Vehicle Safety Institute

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STAMP Modeling of the Accident N4252G

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Graz, March, 2019

AFFIDATIV

I declare that I have authored this thesis independently, that I have not used other than the declared sources/ resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources. The text document uploaded to TUGRAZonline is identical to the present master's thesis.

Graz, March 29, 2019

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Signature

PREFACE

Following a long interest in aviation safety, I have attended the Master's Degree Program of Traffic Accident Research - Aviation Safety at the University of Technology, Graz, Austria.

My experience as a professional pilot ranges from single-engine piston aircraft via the Bombardier Global Express long-range corporate aircraft to the Airbus A320 type. Besides, I have gained experience as a flight operations officer, a flight instructor/ examiner for single-engine piston aircraft, a type-rating instructor/ examiner and flight operations inspector for the Austrian Civil Aviation Authority.

Reoccurring cases of rather similar air crashes with single-engine piston aircraft have initiated various discussions about the model-based improvement of accident investigation processes used for modern General Aviation aircraft, which have led to the development of this thesis.

At this final stage of my studies, I would like to take the opportunity to thank my family and friends for supporting and encouraging me to continue towards my academic goals. Finally, I would like to thank my academic supervisors for their kind help and support during the development of this thesis.

ABSTRACT

The present master's thesis aims to compare the results of a traditional accident investigation report published by the investigating party (NTSB) and a system-theoretical modeling based on Leveson’s STAMP model and CAST methodology (Leveson, 2011).

Today’s accident analyses reports are often based on linear accident models that allow the identification of only a limited number of causes, and safety recommendations for avoiding such accidents in the future. The accident of N4252G was published in great detail via social media by means of photos and video recordings. The associated causes resulting from the accident report, and the safety recommendations did not include all the lessons that could be learnt from this accident. Thus, the motivation was given to systemically model this accident to provide a systemic view of its causes.

On June 9, 2016, a Cirrus SR20 registered aircraft crashed at William P Hobby Airport (HOU), Texas, USA, and all three persons on board lost their lives. The pilot tried several times to land in HOU. The first approach was cancelled by ATC for subsequent commercial air traffic. The aircraft remained on tower frequency under high-traffic situations. The second line up for approach was cancelled by ATC. Two more approaches were executed, which all ended up too high and did not allow a safe landing. During the last go-around procedure, the ATC controller was relieved. The pilot lost control of the aircraft at about 500 ft above ground level, causing a spin. The aircraft impacted in an empty car, which was parked near a hardware store. The accident site was located about half a mile of the approached runway. The weather was characterized by good visibility and strong and gusty crosswinds up to 20 kts.

Considering a list of relevant definitions, the most important facts referring to the accident and technical aspects of the aircraft were summarized in the appendices of this thesis. The time limit of the analysis was defined from the first contact with HOU ATC until the accident. The analysis of post-crash events was excluded. For detailed illustration, relevant stored flight data of the on-board data module and position logs from radar data were presented graphically together with the time-referenced ATC transmissions. Using the Systems-Theoretic Accident Model and Process STAMP (Leveson, 2011), this thesis proposes an STPA-based model of the accident that includes the control structures of ten individual system components, unsafe control actions, dysfunctional interactions and contextual factors. The STAMP-based model of the accident allowed to generate 55 safety recommendations and 64 raised questions. The results illustrate the existing potential of STAMP and CAST (Leveson, 2011) for improving the aviation accident investigation and shows that the present aviation accident could be investigated and understood in more detail by applying STAMP and CAST.

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AC	Advisory Circular (FAA)
AFM	Airplane Flight Manual
AGL	above ground level
AIM	Aeronautical Information Manual
AltB	Barometric corrected Altitude in [feet] above MSL
AME	Aeronautical Medical Examiner
APS	Aircraft Parachute System
ATC	Air Traffic Control
ATCT	Air Traffic Control Tower
ATIS	Automated Terminal Information Service
ATM	Air Traffic Management
ATSAP	Air Traffic Safety Action Program
Avgas	Aviation Gasoline (for spark-ignited piston engines)
CAPS	Cirrus Airframe Parachute System
CAST	Causal Analysis based on STAMP (Leveson, 2011)
CD	Clearance Delivery (ATC)
CDM	Critical Decision Making seminar (by COPA)
CDT	Central Daylight Time (UTC minus 5) in [hours]:[minutes]:[seconds]
CFI	Certified Flight Instructor
CG	Center of Gravity
CFR	Code of Federal Regulations (USA)
CHT	Cylinder Head Temperature
COM	ATC Communicator (52G, LCI, LCT or LCC)
COPA	Cirrus Operator Pilots Association
CPPP	Cirrus Pilot Proficiency Program (by COPA)
CSIP	Cirrus Standardized Instructor Pilot
CTC	Cirrus Training Center

Dist	Distance in [NM]
DMS	Docket Management System
EGT	Exhaust Gas Temperature
FAA	Federal Aviation Administration
FOM	Flight Operations Manual
ft	feet (1 ft equals 0.3048 meters)
FD	Flight Data (ATC)
FITS	FAA Industry Training Standards
FLM	Front Line Manager (ATC)
fpm	feet per minute
GAJSC	General Aviation Joint Steering Committee
GA	General Aviation
GC	Ground Control
GGG	Gregg County Airport, Longview, Texas
GS	Ground Speed in [kts]
H	Hazard
HCL	Higher Control Level
HLSC	High-Level Safety Constraints
Hobby	short form for HOU airport
IFR	Instrument Flight Rules
HCS	Hierarchical Control Structure
HDG	Magnetic Heading in [°]
HOU	William P. Hobby Airport, Houston, Texas
I90	Houston Terminal Radar Approach Control
IAS	Indicated Airspeed in [kts]
ICAO	International Civil Aviation Organisation
ISA	International Standard Atmosphere
kgs	kilograms
KIAS	Indicated Airspeed in [kts]
kts	knots [1 kt is equal to 1NM per hour]
L	Loss

lbs	pounds [1 lb is equal to 2.2 kgs]
LC	Local Control (ATC)
LCC	Local Control – Controller (ATC)
LCT	Local Control – Trainee (ATC)
LCI	Local Control – Instructor (ATC)
LDA	Landing Distance Available
LOC	Loss of Control
mile	equal to nautical mile [NM]
MSL	mean sea level
NM	Nautical Mile [1 NM equals 1852 meters equals 6076 ft]
NATCA	National Air Traffic Controllers Association
NTSB	National Transportation Safety Board (investigating party)
OJT	on-the-job training
OJTI	on-the-job Training Instructor (ATC)
OUN	University of Oklahoma Westheimer Airport
PAPI	Precision Approach Path Indicator
Paxe	Passengers
PD	Police department
PIC	Pilot in command
POH	Pilot's Operating Handbook
PRC	Performance Records of Conference
QR	Questions raised
Radar Altitude	Altitude indicated on ATC radar monitor in [ft]
RDM	Recoverable Data Module
REC	Recommendation
RPM	revolutions per minute
RY	Runway
SA	Situational Awareness
SC	Safety Requirements and Constraints
SRM	Single-Pilot Resource Management

SSR	Secondary Surveillance Radar
STAMP	Systems Theoretic Accident Modeling and Processes (Leveson, 2011)
STARS	Standard Terminal Automation Replacement System
STPA	System-Theoretic Process Analysis (Leveson, 2011)
SWA	Southwest Airlines
TAA	Technologically-Advanced Aircraft
TCI	Training Center Instructor
TrOrg	Training Organisation
UCA	Unsafe Control Action
US	United States
US-gal	US gallon [1 US-gal equals 3.785 liters]
UTC	Universal Time Coordinated (general mean time)
Vfe	maximum flaps extended speed in [kts]
Vno	maximum normal operating speed in [kts]
Vs	Stall speed in [kts]
Vs0	"minimum steady flight speed in the landing configuration" (US Department of Transportation, Pilot's Handbook of Aeronautical Knowledge, 2016, p. 8-9) in [kts]
Vy	"best rate of climb speed" (US Department of Transportation, Pilot's Handbook of Aeronautical Knowledge, 2016, p. G-34) in [kts]
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
WINGS	FAA Pilot Proficiency Program
x-wind	cross-wind
52G	ATC short form for N4252G

Aspects that the author of this thesis considers as safety relevant for the modeling of the accident N4252G using STAMP (Leveson, 2011) are underlined throughout the prevailing document.

"There is almost no human action or decision that cannot be made to look flawed in the misleading light of hindsight. It is essential that the critic should keep himself constantly aware of that fact."

Sir Anthony Hidden QC (March 7, 1936 – February 19, 2016)

1 INTRODUCTION

1.1 Motivation

After an aircraft accident, questions concerning what caused it are soon raised. The aeronautical regulatives provide a framework for the investigation, although in many cases final aircraft accident reports end after identifying causal human errors. Thus, opportunities are missed to identify why humans behaved in the way that they did and what preventive measures could prevent people repeating the same errors in the future. The official investigation report of the N4252G accident clearly describes the events and some related root causes. The analysis of why these human errors occurred could be enlarged using STAMP. Understanding that a human error is a symptom rather than a cause holds utmost importance, as humans generally tend to believe that events as such are more obvious and predictable than before. This is called "hindsight bias", which might ultimately also influence the objectivity in investigation. In the present accident report of N4252G, the NTSB as the investigation board determined the probable causes solely as human-affected errors. As humans do not intentionally make mistakes, the entire mental process in which context decisions were made must be considered, as gaps in the safety control structure ultimately allow accidents to occur. Considering that humans have a certain capacity for performing procedures, it shall be noted that if task demands exceed a pilot's capability, they may either be not performed properly or some may not be performed at all. This understanding is the initial step of a detailed system-theoretic process analysis and was a significant motivation factor for the development of this thesis.

1.2 Objectives

The aim of this thesis is to conduct a detailed analysis of the N4252G accident by applying STAMP (Leveson, 2011). In comparison to conventional state-of-the-art investigation methods used by many accident investigation parties, this thesis investigates the applicability of STAMP for investigating an aircraft accident in systemic approach rather than on the analytical reduction approach that considers the individual components. The focus of this master thesis is to systemically model and analyse complex control structures. The results shall highlight the potential of applying STAMP in accident research and show new perspectives of the accident causes, describe unsafe control actions of individual components, define gaps and open questions from the official investigation and finally specify safety recommendations to address critical safety issues to avoid re-occurrences of similar accidents. The selection of this relative unknown accident as a base for the thesis is deliberate, as it illustrates the requirement of modern investigation methods for the whole aviation safety spectrum.

2 STAMP ANALYSIS OF THE N4252G ACCIDENT

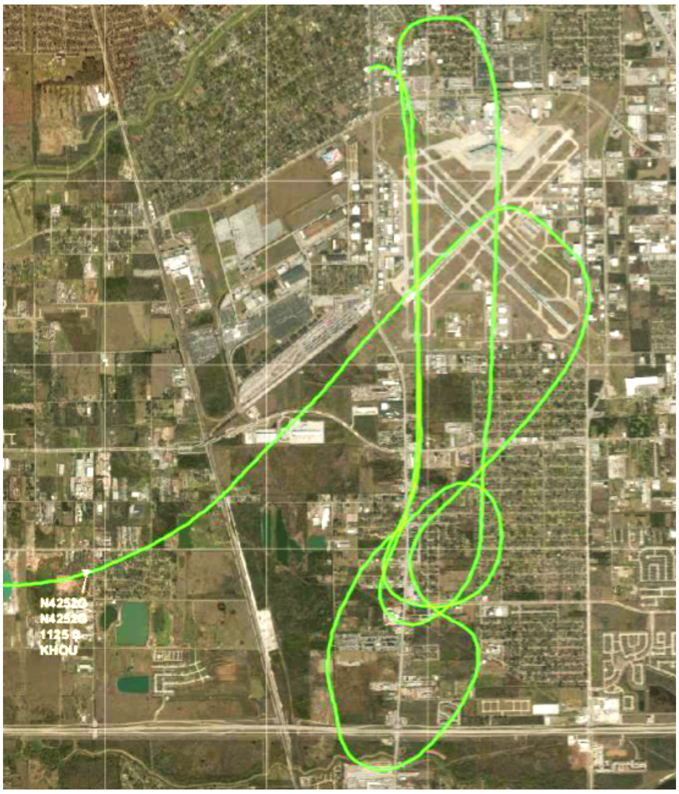
2.1 Definition of Restricting Conditions and Time Line

As an initial step in the prevailing STAMP (Leveson, 2011) modeling, the restricting conditions of the aircraft accident of N4252G from June 9, 2016 were defined by the author. The system-theoretic top-down analysis starts at 12:27:48 CDT (when the pilot first contacted Houston Approach ATC) and lasts until the impact. The post-crash events (e.g. rescue coordination) are excluded from the analysis. The difficulty in the analysis of this accident was that partially crucial information needed for the full understanding was not included in the final report by the investigating party. It must be noted, that this information appears as crucial only when STAMP is being used. These questions are listed in Chapter 3.

The modeling of an accident according STAMP (Leveson, 2011) requires the specification of basic events referenced to the time (“time line”). This is presented in G Appendix in the section Chain of Events.

2.2 Radar Data and Graphical Presentation of Flight Data

As mentioned in the original accident report, “Radar data for this accident was obtained from the Standard Terminal Automation Replacement System (STARS) and from the Harris Opsvue radar replay system licensed to the NTSB” (NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 7). Figure 2-1 shows an overview of the aircraft’s ground track in the vicinity of HOU.



(NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 8)

Figure 2-1 Overview of N4252G’s ground track in the vicinity of HOU

The graphical presentations of the flight track with the associated ATC transcript were analysed by the author to model the complex maneuvers of the aircraft N4252G before the accident. It is based on the plotted radar positions of the N4252G Radar Target File[1].

Figure 2-2 to Figure 2-12 *illustrate the aircraft maneuvers in the vicinity of the airport with annotations from the ATC transcript* (rf. (NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 7)).

[1]The N4252G Radar Target File - HOU ASR Google Earth KML Target File was retrieved from NTSB DMS Website: https://dms.ntsb.gov/pubdms/search/hitlist.cfm?docketID=60618&CFID=2395938&CFTOKEN=81732fd00bba5423-5AB1BC7B-CB39-E91F-3732EB517FD2FBDB

When the ATC transcript in the ATC Factual Report (NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016) was compared with the HOU Tower Accident Package (HOU-ATCT-0064, 2018), the author noticed slight time deviations (in seconds), although it was recognized that the influence for the further analysis was neglectable.

As mentioned in J Appendix, a selection of relevant flight data records was analysed at a physical system level by the author. This data was implemented into diagrams for the application of STAMP (Leveson, 2011), see Diagram 2-1 to Diagram 2-24. The engine parameters CHT and EGT have not been analysed, as the official NTSB investigation excluded any abnormal engine operation until impact. Only the power as set by the pilot was considered.

The following abbreviations were applied for the graphical presentation:

CDT	Local time reference in [hours]:[minutes]:[seconds]
COM	Communicator for ATC-related transmissions (52G, LCI, LCT or LCC)
Heading	Heading referenced to Magnetic North in [°]
RY	Anticipated landing runway for the pilot, as advised by ATC
___T	Radar altitude in [ft]
Ry4-Path	Visual descent angle in [°] from aircraft position (based on actual radar altitude) direct to the aiming point of runway 4 referenced to AltB
Ry35-Path	Visual descent angle in [°] from aircraft position (based on actual radar altitude) direct to the aiming point of runway 35 referenced to AltB
Pitch	Aircraft pitch in [°], a positive pitch number means a nose-up attitude
Roll	Aircraft roll in [°], a positive roll number means a right-bank attitude
Power	Power setting in [%], ranging from 0-100%
Flaps	Flap setting [0, 1, 2], available flap settings correspond to numbers [0%=0, 50%=1, 100%=2]
AltB	Barometric corrected altitude in [ft] above MSL
HOU elevation	43 ft above MSL
IAS	Indicated airspeed in [kts]
Vs	Calculated[2] stall speed (static) of SR20 in [kts] for the respective configuration considering load factor
Vfe/ Vno	Indicates Vfe depending on actual flaps configuration or Vno

[2]Reference stall speed applied for Diagram 2-1 to Diagram 2-24 (for 0° bank) acc. POH-SR20 (2015): *69 KIAS (for flaps 0), 65 KIAS (for flaps 50%), 60 KIAS (for flaps 100%)* (rf. (POH-SR20 2015, p. 5-12)).

The following Table 2-1 summarizes the ATC transmissions from initial ATC contact until the first go-around as retrieved from the HOU Tower Accident Package N4252G (2018).

CDT	COM	ATC Transmission/ Note	RY
12:52:47	52G	*The pilot contacted the HOU tower LC position at 1252:47 and reported at 1600 ft.*	4
12:53:04	LCT	*The trainee (LCT) missed the source of the call and thought it was a Southwest Airlines (SWA) flight. He responded as if the SWA pilot had called, then realized that it had actually been the pilot of N4252G.*	4
12:53:12	LCT	*After resolving the confusion, the LCT transmitted, "… you're number 2 following a 737 on a 3 mile final, caution wake turbulence, runway 4 cleared to land".*	4
12:53:20	52G	*"We will be runway uh number two following the Boeing runway 4 cleared to land …"*	4
12:53:25	LCT	*"yes ma'am and say parking"*	4
12:53:28	52G	*"We'll be parking Million Air 4252G"*	4
12:53:51	LCI	*"Cirrus 4252G proceed direct to the numbers, you're going to be inside a 737 intercepting a 10 mile final"*	4
12:54:00	52G	*"OK you would like me to proceed to the numbers 4252G"*	4
12:54:04	LCI	*"November 52G, what did approach tell you before?"*	4
12:54:09	52G	*"Uh, to land left base runway 4 and follow the Boeing, 4252G"*	4
12:54:16	LCI	*"... proceed direct the numbers for runway 4, direct to Hobby"*	4
12:54:21	52G	*"Direct to Hobby, 4252G"*	4
12:54:24	I90	*The Hobby Final controller called the LC controllers to ask that they have the Cirrus proceed direct to the numbers, and the LCI controller responded that the pilot had been directed to do so.*	4
12:54:39	LCT	*The LCT controller asked the pilot to maintain maximum forward speed and proceed direct to the numbers, advising her that there was a 737 on 9 mile final following the Cirrus that was overtaking it by 80 kts. The pilot responded that she would proceed direct to the numbers and keep her speed up.*	4
12:55:49	LCT	*The controller broadcasted to all aircraft that HOU ATIS information India was current, altimeter 29.94. The pilot was not required to acknowledge the updated ATIS announcement and did not do so.*	4
12:55:59	LCT	*SWA235 contacted HOU, reporting that they were on 5 mile final for runway 4. The LCT controller responded that they were number 2 following a Cirrus on 2 mile final, cleared the pilot to land, and instructed him to slow to final approach speed.*	4
12:56:19	LCT	*wind check of "080 degrees at 13 kts gusting to 18 kts" was broadcasted*	4
12:57:02	LCI	*"just go-around and fly runway heading for now, maintain VFR, and I'm going to put you back on the downwind for runway 35. The winds are 090 at 13 gusts 18 [kt]. Can you accept runway 35?"*	4

(rf. (HOU-ATCT-0064, 2018, p. 42, 43, 44)).

