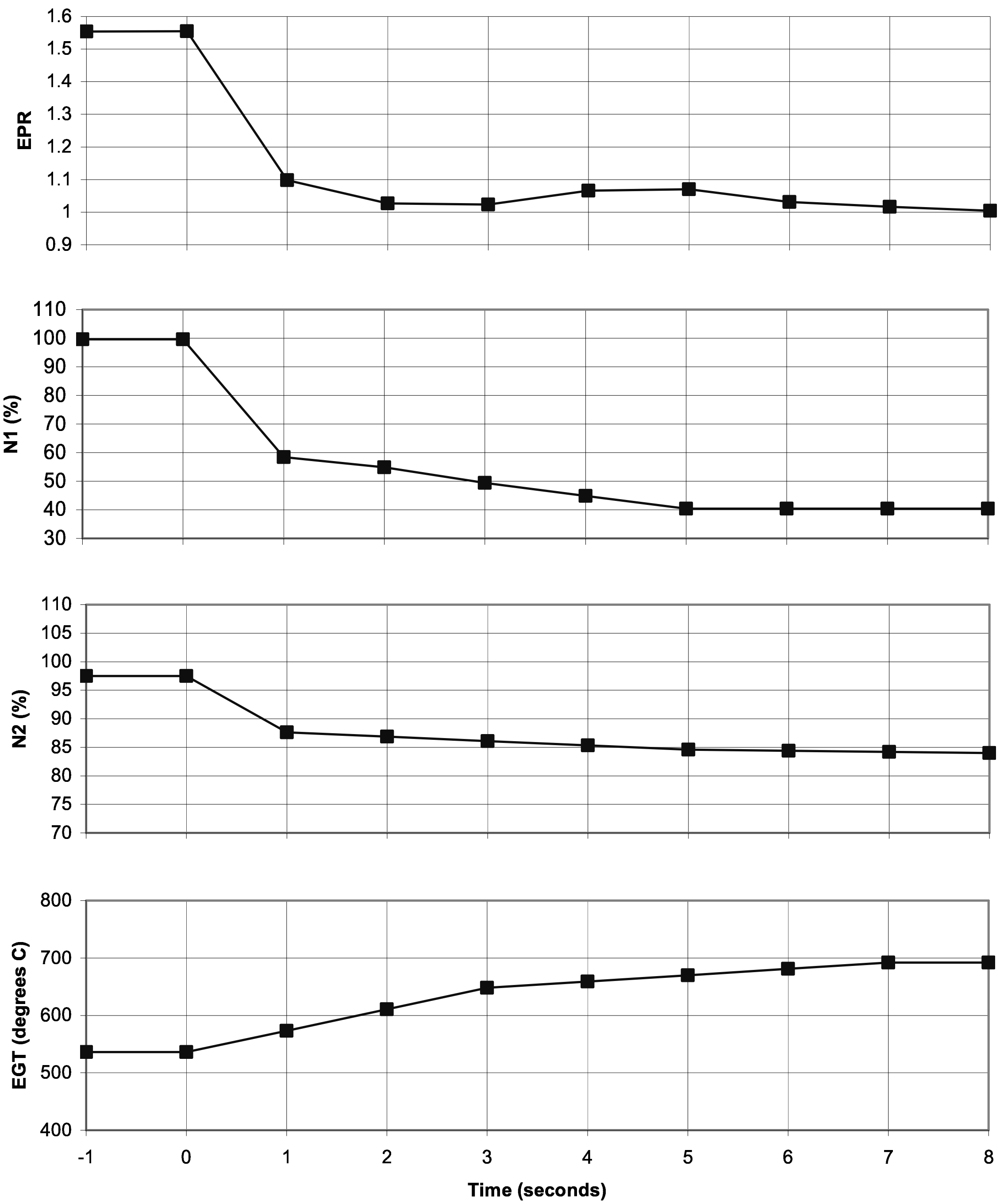
Event No. 4

Type 2: Recoverable Surge with Crew action (Single Bang)
Engine Thrust Class: > 50,000 lbs-thrust turbofan
Airplane Phase/Altitude: Takeoff / 500 feet above ground level
Airplane Speed: 160 knots (CAS)
Thrust Lever Action: Retarded slightly with recovery
Data Sample Rate: 200 per second