Table 2-1 Summary of ATC transmissions, 12:52:47 - 12:57:02 CDT

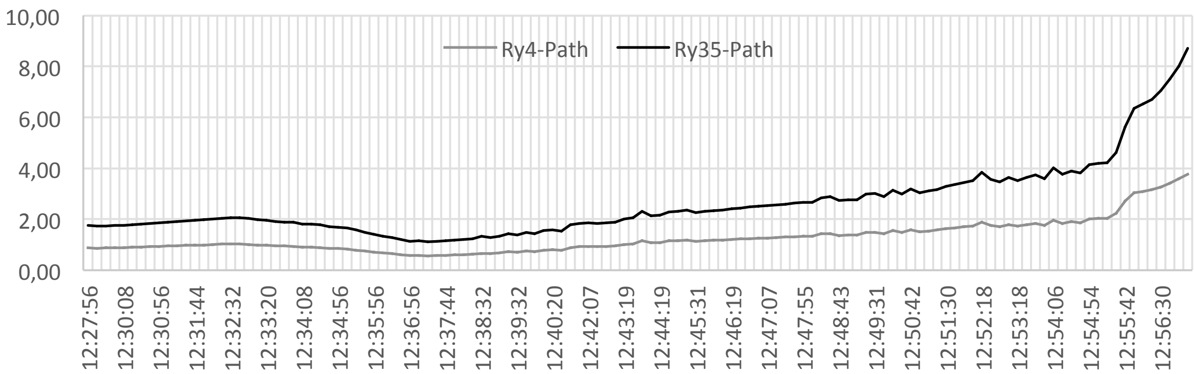


Diagram 2-1 Visual descent angle direct to the aiming point, 12:27:56 - 12:56:30 CDT

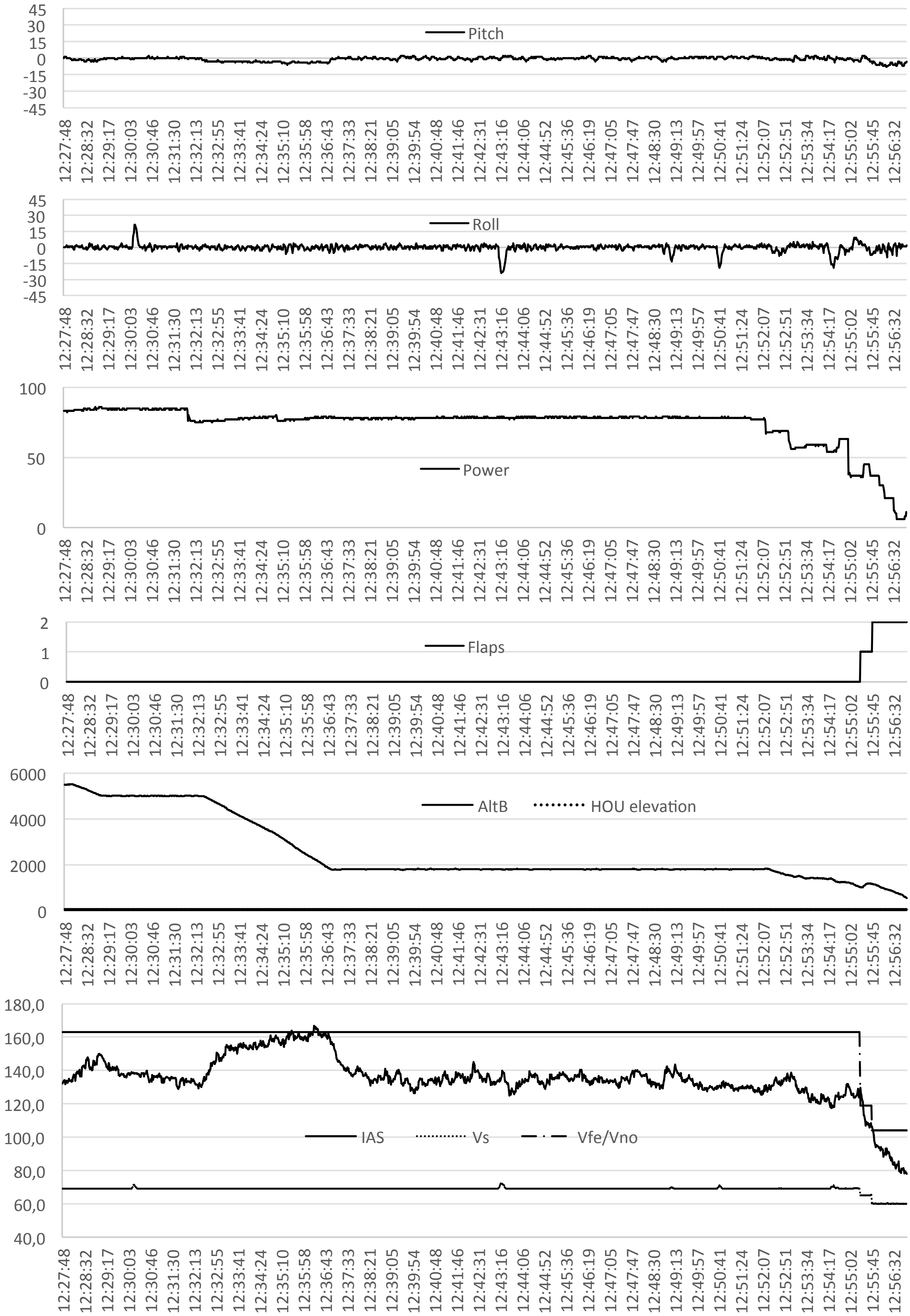
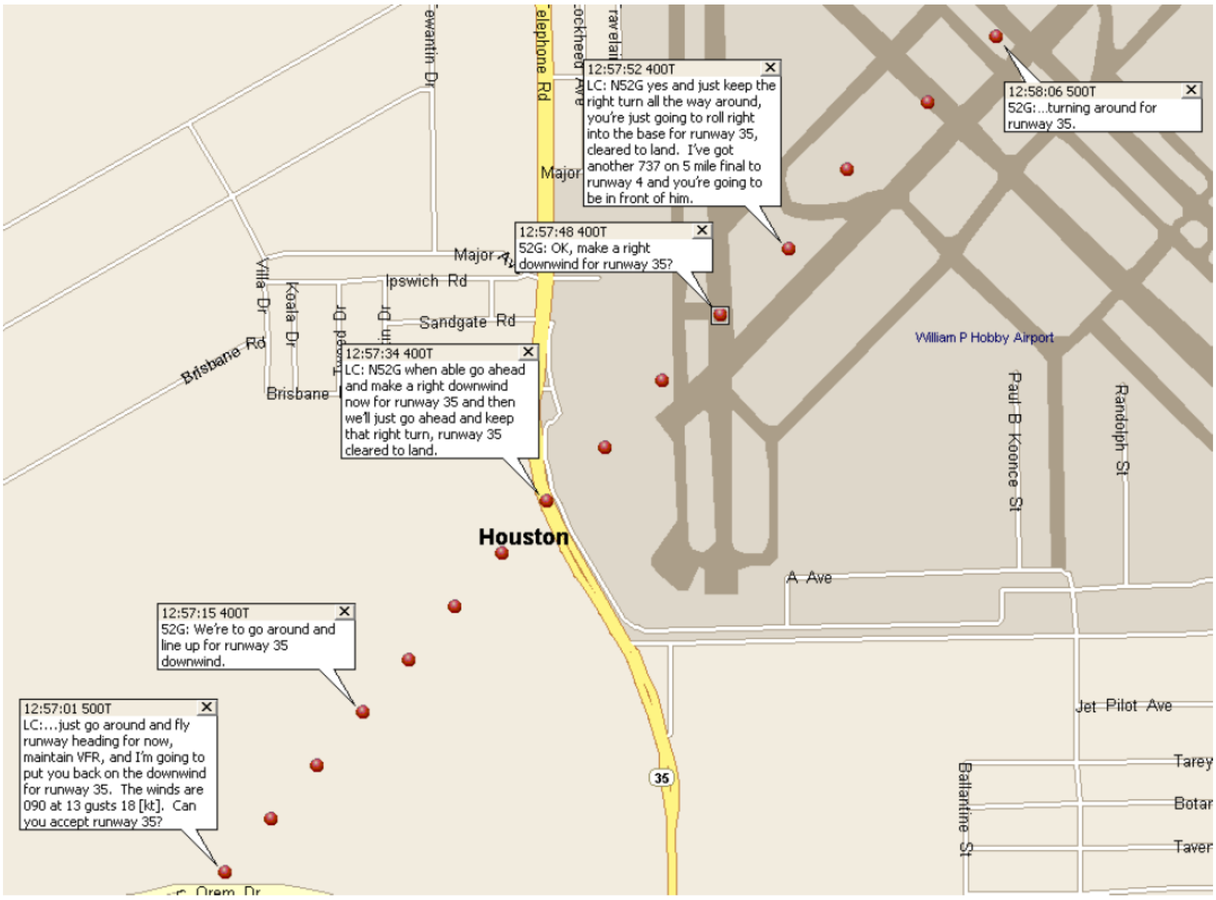


Diagram 2-2 Graphical depiction of basic flight data, 12:27:48 - 12:56:32 CDT

The detailed analysis of the flight data and the graphical presentation of the aircraft's flight parameters in Diagrams 2-1 (12:27:56 - 12:56:30 CDT) and 2-2 (12:27:48 - 12:56:32 CDT) in relation to the ATC transcript in Table 2-1 (12:52:47 - 12:57:02 CDT) for the first approach of N4252G were analysed in detail.

It reveals that between 12:35:34 CDT and 12:36:27 CDT the Vno was exceeded by up to 3.7 kts. This is permitted in smooth flight conditions. As the conditions of turbulence could not be extracted, exceeding the Vno cannot be considered as an unsafe control action. At 12:55:23 CDT, the pilot selected the flaps to 50% at a speed of 129.5 KIAS, thereby exceeding Vfe of 119 KIAS by 10.5 kts. Until 12:55:28 CDT, the Vfe limit was exceeded (considering the ATC request to "keep speed up"). When selecting the flaps to 100% at 12:55:47 CDT, Vfe was exceeded by 2 kts for 1 second. The aircraft's final approach speed was gradually decreasing but not deceeding the normal approach speeds (83 KIAS for flaps 50%, 78 KIAS for flaps 100%, for procedural details refer to E Appendix), which - together with the minor flight path corrections and the visual descent angle of around 3 degrees to the aiming point of runway 4 - concluded that stabilized approach criteria were fulfilled. According to the Cirrus Envelope of Safety (refer to L Appendix, Figure 6-3 Envelope of Safety), the reported wind ("080 degrees at 13 kts gusting to 18 kts") exceeded[3] the personalized x-wind limit (wind limit 15 kts, x-wind limit 5 kts, maximum gust 5 kts) according to the Pilot's Capability Category (for details, refer to D Appendix).

[3]The author of this thesis recalculated the wind components considering Figure 6-4 Wind component diagram as follows: 080°/ 13 kts steady (gusts up to 18 kts) equals 10 kts (gusts up to 14 kts) headwind and 8 kts (gusts up to 11 kt) crosswind for runway 4 (041° runway track).



(NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 9)

Figure 2-2 Initial approach to runway 4 and ATC-directed go-around

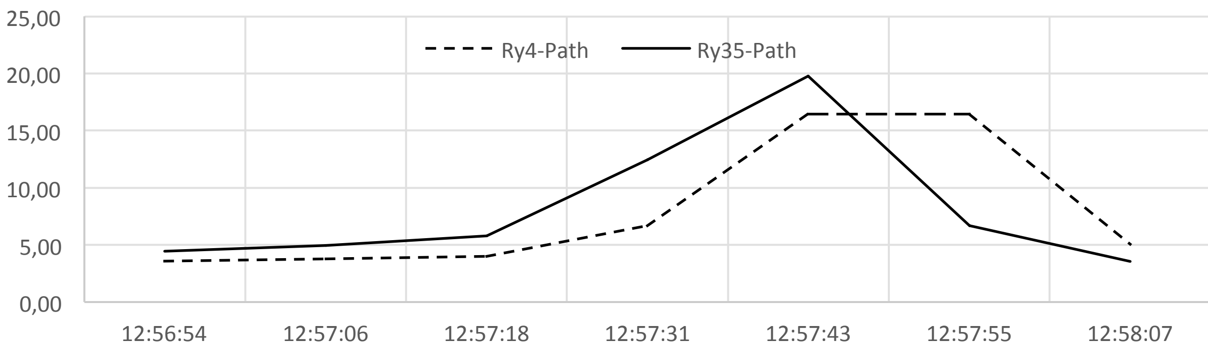


Diagram 2-3 Visual descent angle direct to the aiming point, 12:56:54 - 12:58:07 CDT

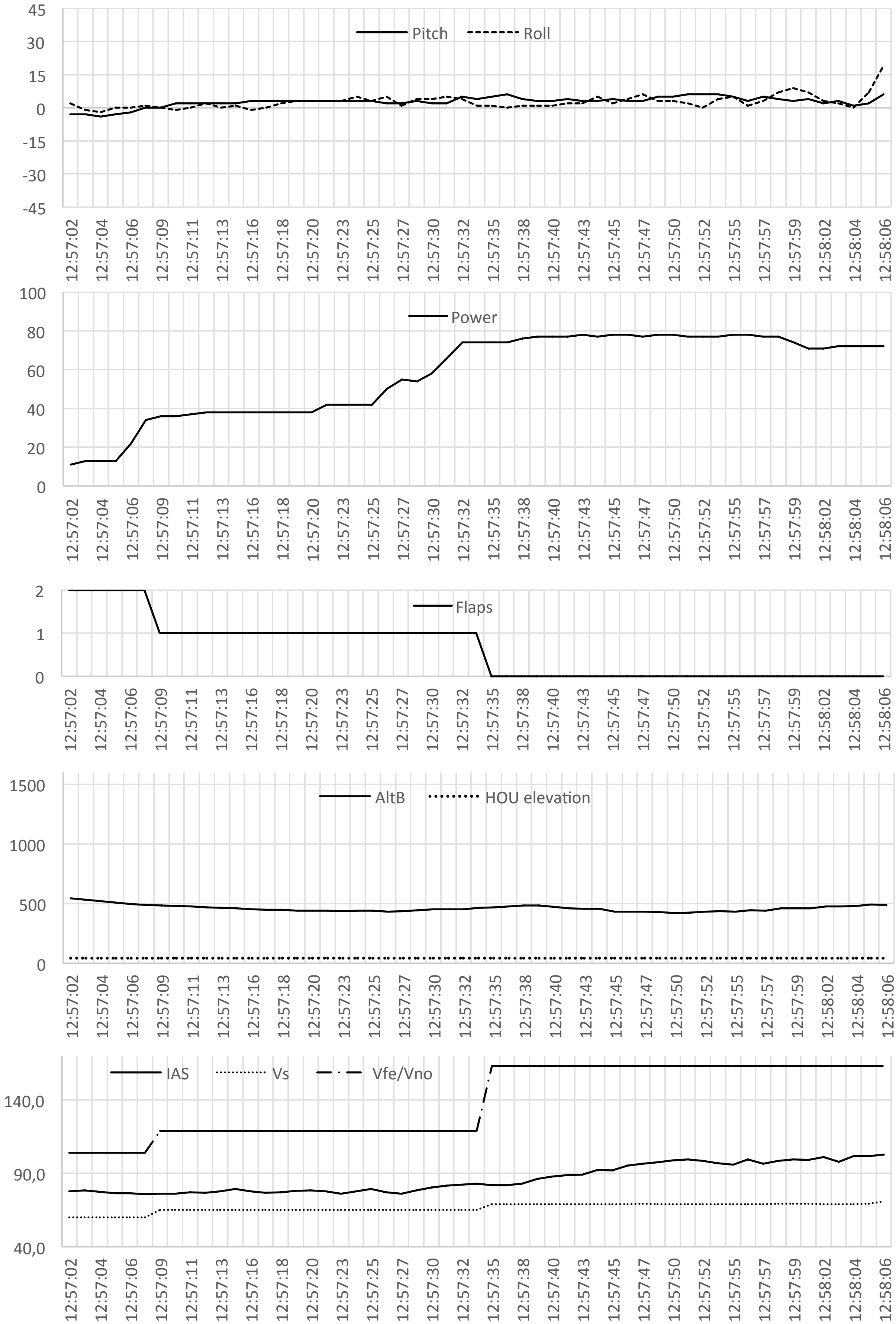
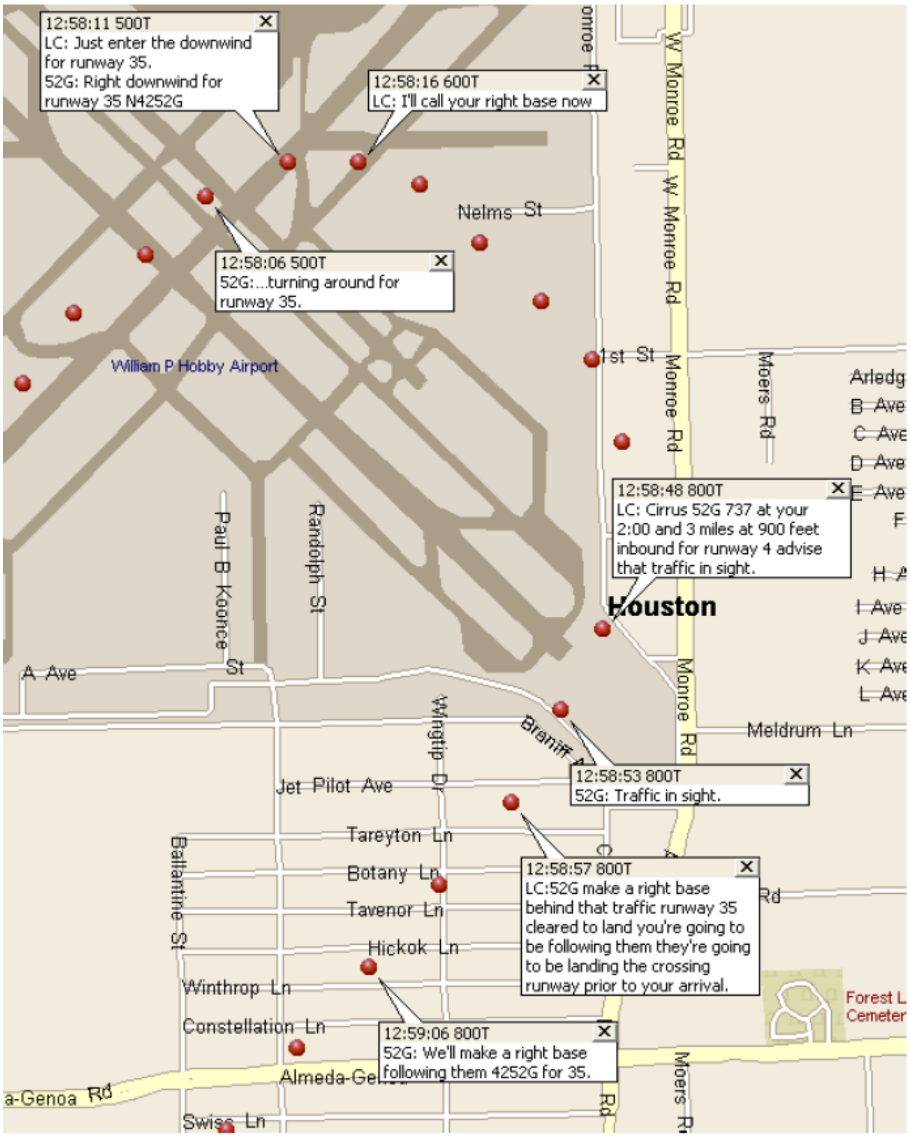