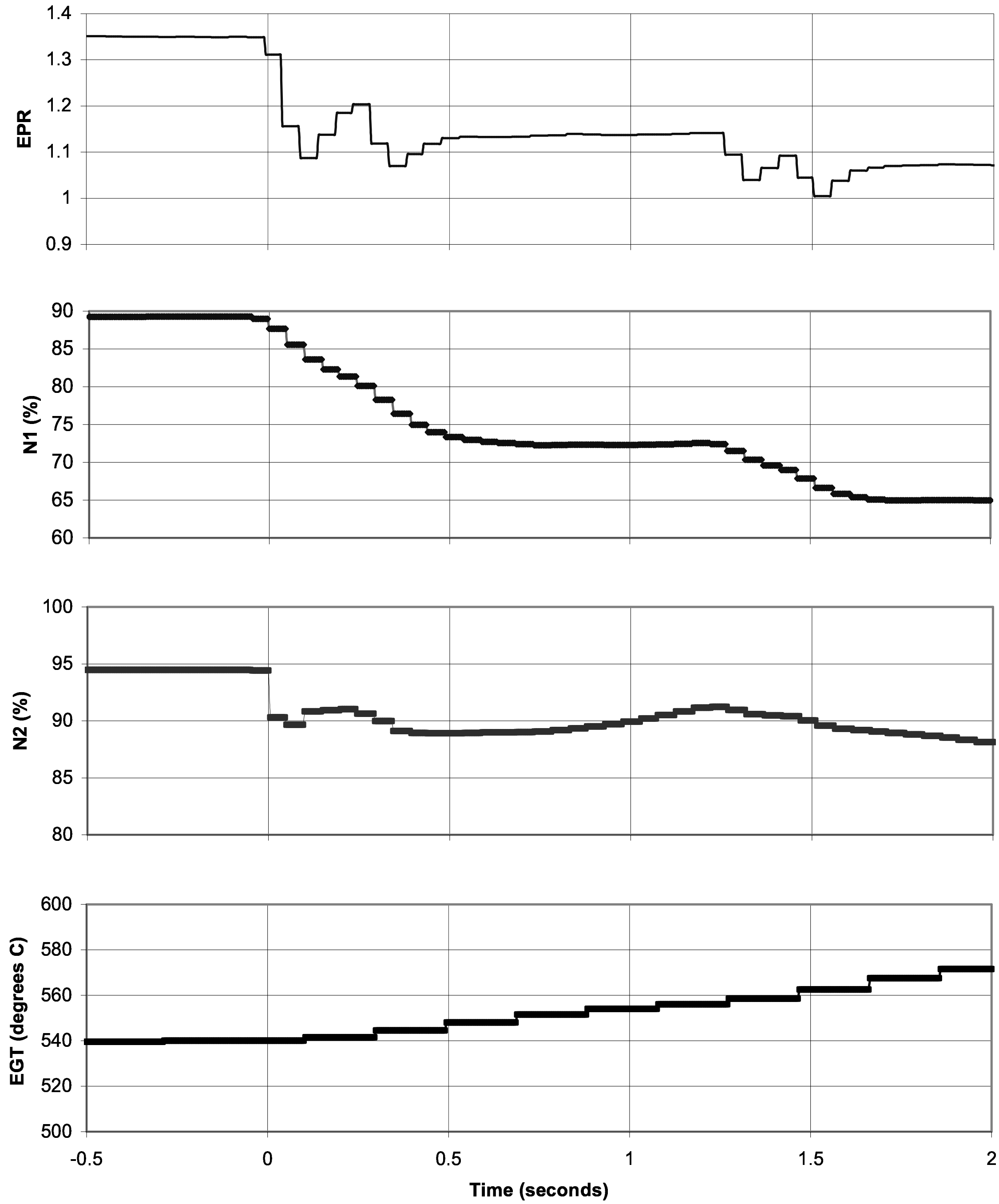
Event No. 5

Type 2: Recoverable Surge with Crew action (Single Bang)
Engine Thrust Class: > 50,000 lbs-thrust turbofan
Airplane Phase/Altitude: Takeoff/10 feet above ground level
Airplane Speed: 182 knots (CAS)
Thrust Lever Action: Retarded to part-power level with recovery
Data Sample Rate: 1 per second



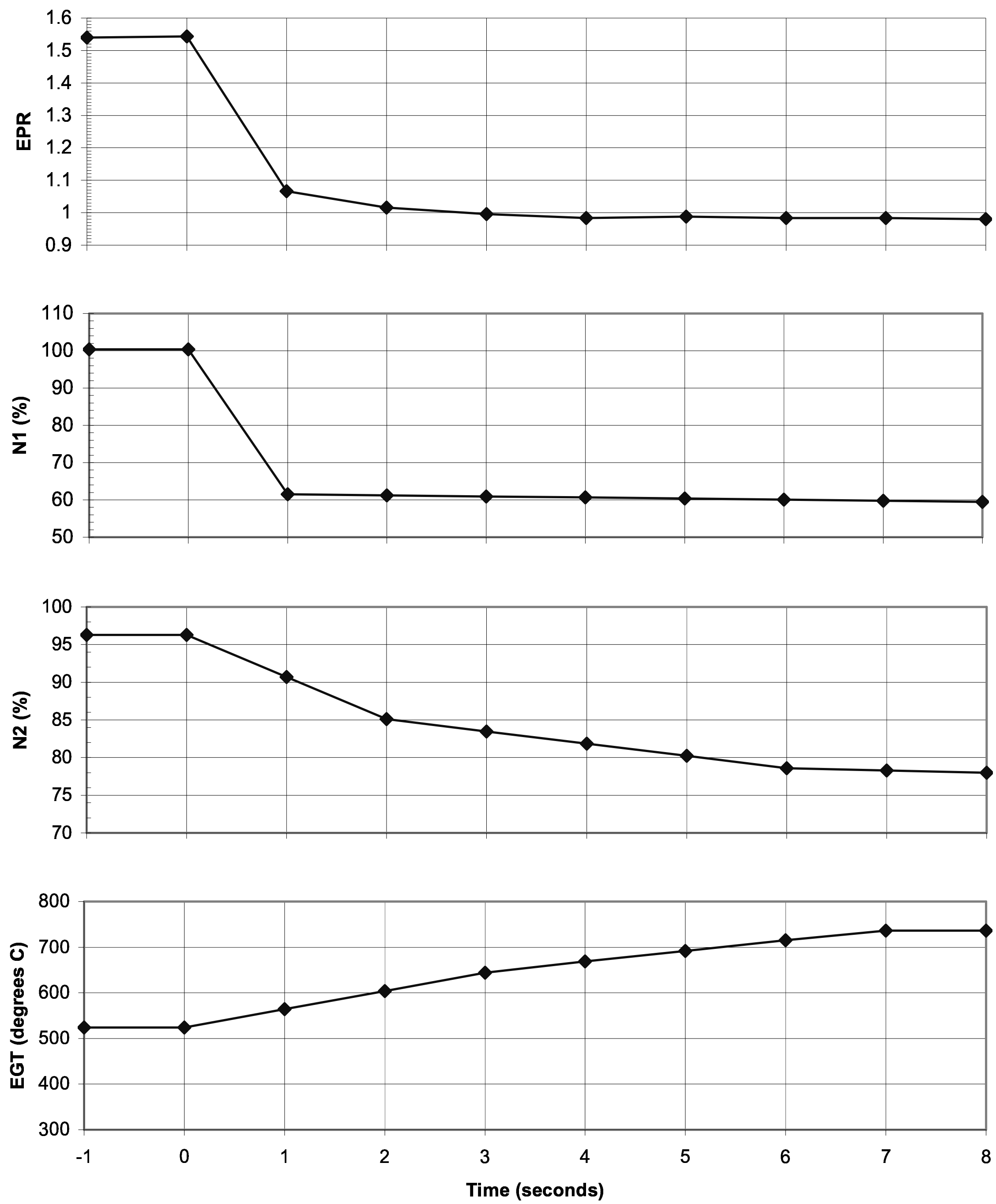
Event No. 6

Type 2: Recoverable Surge with Crew action (Double Loud Bang)
Engine Thrust Class: > 50,000 lbs-thrust turbofan
Airplane Altitude: 160 feet above ground level
Airplane Speed: 173 knots (CAS)
Thrust Lever Action: Retarded from 67.6 TRA to 65.1 for 0.5 seconds, then retarded to idle immediately following second surge event
Data Sample Rate: 200 per second