Diagram 2-4 Graphical depiction of basic flight data, 12:57:02 - 12:58:06 CDT

The detailed analysis of the flight data and the graphical presentations of the flight track with the associated ATC transcript in Figure 2-2 and the graphical presentation of the aircraft's flight parameters in Diagrams 2-3 (12:56:54 - 12:58:07 CDT) and 2-4 (12:57:02 - 12:58:06 CDT) in relation to the ATC transcript for the initial approach of N4252G to runway 4 were analysed in detail.

It reveals that the approach was cancelled by ATC at 12:57:01 by requesting N4252G to go-around. Up to then, the aircraft had been fulfilling stabilized approach criteria for landing on runway 4. When initiating the go-around, maximum power for the go-around procedure was not set (for procedural details, refer to E Appendix), which the author assumes as the pilot's intention to maintain the present altitude (AltB) of approximately 500 ft and avoid overspeed conditions with excessive power. The flaps were retracted to 50% at 75 KIAS and to 0% at 83 KIAS, which is within safe limits and according to the POH procedures (for procedural details, refer to E Appendix). Questioning the right downwind for runway 35 at 12:57:48 CDT by the pilot shows that uncertainty about the ATC intentions was present.



(NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 10)

Figure 2-3 Maneuvers following the initial go-around

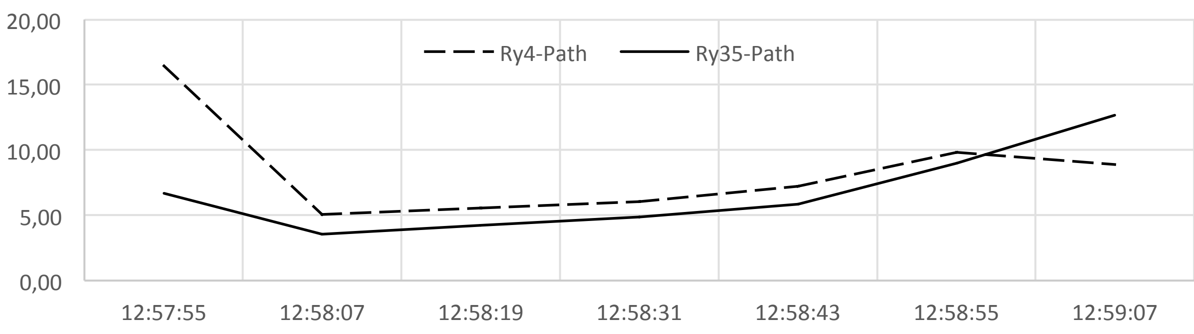


Diagram 2-5 Visual descent angle direct to the aiming point, 12:57:55 - 12:59:07 CDT

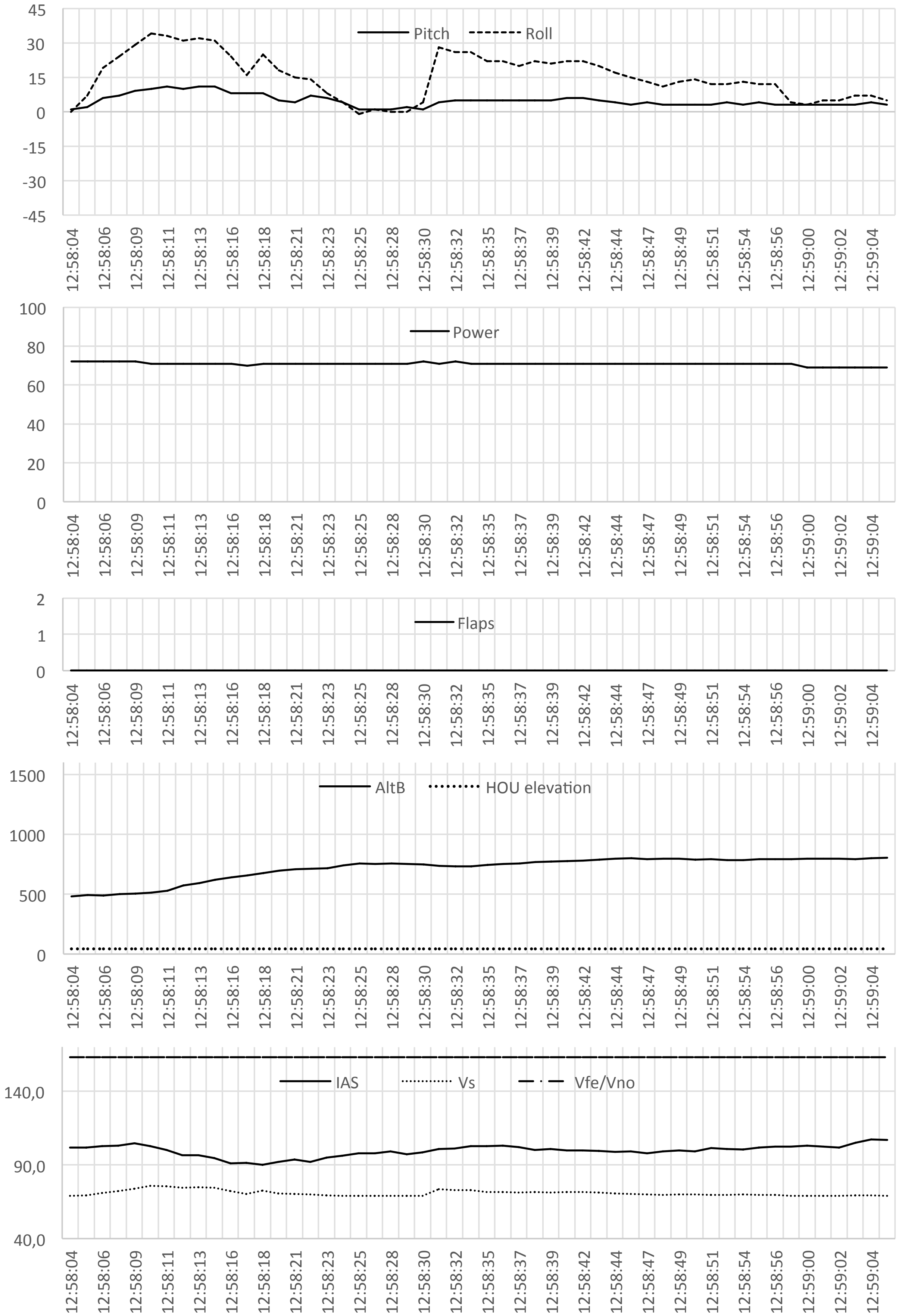
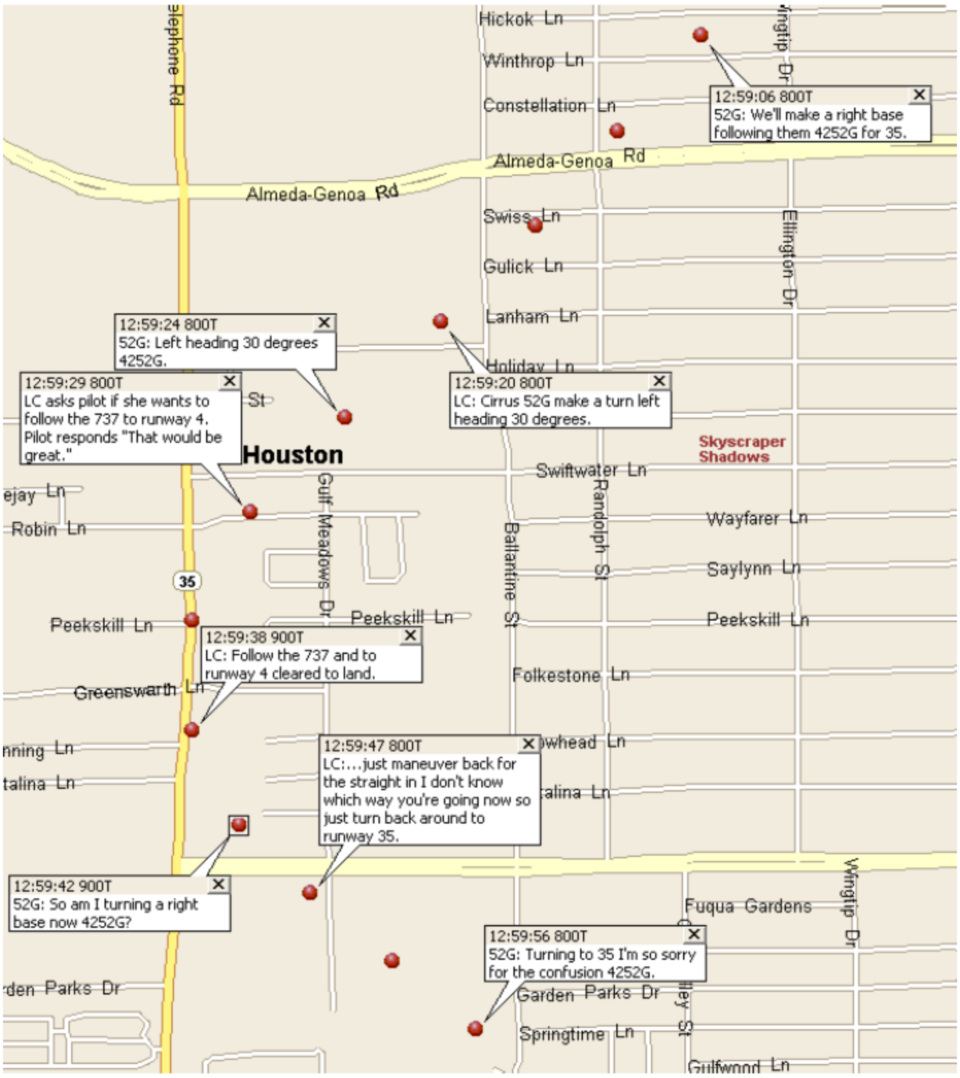


Diagram 2-6 Graphical depiction of basic flight data, 12:58:04 - 12:59:04 CDT

The detailed analysis of the flight data and the graphical presentations of the flight track with the associated ATC transcript in Figure 2-3 and the graphical presentation of the aircraft's flight parameters in Diagrams 2-5 (12:57:55 - 12:59:07 CDT) and 2-6 (12:58:04 - 12:59:04 CDT) for the maneuvers following the initial go-around of N4252G reveals that no unsafe control actions had been performed by the pilot.



(NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 11)

Figure 2-4 Continued pattern maneuvers

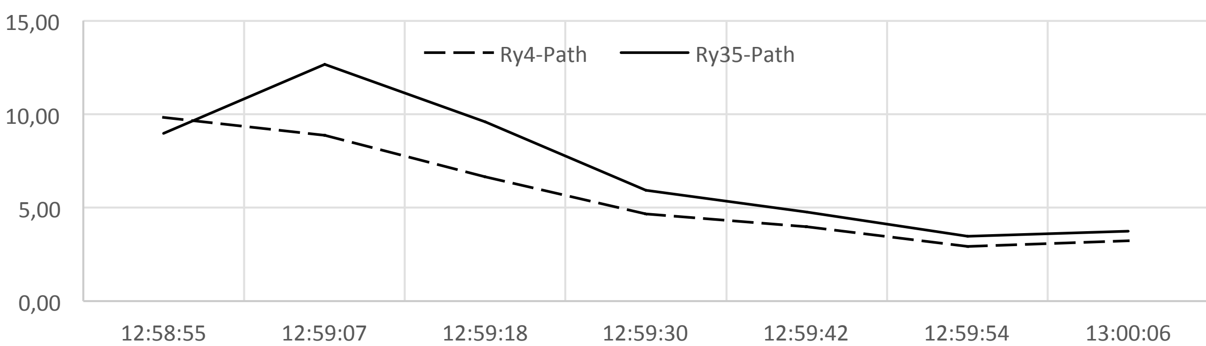


Diagram 2-7 Visual descent angle direct to the aiming point, 12:58:55 - 13:00:06 CDT

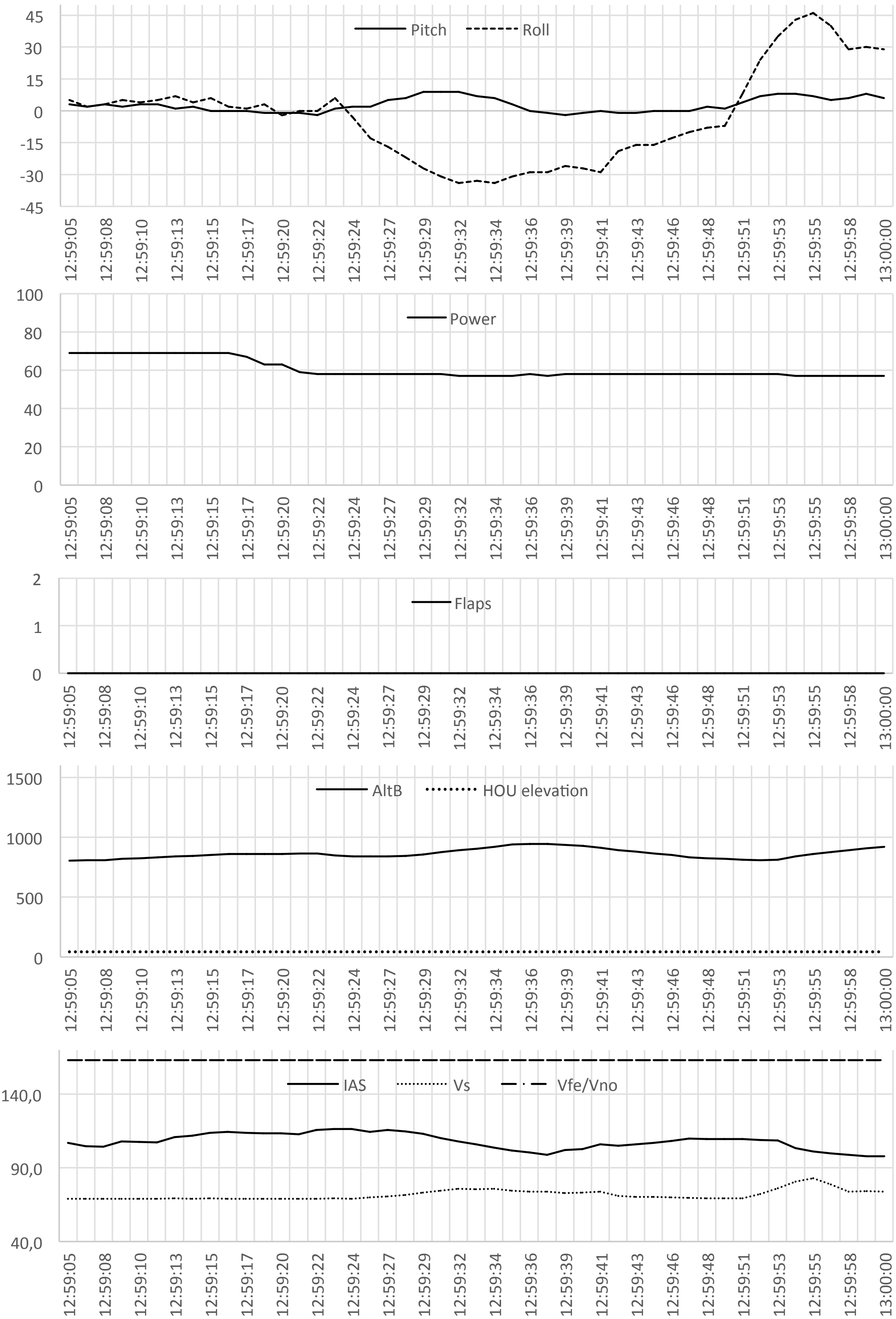


Diagram 2-8 Graphical depiction of basic flight data, 12:59:05 - 13:00:00 CDT

The detailed analysis of the flight data and the graphical presentations of the flight track with the associated ATC transcript in Figure 2-4 and the graphical presentation of the aircraft's flight parameters in Diagrams 2-7 (12:58:55 - 13:00:06 CDT) and 2-8 (12:59:05 - 13:00:00 CDT) for the continued pattern maneuvers of N4252G were analysed in detail.

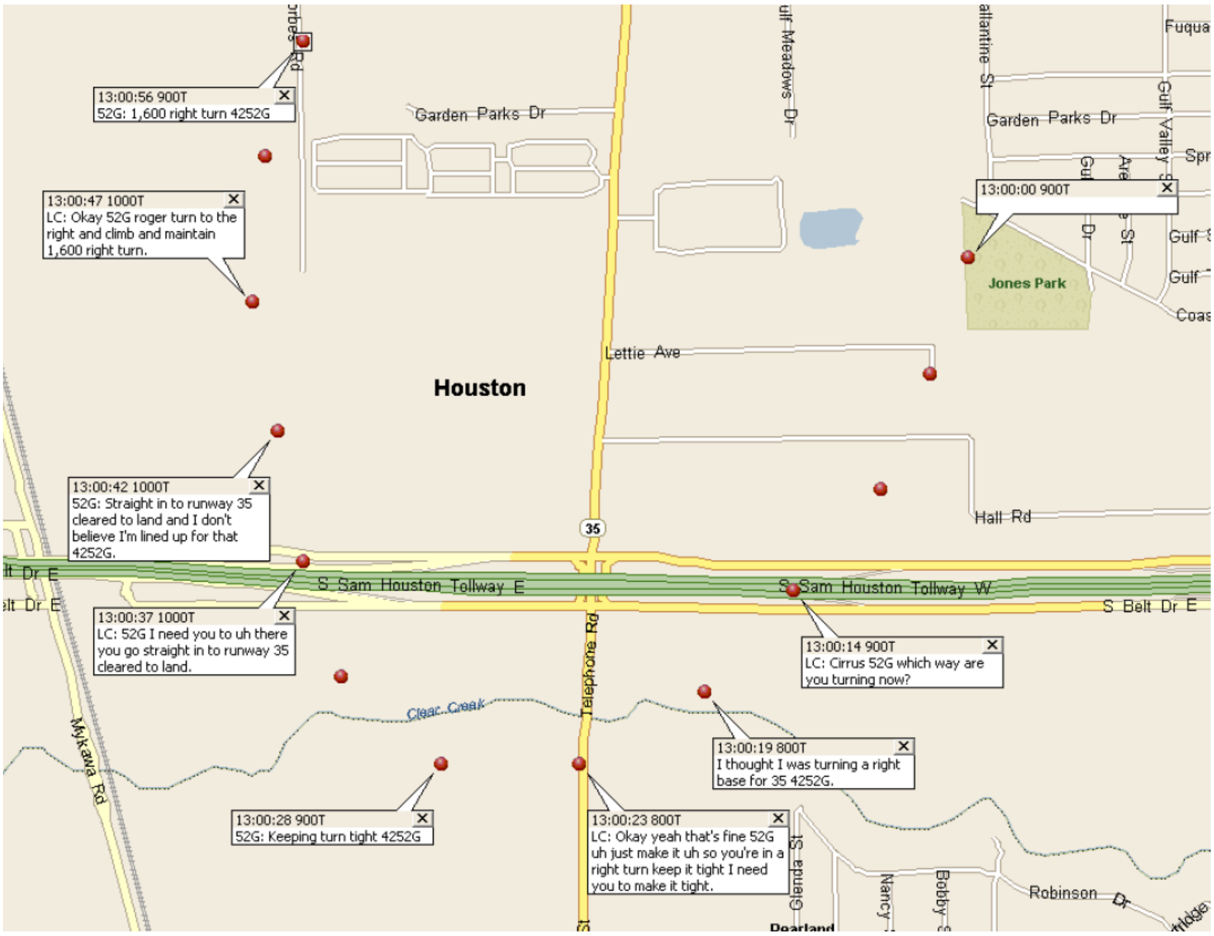
It reveals that between 12:59:22 and 12:59:56 CDT the bank angle was rapidly changing from a wings-level flight via a left roll of 34 degrees up to a right steep turn[4] of 46 degrees.

The AOPA website (2019) states that *flying a visual pattern should be limited to a maximum bank angle of 30 degrees* (rf. (AOPA.org retrieved from https://www.aopa.org/training-and-safety/Students/presolo/skills/entering-the-traffic-pattern, 2019)).

The non-standard phraseology[5] ("left heading 30 degrees" instead of "turn left heading 030 degrees" or "turn left by 30 degrees") at 12:59:20 CDT and runway assignment changes through ATC (from runway 35 to runway 4 and back to runway 35) within less than 1 minute (12:58:57 CDT – 12:59:47 CDT).

[4]*In visual flight turns exceeding 45 degrees of bank are defined as "steep turns"* (rf. (US Department of Transportation, Pilot's Handbook of Aeronautical Knowledge, 2016, G29)).

[5]Standard ATC Phraseologies for Vectors to Final Approach are defined in ICAO Document 9432 (2007), Manual of Radiotelephony, Chapter 7.5



(NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 12)

Figure 2-5 Continued pattern maneuvers

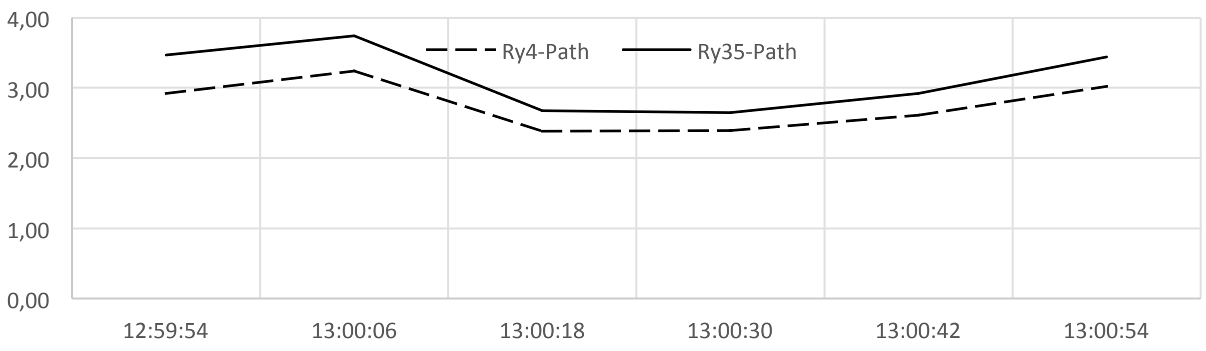


Diagram 2-9 Visual descent angle direct to the aiming point, 12:59:54 - 13:00:54 CDT

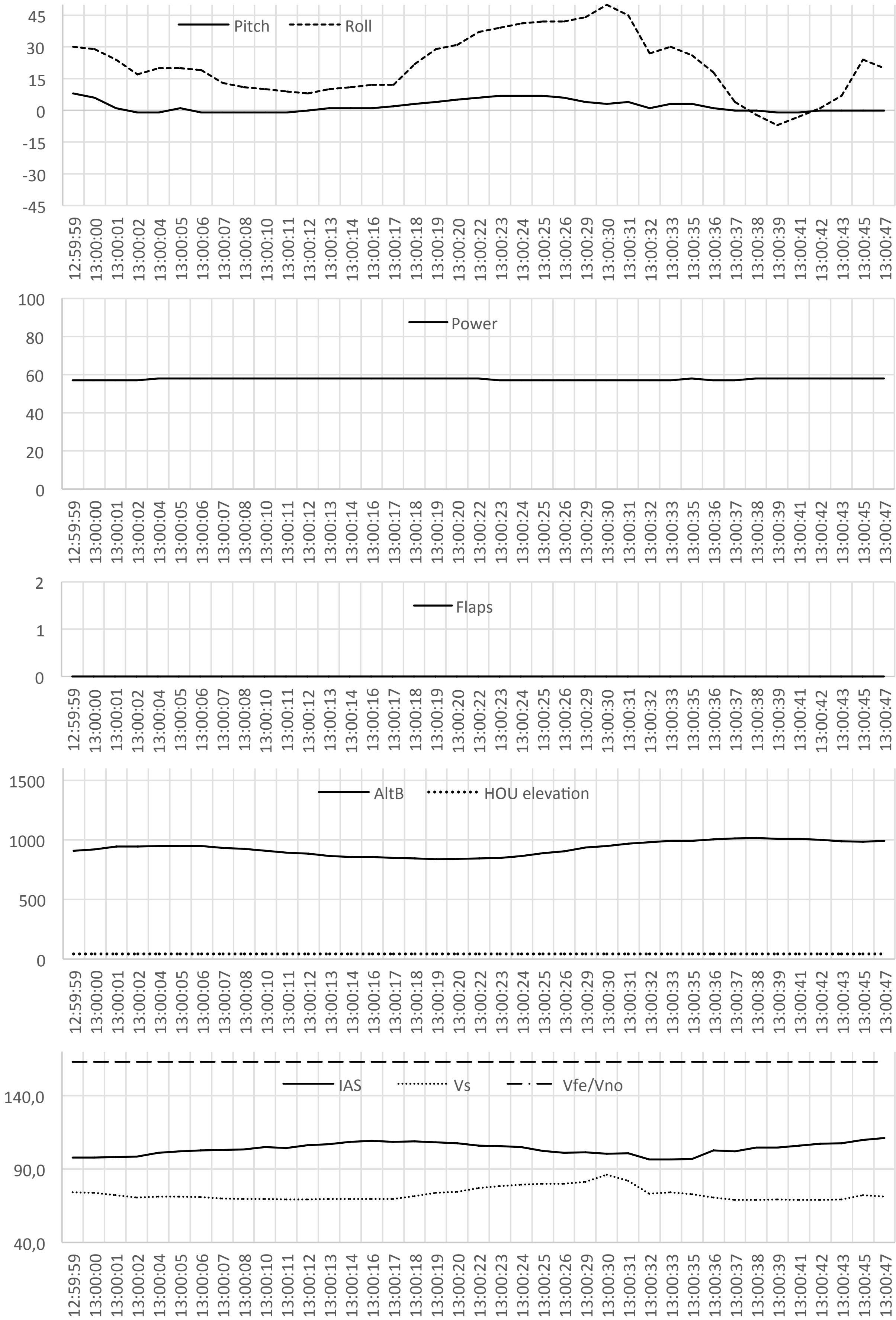


Diagram 2-10 Graphical depiction of basic flight data, 12:59:59 - 13:00:47 CDT

The detailed analysis of the flight data and the graphical presentations of the flight track with the associated ATC transcript in Figure 2-5 and the graphical presentation of the aircraft's flight parameters in Diagrams 2-9 (12:59:54 - 13:00:54 CDT) and 2-10 (12:59:59 - 13:00:47 CDT) for the continued pattern maneuvers of N4252G were analysed in detail.

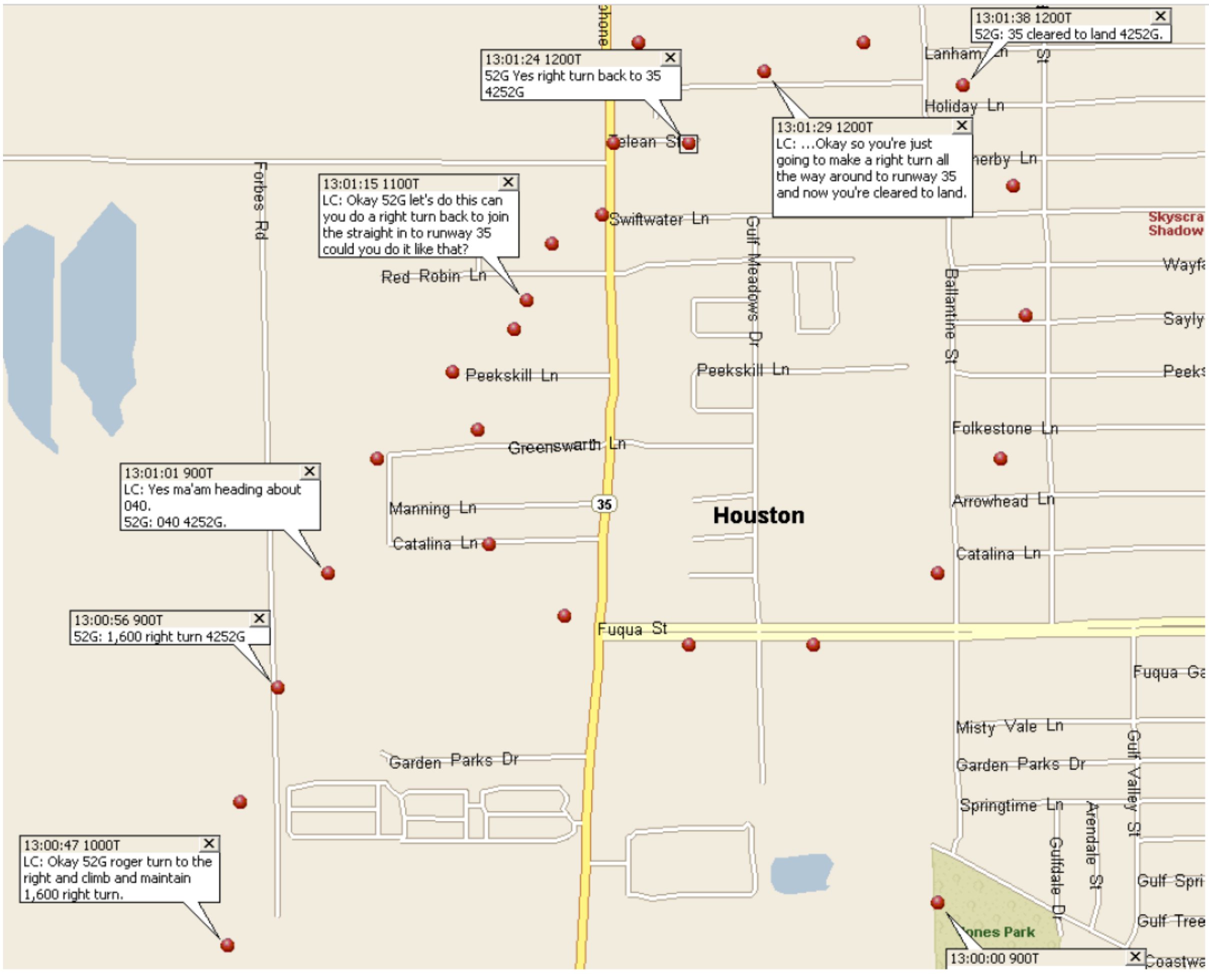
It reveals that at 13:00:14 CDT the ATC was uncertain in which direction N4252G was turning. After clarification the pilot was cleared by ATC for a tight turn ("keep it tight, I need you to make it tight"), which is a non-standard ICAO phraseology. The following bank angle was increased to a maximum of 50 degrees at 13:00:30 CDT, which reduced the stall speed margin[6] to 15 kts.

At 13:00:42, the aircraft was at a position (altitude 998 ft, direct visual descent angle 2.92°, speed 107 KIAS, approximately[7] 15 degrees left of centerline) suitable for landing at runway 35. For an unknown reason, the pilot advised ATC about her uncertainty of being correctly lined up for runway 35, most probably due a severe degradation of situational awareness due to the high workload situation. At 13:00:47 CDT, ATC cleared the pilot to turn right (without any heading assignment, which is not in compliance with ICAO standard phraseology) and a climb to 1600 ft[8].

[6] as difference between IAS and Vs in [kts]

[7] measured by the author with Google Earth Pro Application, considering the N4252G Radar Target File - HOU ASR Google Earth KML Target File as retrieved from NTSB DMS Website: https://dms.ntsb.gov/pubdms/search/hitlist.cfm?docketID=60618&CFID=2395938&CFTOKEN=81732fd00bba5423-5AB1BC7B-CB39-E91F-3732EB517FD2FBDB

[8] Author's note: ATC clearance to climb to 1600 ft above MSL (considering HOU airport elevation of 43 ft above MSL) seems unusual high for expecting to keep a single engine aircraft visually in an airport's traffic pattern.



(NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 13)

Figure 2-6 Changing approach from runway 4 to runway 35

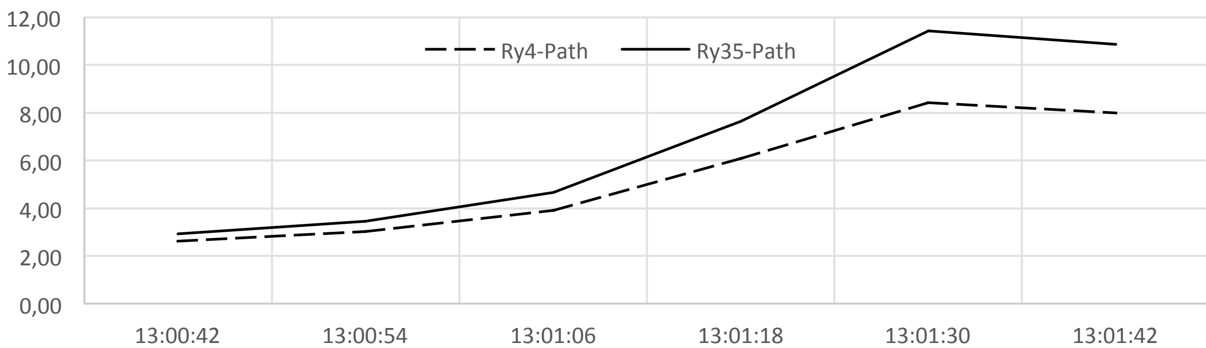


Diagram 2-11 Visual descent angle direct to the aiming point, 13:00:42 - 13:01:42 CDT

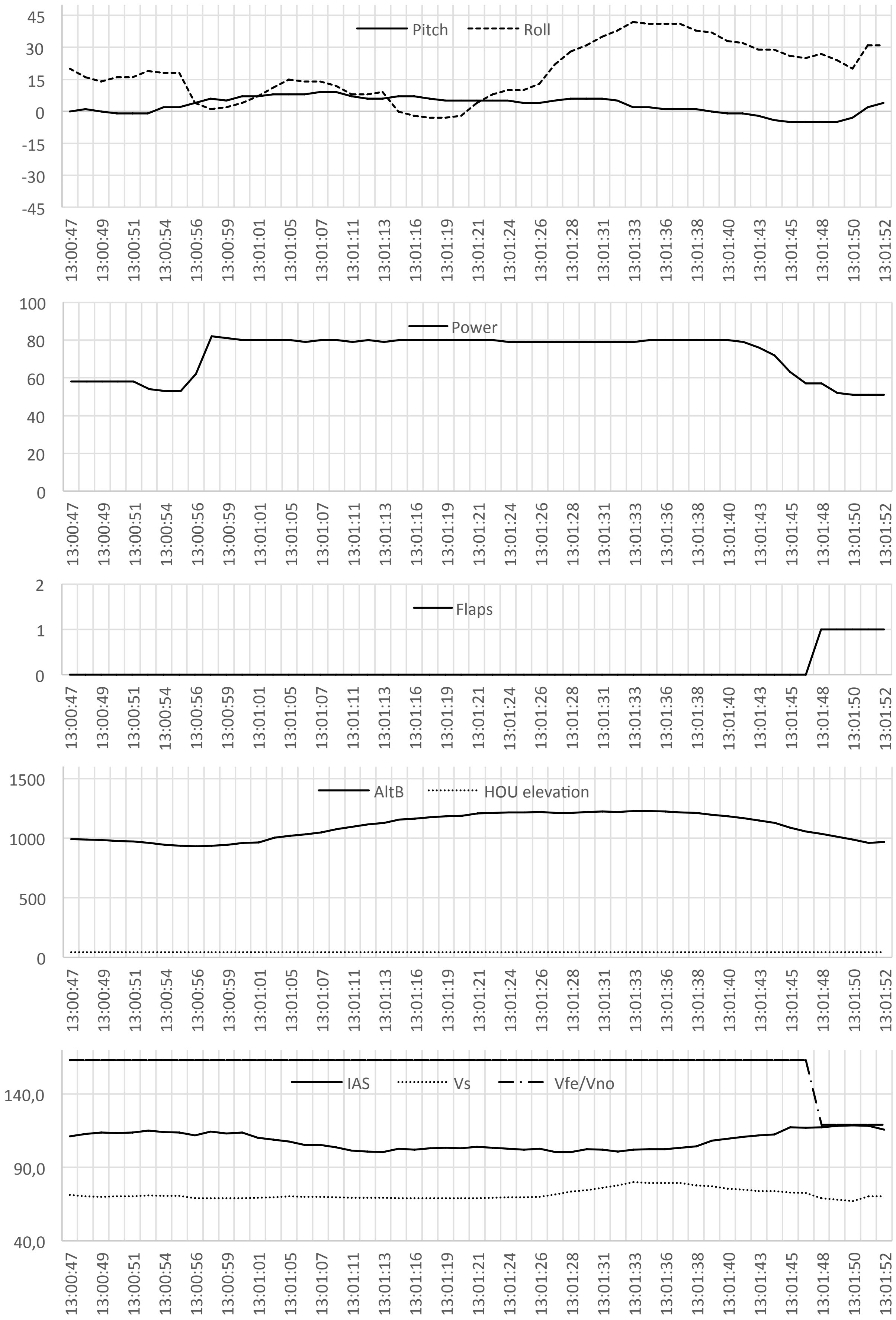
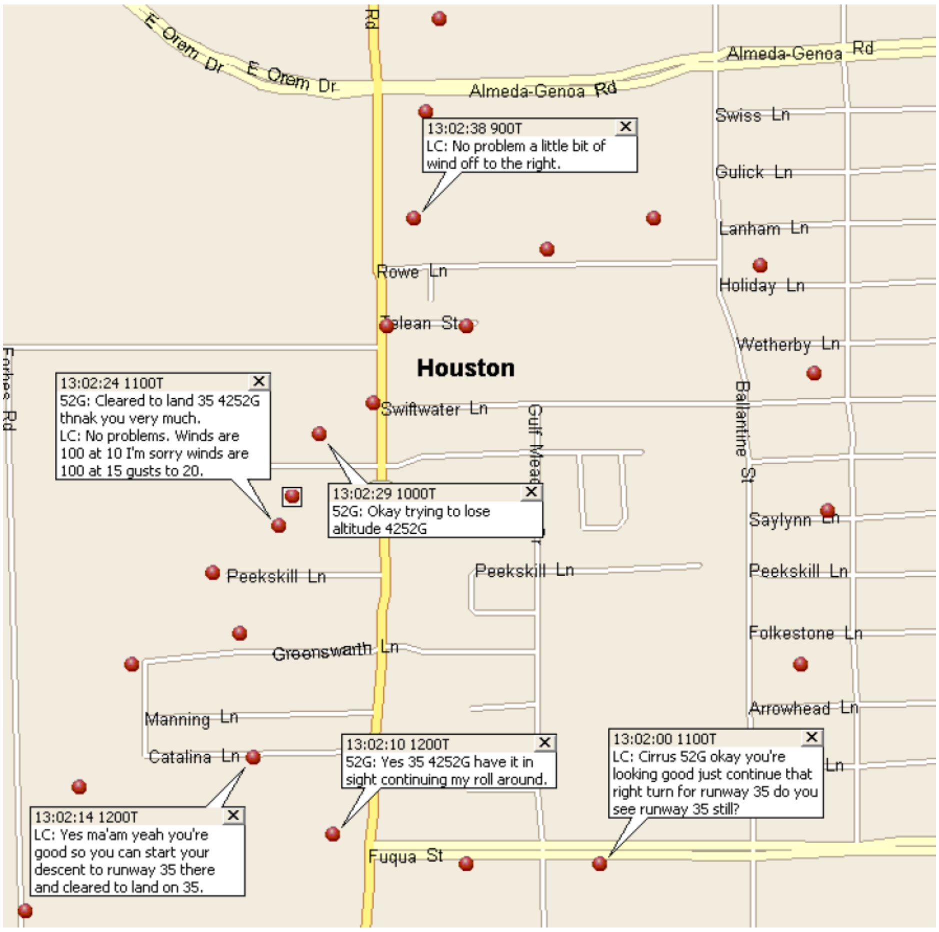


Diagram 2-12 Graphical depiction of basic flight data, 13:00:47 - 13:01:52 CDT

The detailed analysis of the flight data and the graphical presentations of the flight track with the associated ATC transcript in Figure 2-6 and the graphical presentation of the aircraft's flight parameters in Diagrams 2-11 (13:00:42 - 13:01:42 CDT) and 2-12 (13:00:47 - 13:01:52 CDT) for the pattern maneuvers of N4252G when the approach was changed from runway 4 to runway 35 were analysed in detail.

It reveals that for the discontinued approach the power was increased from 53% to 82% at 13:00:57 CDT. As the flaps were not extended the missed approach procedure was performed without the requirement to retract the flaps. The airspeed at the time of the missed approach was 114 KIAS. From 13:01:33 CDT till 13:01:37 CDT the bank angle was exceeding 40 degrees. At 13:01:29 CDT ATC advised to make a right turn "all the way around" to runway 35, while the pilot was increasing the bank angle up to 42 degrees (at 13:01:33 CDT) in a right turn. At 13:01:42 CDT the aircraft was on a visual descent angle to the aiming point of runway 35 of 10.9 degrees (note that the PAPI for runway 35 was calibrated for 3.0 degrees) in a right banking turn of 32 degrees. At 13:01:46 CDT the pilot selected the flaps to 50% with a speed of 117 KIAS (2 kts below Vfe) in a right turn with a bank angle of 25 degrees.



(NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 14)

Figure 2-7 Setting up for initial straight-in approach to runway 35

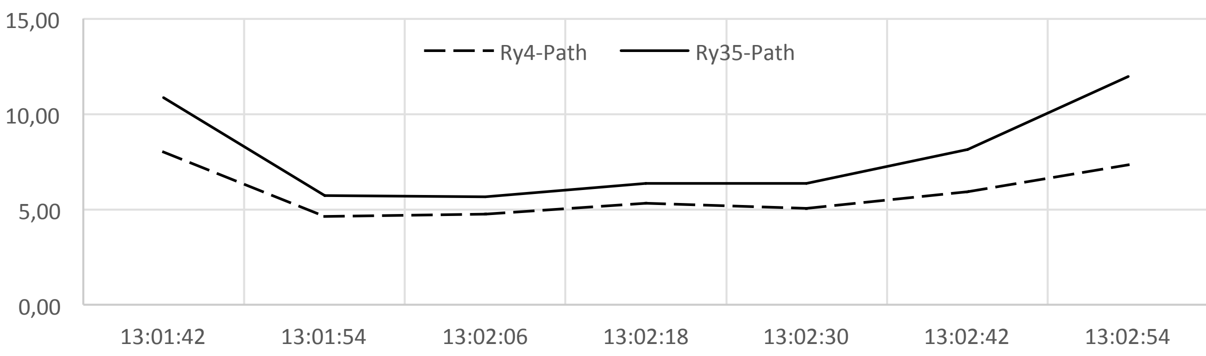


Diagram 2-13 Visual descent angle direct to the aiming point, 13:01:42 - 13:02:54 CDT

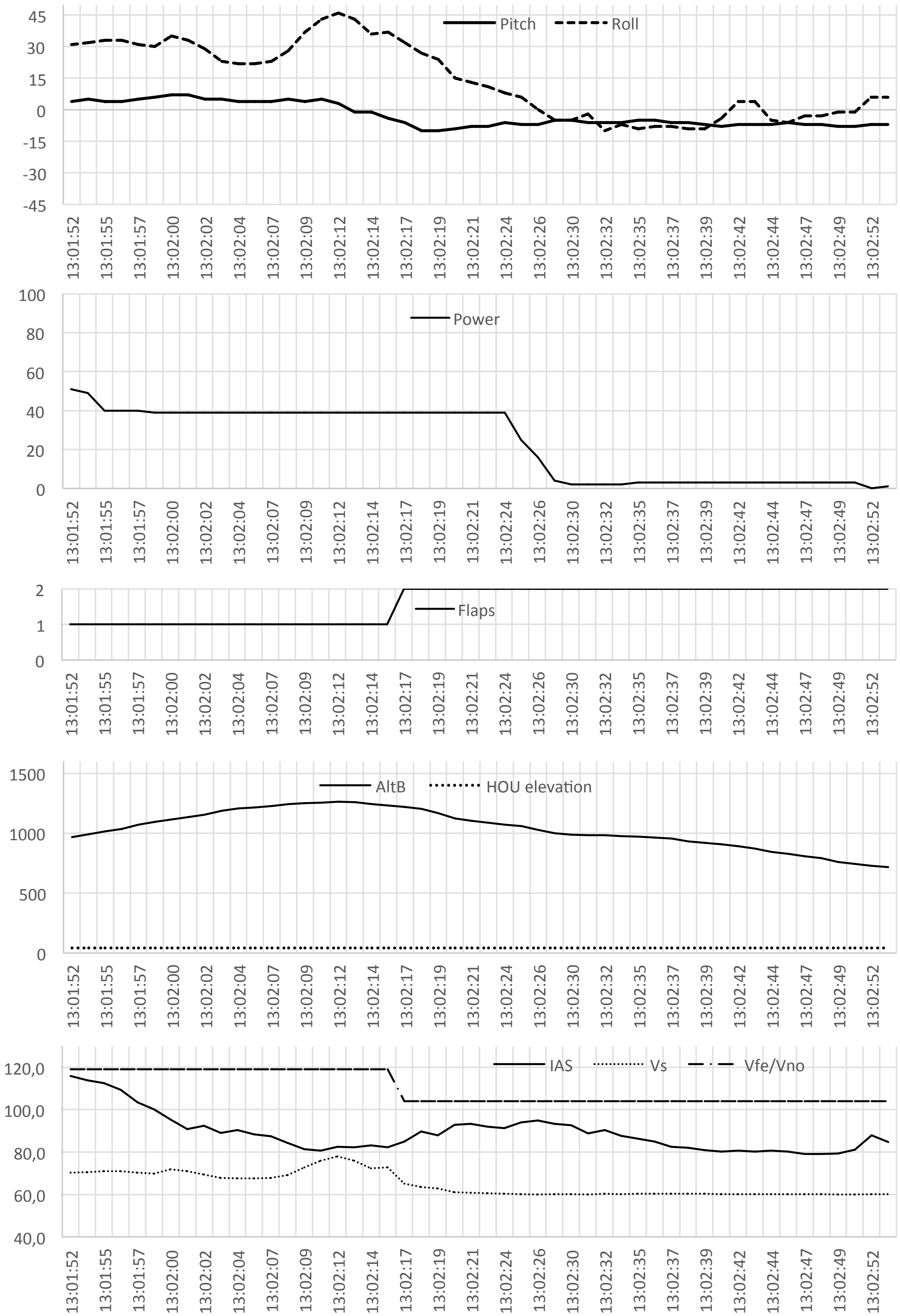


Diagram 2-14 Graphical depiction of basic flight data, 13:01:52 - 13:02:52 CDT

The flight data and the graphical presentations of the flight track with the associated ATC transcript in Figure 2-7 and the graphical presentation of the aircraft's flight parameters in Diagrams 2-13 (13:01:42 - 13:02:54 CDT) and 2-14 (13:01:52 - 13:02:52 CDT) for the setup of N4252G for the initial straight-in approach to runway 35 were analysed in detail.

At 13:02:00 CDT, the ATC advised the pilot "looking good to start the descent to runway 35". The aircraft was at a position with 5.7 degrees visual descent angle to runway 35, at an altitude AltB of 1117 ft with 95 KIAS, still climbing with a 35 degrees bank angle.

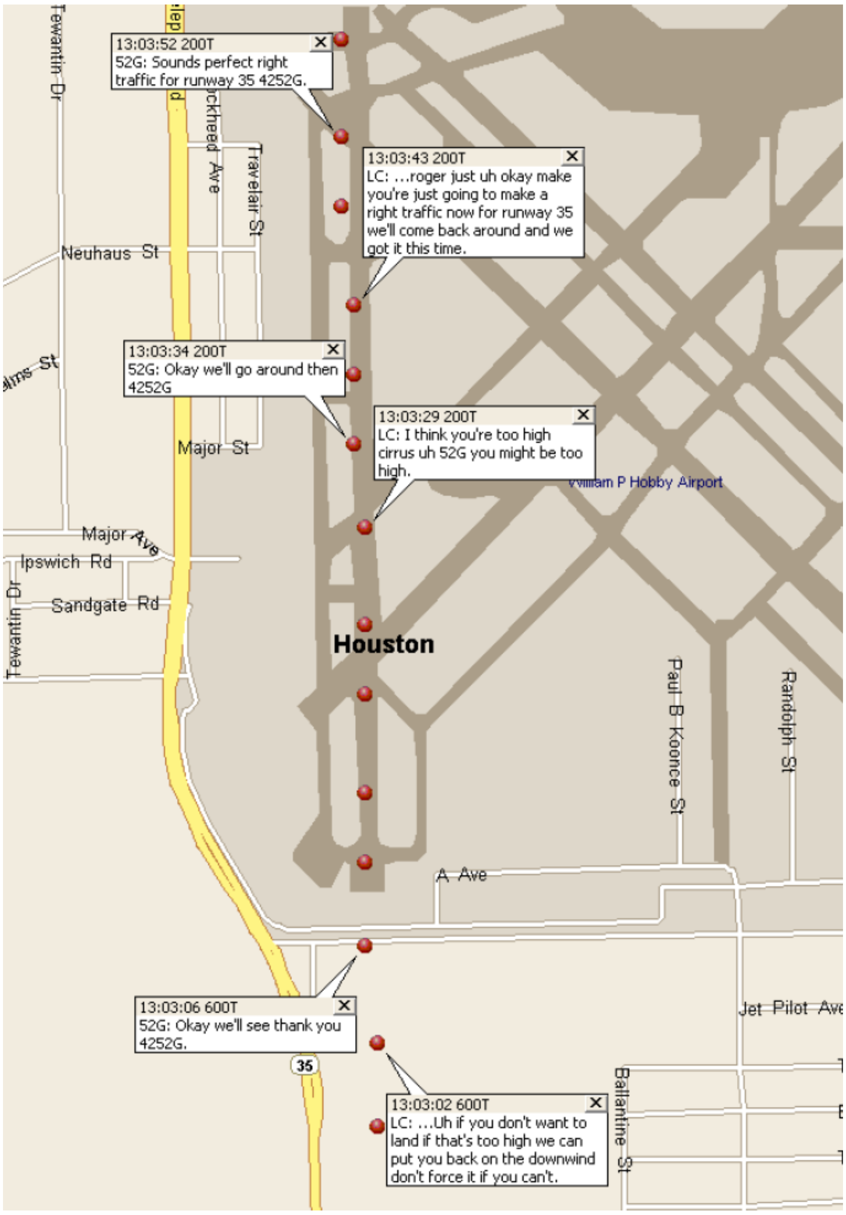
At 13:02:12 CDT, when the pilot reported the runway in sight the aircraft was at a position with 6.0 degrees visual descent angle to runway 35 (note that the PAPI for runway 35 was calibrated for 3.0 degrees), with an airspeed of 82.4 KIAS, turning right in a steep turn of 46 degrees of bank angle. The high bank angle reduced the stall speed margin to 4 kts. Therefore, it can be assumed that the stall warning was triggered[9]. The pilot subsequently reduced the angle of pitch and roll and the stall speed margin increased. At 13:02:15 CDT, the flaps were extended to 100% whilst turning right with a bank angle of 37 degrees.