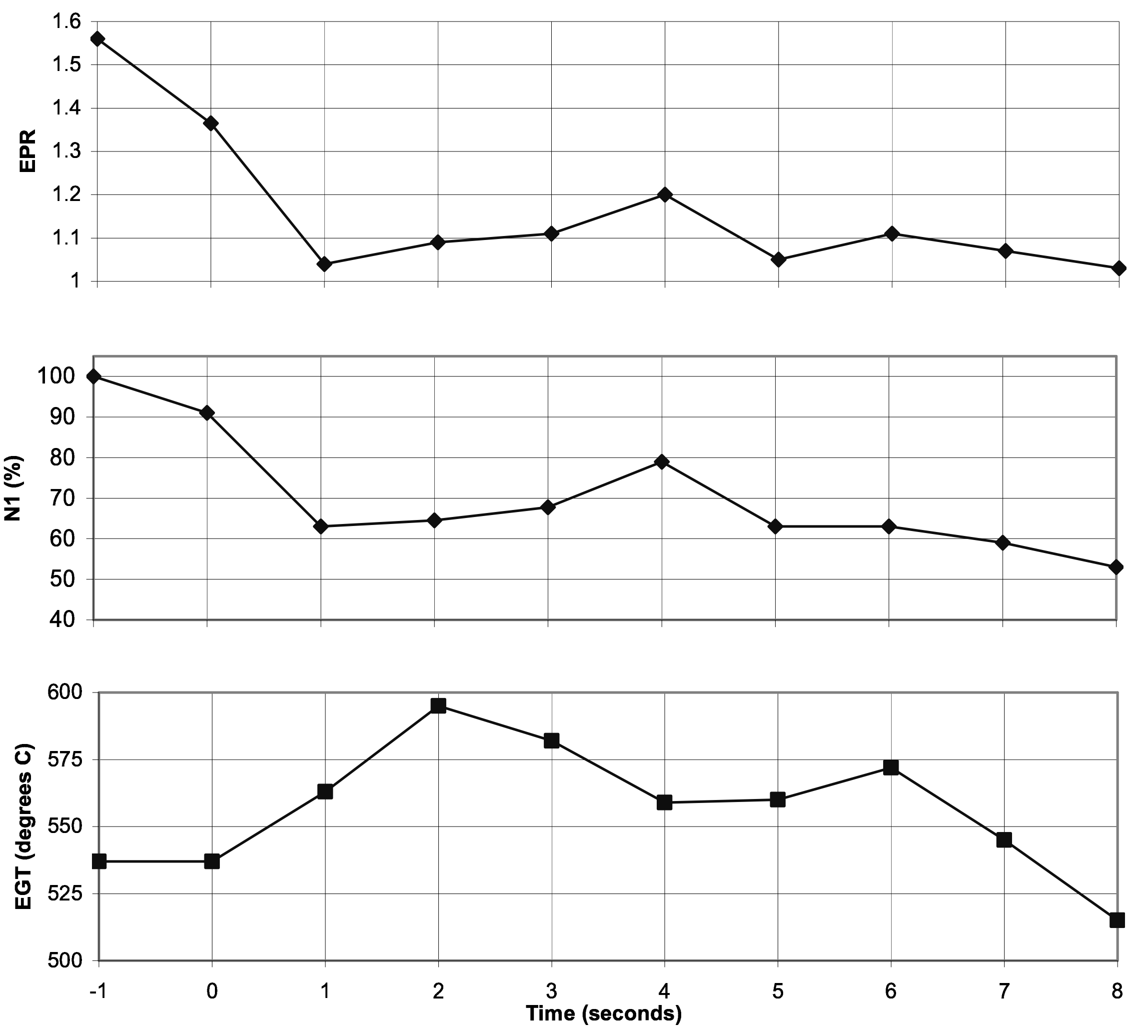
Event No. 7

Type 2: Recoverable Surge with Crew action (Single Bang)
Engine Thrust Class: > 50,000 lbs-thrust turbofan
Airplane Phase/Altitude: Takeoff/330 feet above ground level
Airplane Speed: 192 knots (CAS)
Thrust Lever Action: Retarded slightly, then 44 secs later retarded to idle
Data Sample Rate: 1 per second