At 13:02:24 CDT, the power was reduced to idle within 5 seconds. Simultaneously, ATC advised the landing clearance and the actual wind of 100 degrees at 15 kts with gusts to 20 kts for runway 35. According to the Cirrus Envelope of Safety (refer to L Appendix, Figure 6-3 Envelope of Safety), the reported wind was exceeding[10] the personalized x-wind limit (wind limit 15 kts, x-wind limit 5 kts, maximum gust 5 kts) according to the Pilot's Capability Category (for details, refer to D Appendix).

At 13:02:29, the pilot advised to ATC "trying to lose altitude". The initiated descent rate for a stabilized approach to the aiming point of runway 35 was not sufficient and the visual descent angle further increased. At 13:02:54, CDT the visual descent angle to the aiming point of runway 35 was 12.0 degrees, far above the nominal PAPI angle of 3.0 degrees.

[9]"the stall speed warning horn sound[s] between 5 and 10 kts before the stall" (POH-SR20, 2015, p. 4-23). For the prevailing analysis the author has anticipated that stall warning triggers if IAS < (Vs + 5 kts).

[10]The author of this thesis recalculated the wind components considering Figure 6-4 Wind component diagram as follows: 100°/ 15 kts steady (gusts up to 20 kts) equals 4 kts (gusts up to 5 kts) tailwind and 15 kts (gusts up to 19 kts) crosswind for runway 35 (356° runway track).



(NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 15)

Figure 2-8 Runway 35 first approach and go-around

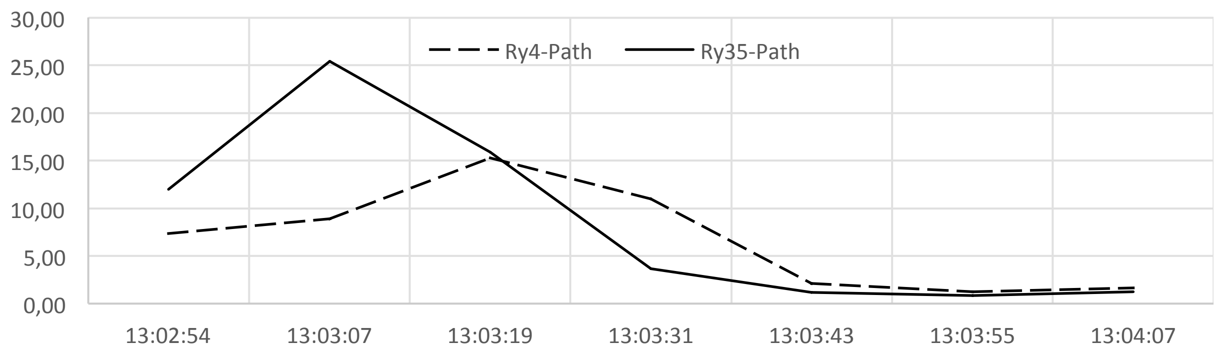


Diagram 2-15 Visual descent angle direct to the aiming point, 13:02:54 - 13:04:07 CDT

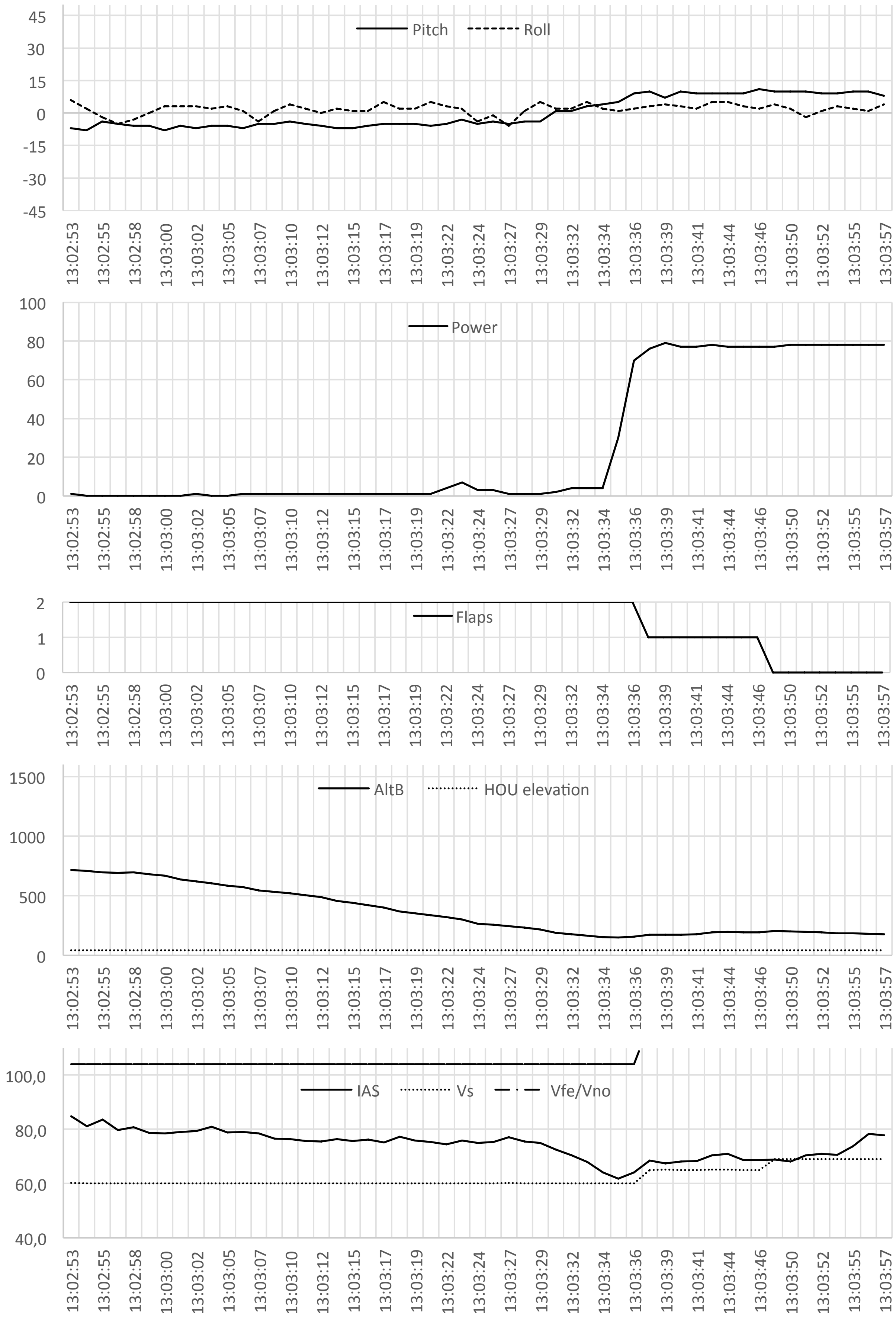


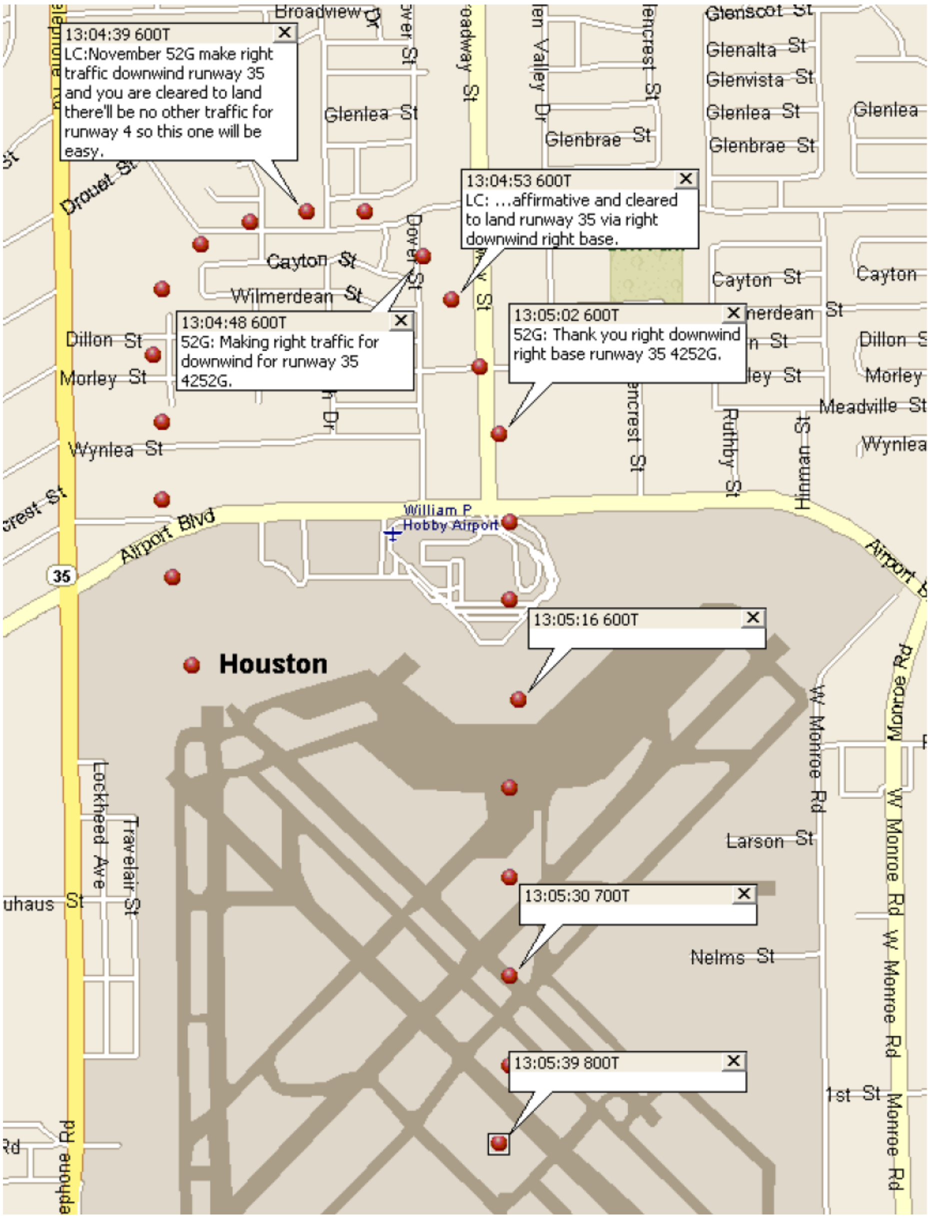
Diagram 2-16 Graphical depiction of basic flight data, 13:02:53 - 13:03:57 CDT

The flight data and the graphical presentations of the flight track with the associated ATC transcript in Figure 2-8 and the graphical presentation of the aircraft's flight parameters in Diagrams 2-15 (13:02:54 - 13:04:07 CDT) and 2-16 (13:02:53 - 13:03:57 CDT) for the first approach and go-around of N4252G to runway 35 were analysed in detail.

At 13:03:29 CDT, when the aiming point of runway 35 was already overflown and the pilot still seemed to intend to land on runway 35, ATC advised the pilot about the aircraft's high position ("you might be too high"). The pilot initiated a go-around at 13:03:34 CDT. The power was not set to maximum power (for procedural details, refer to E Appendix). The airspeed was at 64.1 KIAS, when the flaps were retracted to 50% at 13:03:36 CDT. The stall speed margin decreased to 2 kts with an active stall warning[11]. ATC advised at 13:03:43 CDT that the pilot should expect a right traffic pattern for runway 35.

At 13:03:46 CDT, at an altitude of 192 ft the flaps were retracted to 0% at 68.7 KIAS (well below the recommended speed of 83 KIAS) with a stall speed margin of 4 kts and the power set to 77% instead of maximum power (for procedural details, refer to E Appendix). The pitch angle was not reduced and the speed further decreased until reaching the stall speed at 13:03:49 CDT. Subsequently, the pitch angle was slightly reduced and the aircraft left the speed regime triggering a stall warning at an altitude of 183 ft at 13:03:56 CDT with a positive speed trend.

[11] "the stall speed warning horn sound[s] between 5 and 10 kts before the stall" (POH-SR20, 2015, p. 4-23). For the prevailing analysis the author has anticipated that stall warning triggers if IAS < (Vs + 5 kts).



(NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 16)

Figure 2-9 Preparing for second approach to runway 35

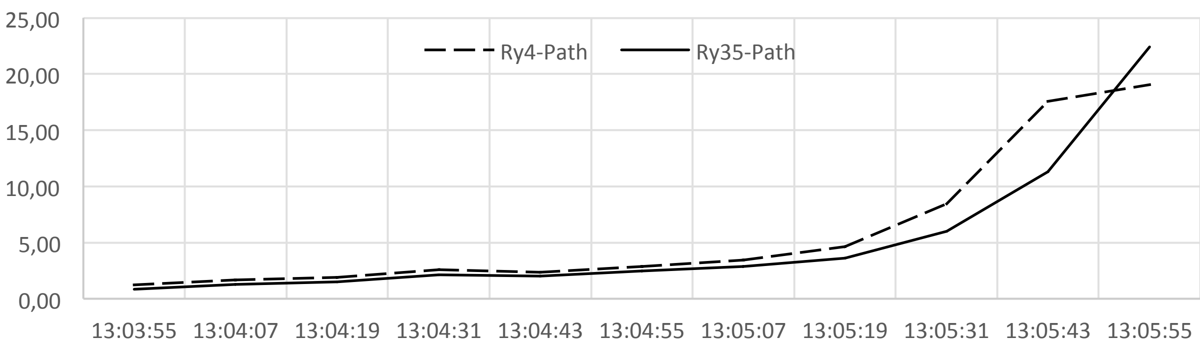


Diagram 2-17 Visual descent angle direct to the aiming point, 13:03:55 - 13:05:55 CDT