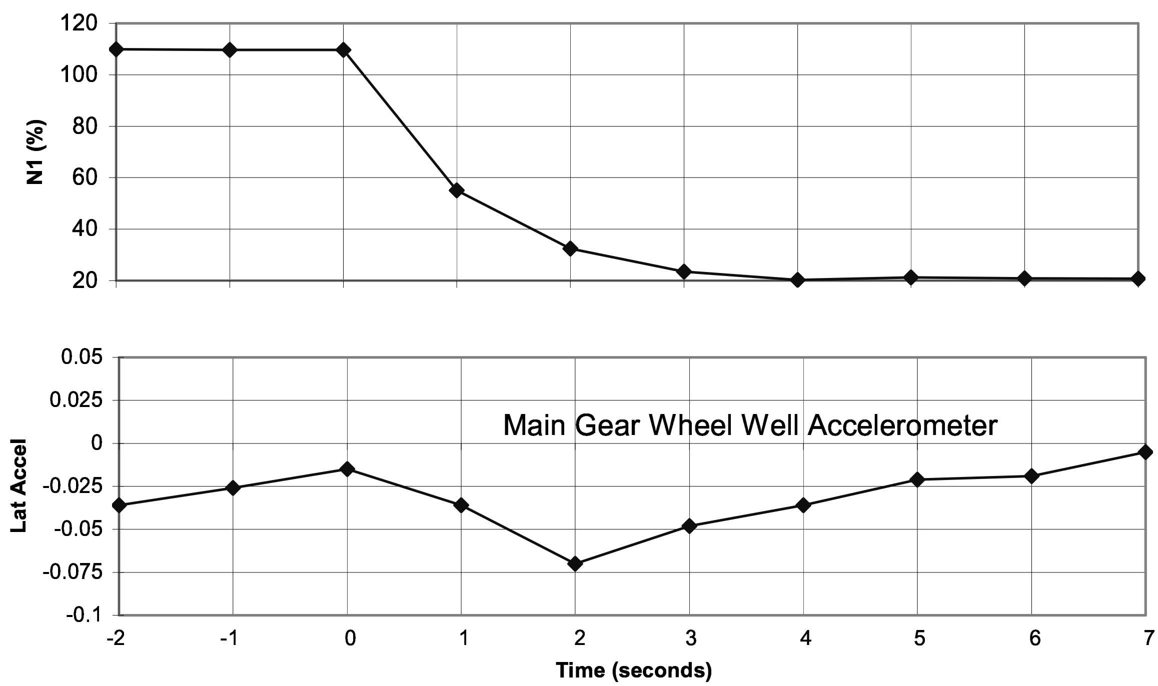
Event No. 8

Type 2: Recoverable Surge with Crew action (Single Bang)
Engine Thrust Class: > 50,000 lbs-thrust turbofan
Airplane Phase/Altitude: Takeoff / 500 feet above ground level
Airplane Speed: 190 knots (CAS)
Thrust Lever Action: Retarded to idle with, with momentary re-advance then to idle and recovery
Data Sample Rate: 1 per second



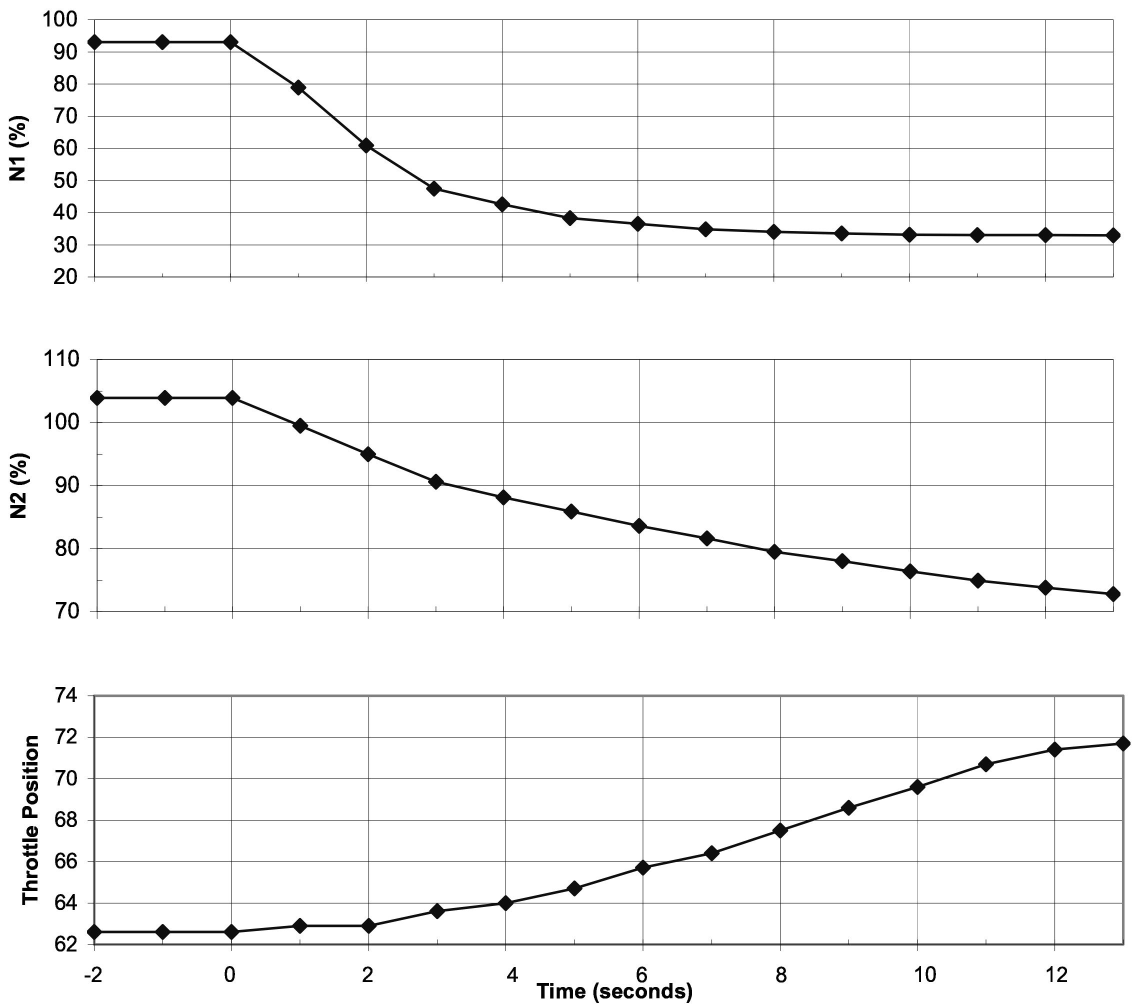
Event No. 9

Type 3: Severe Engine Damage -- Non-Recoverable
Engine Thrust Class: > 40,000 lbs-thrust turbofan
Airplane Phase/Altitude: Takeoff/Climb, 210 ft
Airplane Speed: 180 Kts
Thrust Lever Action: Retarded to Idle after the event
Data Sample Rate: 1 per second



Event No. 10

Type 3: Severe Engine Damage -- Non-Recoverable
Engine Thrust Class: > 50,000 lbs-thrust turbofan
Airplane Phase/Altitude: Cruise 35,000 ft
Airplane Speed: 286 Kts CAS
Thrust Lever Action: Pilot-initiated throttle increase
Data Sample Rate: 1 per second



Event No. 11

Type 3: Severe Engine Damage -- Non-Recoverable
Engine Thrust Class: > 50,000 lbs-thrust turbofan
Airplane Phase/Altitude: Takeoff Roll
Airplane Speed: 136 knots (CAS)
Thrust Lever Action: Retarded to idle
Data Sample Rate: 1 per second