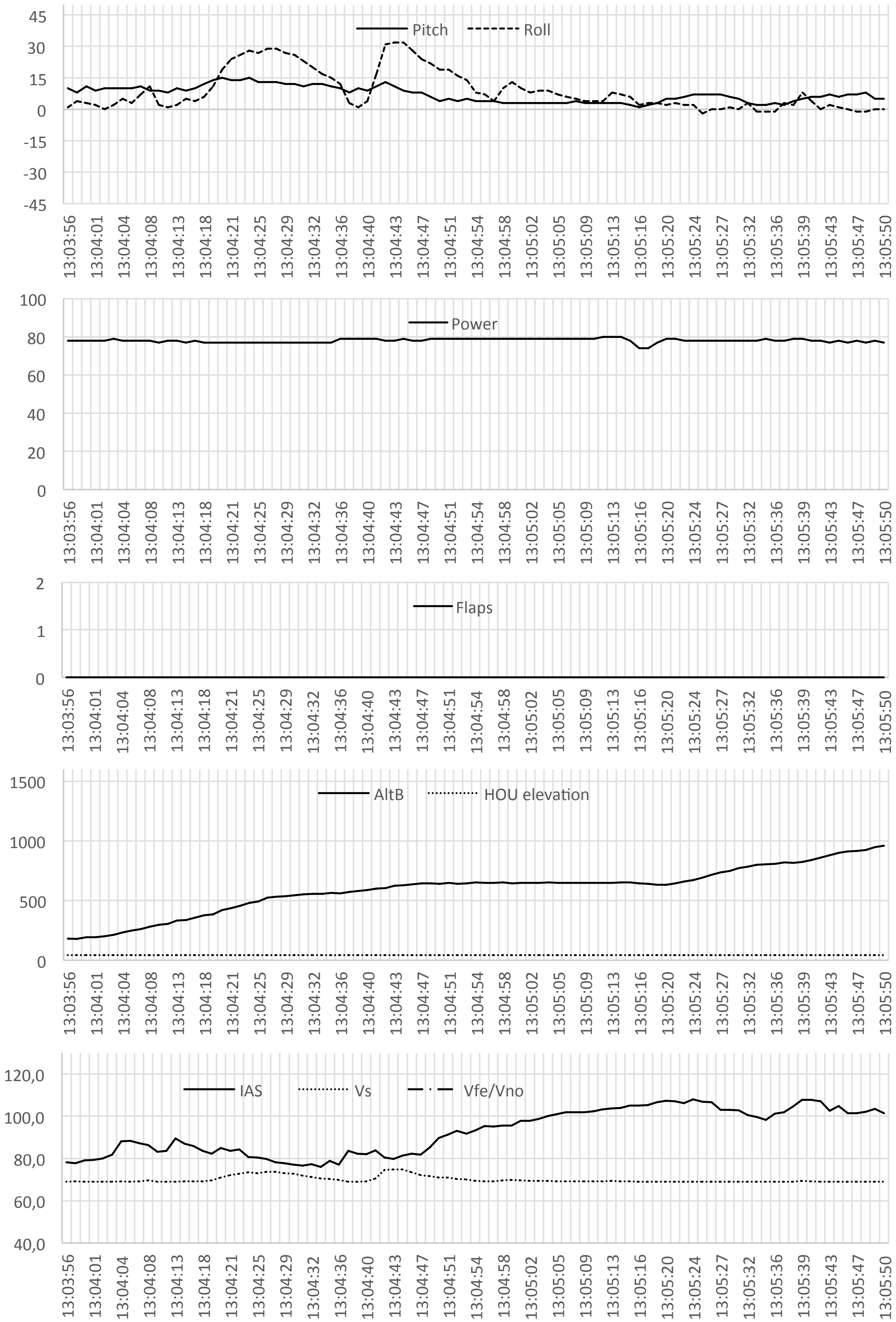
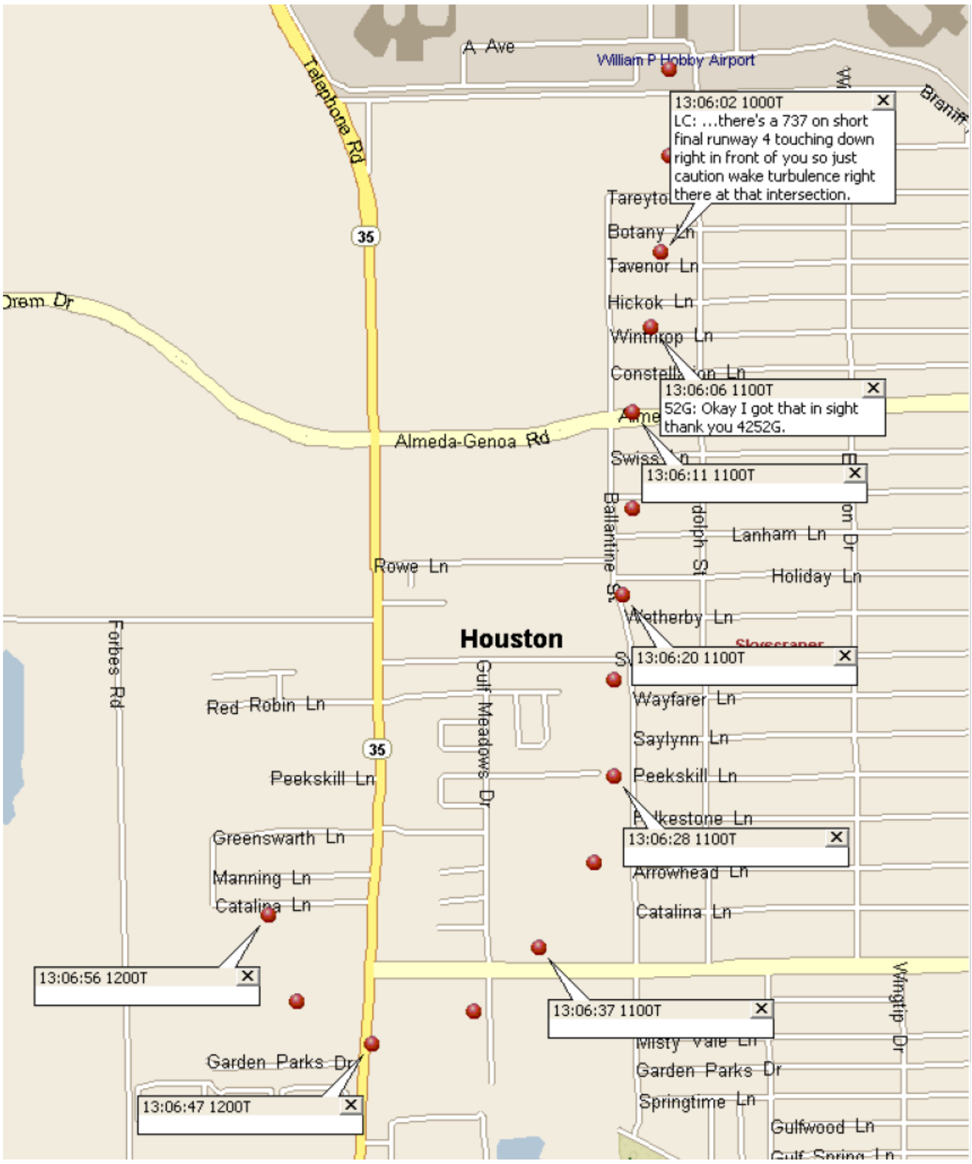


Diagram 2-18 Graphical depiction of basic flight data, 13:03:56 - 13:05:50 CDT

The flight data and the graphical presentations of the flight track with the associated ATC transcript in Figure 2-9 and the graphical presentation of the aircraft's flight parameters in Diagrams 2-17 (13:03:55 - 13:05:55 CDT) and 2-18 (13:03:56 - 13:05:50 CDT) whilst preparing for the second approach of N4252G to runway 35 were analysed in detail. At 13:04:39 CDT the ATC advised to enter the right downwind for runway 35. As there was no other traffic reported for runway 4 by ATC, proper application of risk assessment had resulted in requesting runway 4 to improve the prevailing wind conditions for approach and landing.

At 13:04:27, whilst in a 29 degree banked right turn with a speed of 74 KIAS the stall speed margin was reduced to 4 kts. Therefore, it can be assumed that the stall warning was triggered[12] for 4 seconds.

[12]"the stall speed warning horn sound[s] between 5 and 10 kts before the stall" (POH-SR20, 2015, p. 4-23). For the prevailing analysis the author has anticipated that stall warning triggers if IAS < (Vs + 5 kts).



(NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 17)

Figure 2-10 Downwind to final turn, second approach to runway 35

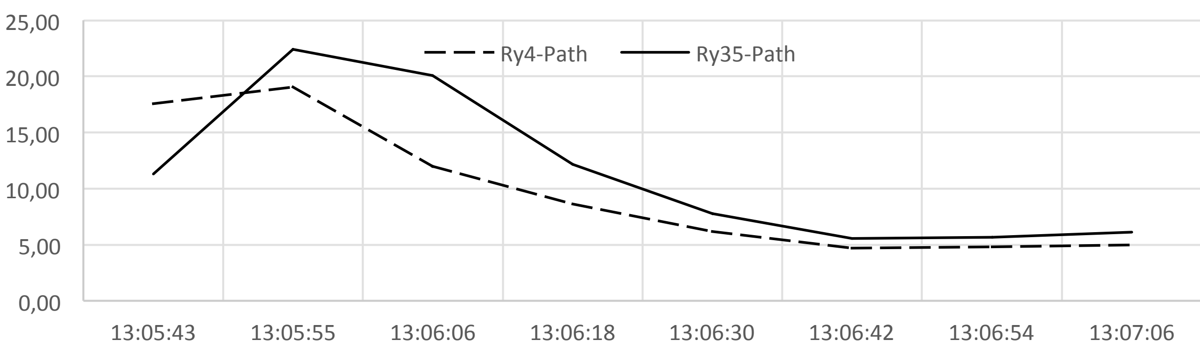


Diagram 2-19 Visual descent angle direct to the aiming point, 13:05:43 - 13:07:06 CDT

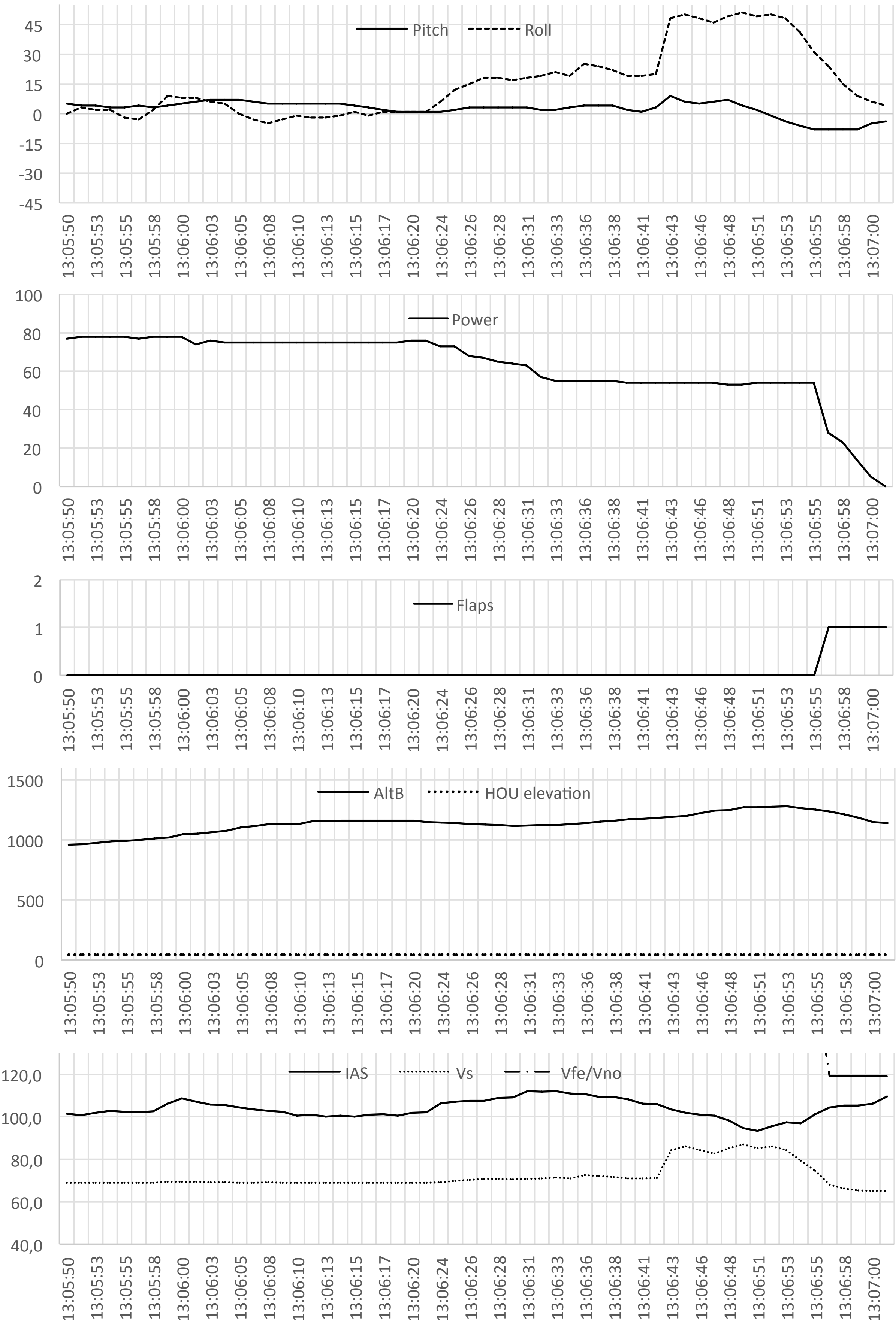
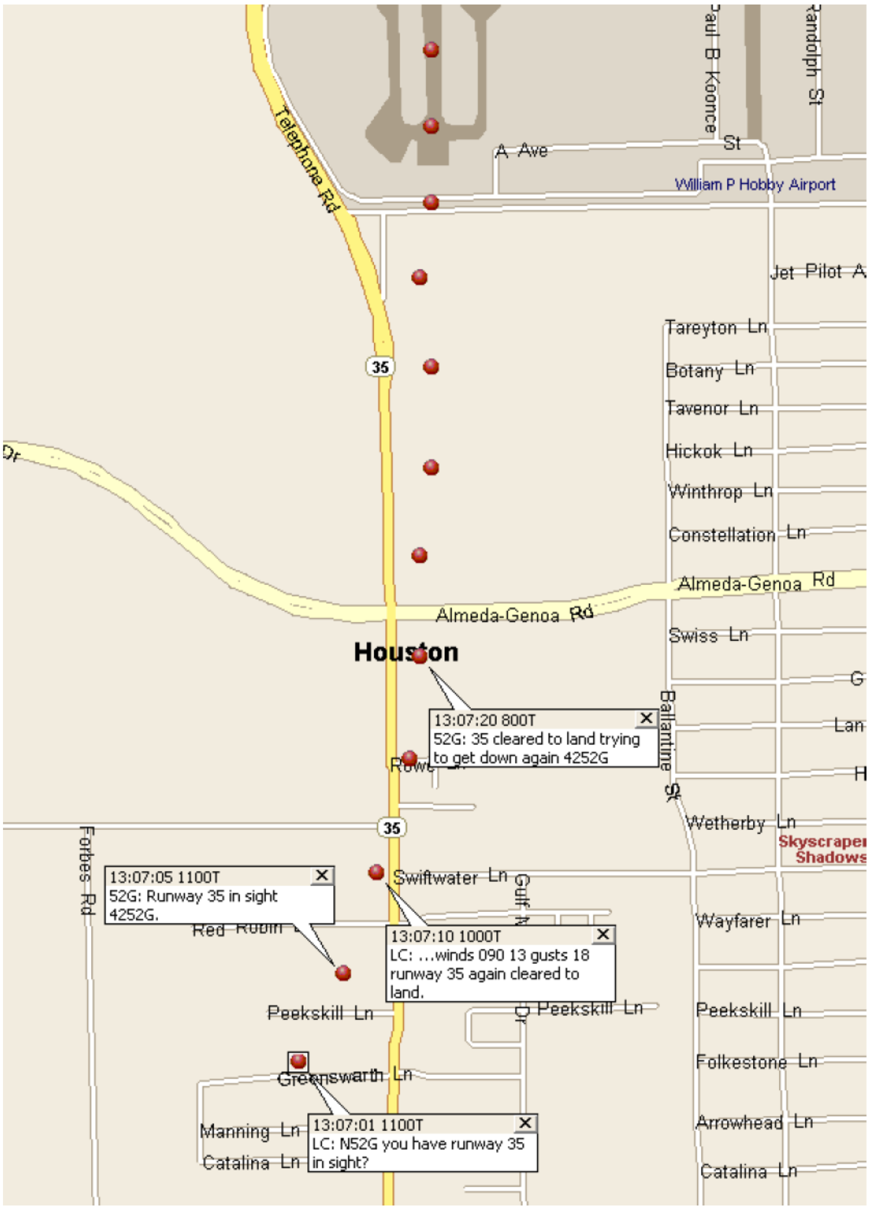


Diagram 2-20 Graphical depiction of basic flight data, 13:05:50 - 13:07:00 CDT

The flight data and the graphical presentations of the flight track with the associated ATC transcript in Figure 2-10 and the graphical presentation of the aircraft's flight parameters in Diagram 2-19 (13:05:43 - 13:07:06 CDT) and 2-20 (13:05:50 - 13:07:00 CDT) whilst proceeding on downwind and to the final turn for the second approach to runway 35 of N4252G were analysed in detail. Between 13:06:42 and 13:06:53 CDT, when turning on final for runway 35 the bank angle was increased up to a maximum of 51 degrees. At 13:06:55 CDT, the flaps were extended to 50% and the power reduced to idle, whilst the visual descent angle was at 5.7 degrees (note that the PAPI for runway 35 was calibrated for 3.0 degrees) with 101.3 KIAS in a 31 degrees of bank angle turn.



(NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 18)

Figure 2-11 Second approach to runway 35

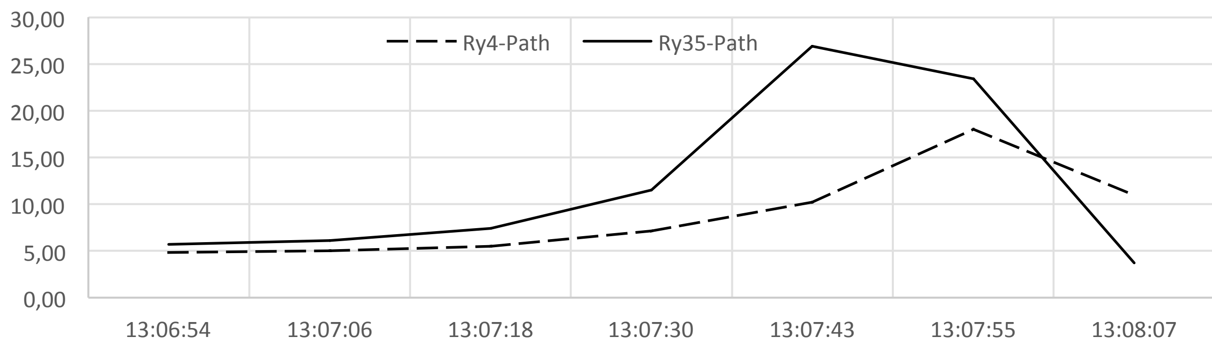


Diagram 2-21 Visual descent angle direct to the aiming point, 13:06:54 - 13:08:07 CDT

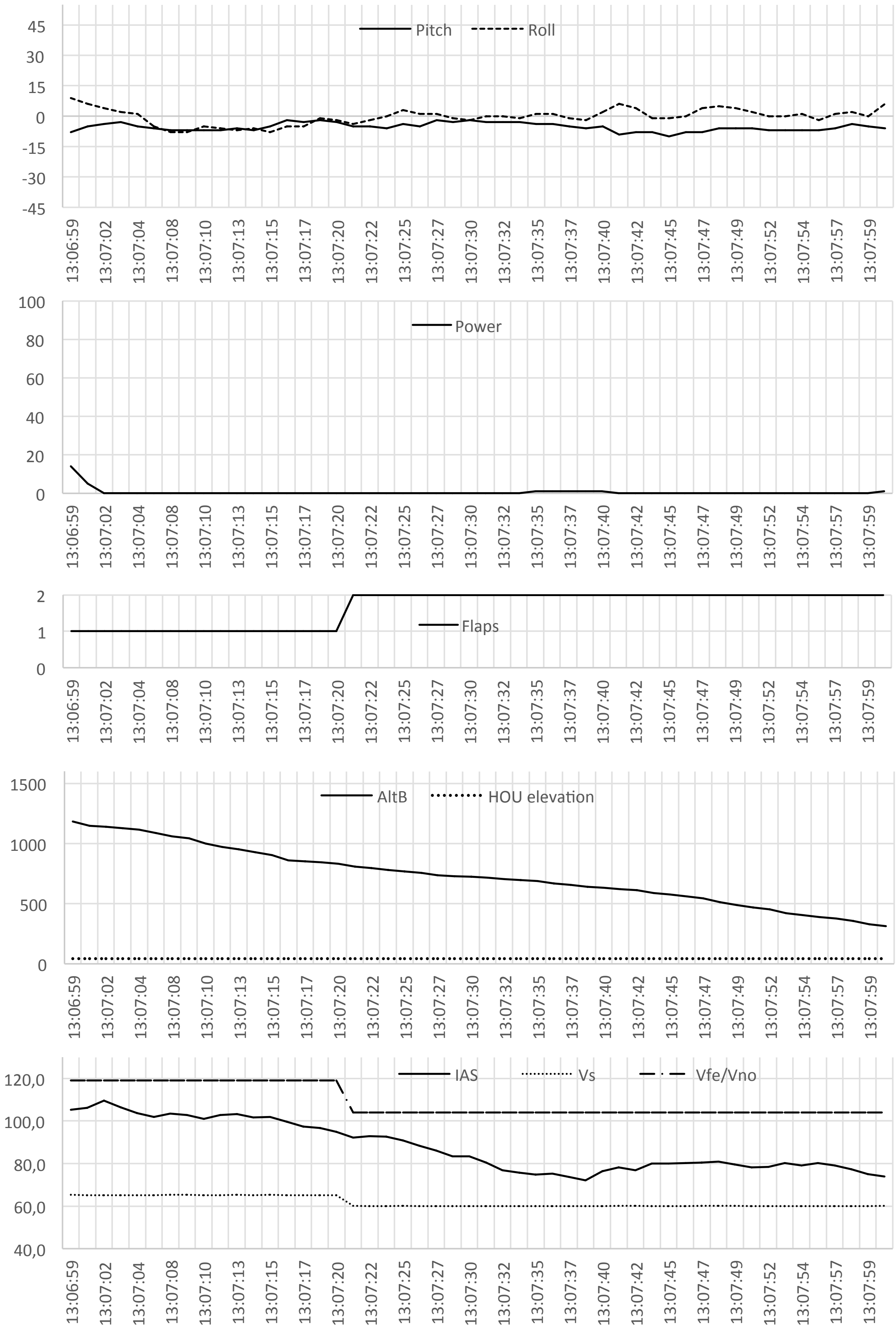


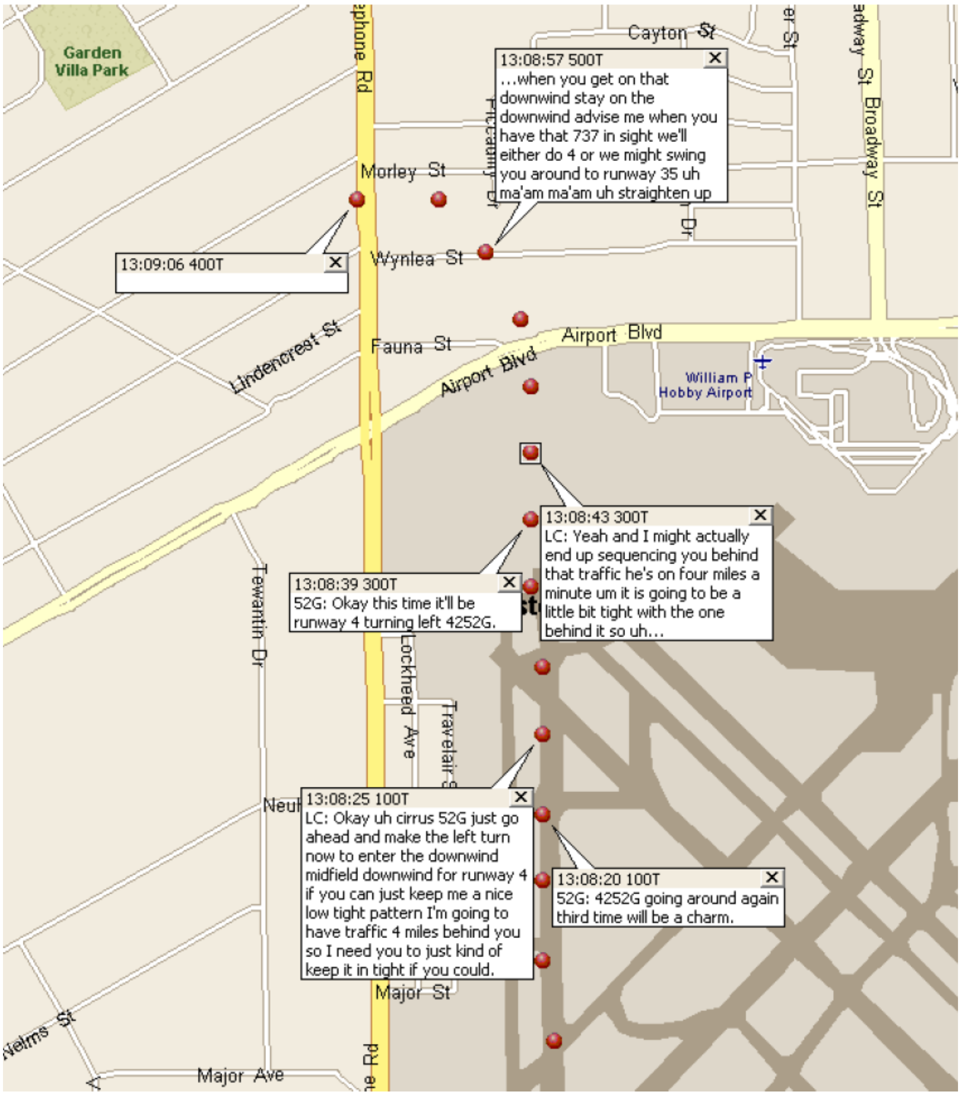
Diagram 2-22 Graphical depiction of basic flight data, 13:06:59 - 13:07:59 CDT

The flight data and the graphical presentations of the flight track with the associated ATC transcript in Figure 2-11 and the graphical presentation of the aircraft's flight parameters in Diagrams 2-21 (13:06:54 - 13:08:07 CDT) and 2-22 (13:06:59 - 13:07:59 CDT) whilst performing the second approach to runway 35 of N4252G were analysed in detail.

The power was set to idle at 13:07:02 CDT. At 13:07:05 CDT, the pilot of N4252G reported the runway in sight to ATC. At 13:07:10 CDT ATC advised the landing clearance and the actual wind of 090 degrees at 13 kts with gusts to 18 kts for runway 35. According to the Cirrus Envelope of Safety (refer to L Appendix, Figure 6-3 Envelope of Safety), the reported wind was exceeding[13] the personalized x-wind limit (wind limit 15 kts, x-wind limit 5 kts, maximum gust 5 kts) according to the Pilot's Capability Category (for details, refer to D Appendix).

At 13:07:18 CDT, before the flaps were set to 100% the visual descent angle was 7.7 degrees with an increasing trend (note that the PAPI for runway 35 was calibrated for 3.0 degrees). When the pilot of N4252G read back the landing clearance for runway 35 and advised "trying to get down again", the flaps were simultaneously extended from 50% to 100%, whilst the speed was at 94.8 KIAS. From 13:07:32 until 13:07:42 CDT the speed was decreasing below 78 KIAS (down to a minimum of 72 KIAS at 13:07:38 CDT), which is the recommended approach speed (for procedural details refer to E Appendix) for the 100% flaps configuration.

[13]The author of this thesis recalculated the wind components considering Figure 6-4 Wind component diagram as follows: 090°/ 13 kts steady (with gusts up to 18 kts) equals 1 kt (no gusts) tailwind and 13 kts (gusts up to 18 kts) crosswind for runway 35 (356° runway track).



(NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 19)

Figure 2-12 Go-around following second approach to runway 35 and loss of contact

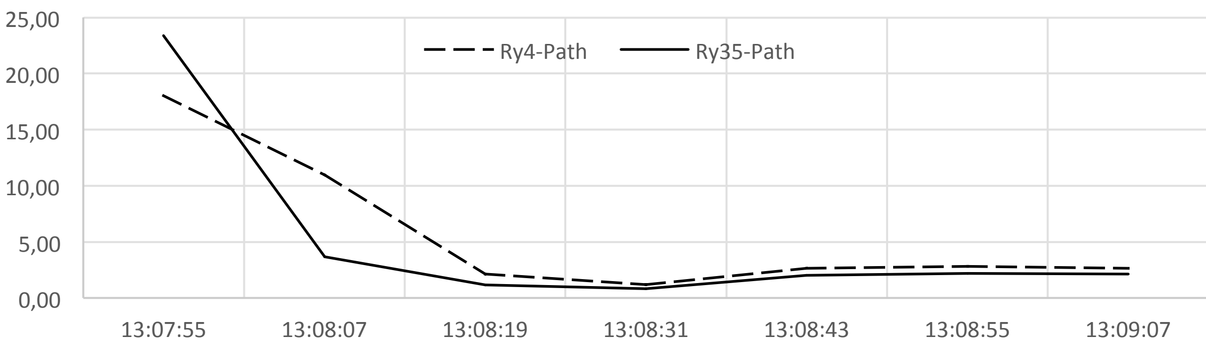


Diagram 2-23 Visual descent angle direct to the aiming point, 13:07:55 - 13:09:07 CDT

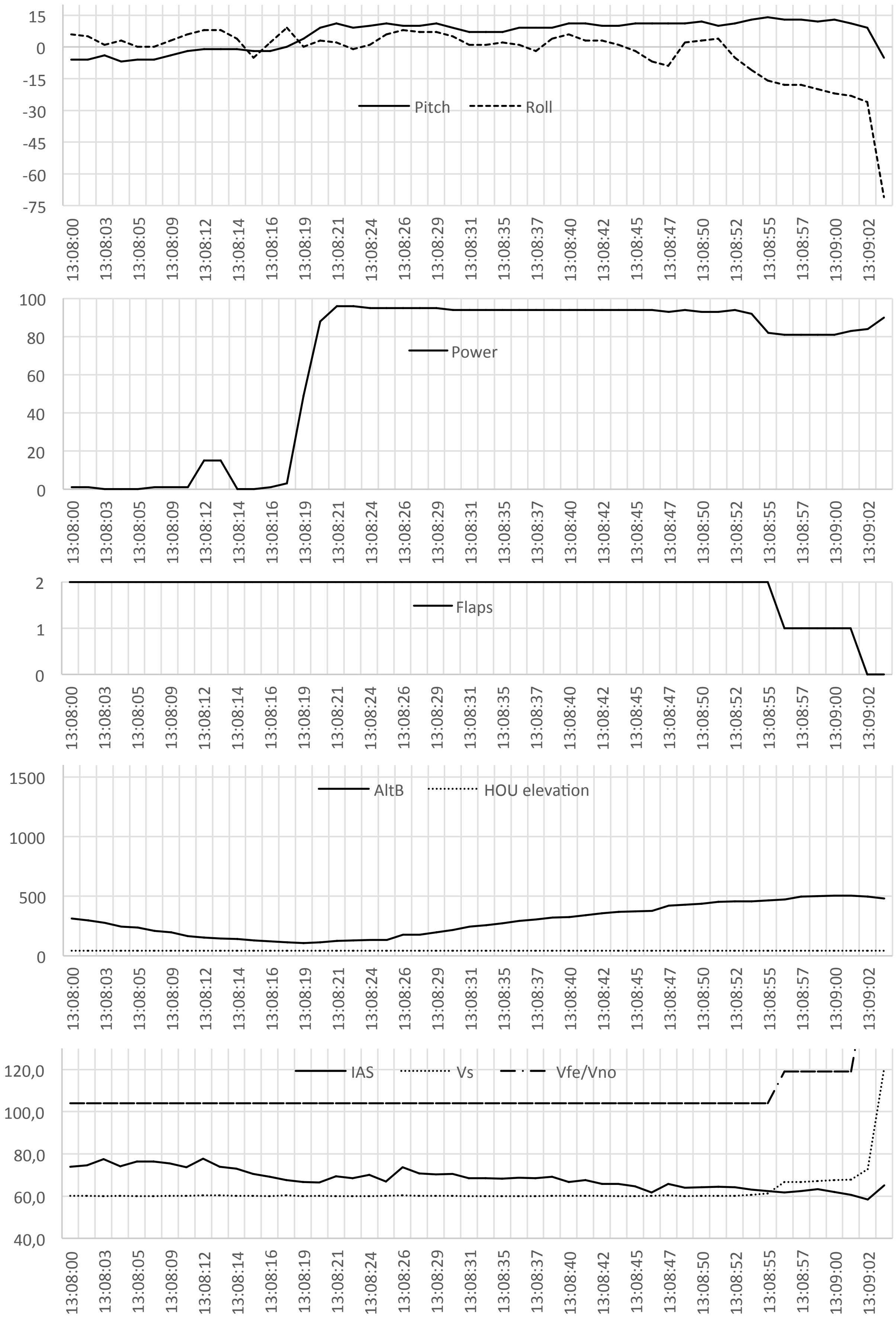


Diagram 2-24 Graphical depiction of basic flight data, 13:08:00 - 13:09:02 CDT

The flight data and the graphical presentations of the flight track with the associated ATC transcript in Figure 2-12 and the graphical presentation of the aircraft's flight parameters in Diagrams 2-23 (13:07:55 - 13:09:07 CDT) and 2-24 (13:08:00 - 13:09:02 CDT) whilst performing the second approach to runway 35 of N4252G were analysed in detail.

The pilot continued the final approach to runway 35. At 13:08:19 CDT at a position in the last third of runway 35 (refer to Figure 2-12) at an altitude of 107 ft (64 ft above ground) and at a speed of 66.7 KIAS (note that the recommended approach speed with flaps 100% is 78 KIAS; for procedural details, refer to E Appendix) the go-around was initiated. The power was set to 96%. The airspeed at the time of go-around was 66.4 KIAS. The flaps were not retracted and left at 100%.

At 13:08:45 CDT, the altitude was at 374 ft whilst performing a slight left banked turn. The stall speed margin reached 5 kts and it can be assumed that the stall warning was triggered[14]. The pitch angle was not reduced. At 13:08:53 CDT, with a stall speed margin of 2 kts the power was reduced to 78%.

At 13:08:55 CDT, at an altitude of 463 ft with 62.4 KIAS and a stall speed margin of 1 kt the flaps were retracted to 50%. Although the indicated airspeed was already below the calculated stall speed and the pitch angle was not reduced, the pilot continued to fly in a slight left turn with a bank angle of approximately 20 degrees. The turn increased the tailwind component and further lowered the energy state of the aircraft.

At 13:09:02 CDT, with a pitch angle of 9 degrees, in a 26 degrees banked left turn, the power set to 84%, at 58.4 KIAS (14.6 kts below the calculated stall speed), at an altitude of 496 ft the flaps were retracted to 0%. Subsequently, the control of the aircraft was lost.

The last data read out before the impact at 13:09:03 CDT indicated a left bank angle of 71 degrees.

[14] "the stall speed warning horn sound[s] between 5 and 10 kts before the stall" (POH-SR20, 2015, p. 4-23). For the prevailing analysis the author has anticipated that stall warning triggers if IAS < (Vs + 5 kts).

2.3 General Definitions for the Present CAST Analysis

Referring to Leveson (2018), *distinguishing between hazards and losses is required, given that losses may involve aspects of the environment over which the system controllers or operators have only partial control or no control at all* (rf. (Leveson, STPA Handbook, 2018, p. 17)).

For the prevailing STAMP (Leveson, 2011) modeling of the N4252G accident the author of this thesis has specified in the following the Loss [L], the involved Hazards [H] and the associated High-Level Safety Constraints [HLSC]:

[L]	The loss of life or injury to people as a result of a pilot's loss of aircraft control in flight whilst intending to land a technologically-advanced aircraft (TAA) in a busy airport environment.

The following hazards [H] describe system states or conditions that lead to the above-defined loss of aircraft control in a worst-case scenario:

[H-1]	Aircraft approved envelope of flight is exceeded.
[H-2]	"Aircraft airframe integrity is lost" (Leveson, STPA Handbook, 2018, p. 20).
[H-3]	Regaining lost aircraft control in flight is not achieved before a safe ground contact.
[H-4]	Aircraft is uncontrolled.
[H-5]	CAPS is not deployed in a life-threatening emergency.
[H-6]	Biennial flight review is exceeded.
[H-7]	Pilot's workload exceeds safely manageable capabilities and degrades SA.
[H-8]	ATC Clearances are complex and changed unpredictably within a short time frame.
[H-9]	The final approach is continued without meeting stabilized approach criteria.

Referring to Nancy Leveson's definition of hazard in A Appendix, it seems obvious that environmental conditions can affect a controller's process model, in so far that in a worst-case scenario all of the unsafe control actions initiated by the individual components interact together such that the result is a loss (accident). Therefore, respective safety constraints need to be put in place to mitigate the encounter of unsafe control actions and the interactions of the components as a whole.

The high-level safety constraints [HLSC] and requirements associated with each of the afore-mentioned hazards are defined as follows:

[HLSC-1]	*If an aircraft exceeds the approved envelope of flight, then the exceedance must be detected and measures taken to avoid a pilot's loss of aircraft control* (rf. (Leveson, STPA Handbook, 2018, p. 20)).
[HLSC-2]	"Aircraft airframe integrity must be maintained under worst-case conditions" (Leveson, STPA Handbook, 2018, p. 20).
[HLSC-3]	If regaining lost aircraft control in flight cannot be expected before a safe ground contact, then measures shall be taken on time to minimize loss-of-life or injury to people.
[HLSC-4]	Aircraft control must be maintained under all conditions.
[HLSC-5]	If CAPS is not deployed in a life-threatening emergency, then alternative measures must be performed.
[HLSC-6]	If the biennial flight review is exceeded, then measures must be enforced to prohibit exercising privileges as pilot in command.
[HLSC-7]	If the pilot's workload exceeds its safely manageable capabilities, then measures to regain a safe level of workload must be performed.
[HLSC-8]	If traffic situations require revised ATC strategies on short notice, then measures must be enforced to enable a clear understanding for all involved parties.
[HLSC-9]	If the stabilized approach criteria are not met an immediate go around shall be initiated.

2.4 General Model of Hierarchical Control Structure

For modeling the accident of N4252G's operation prior to its final ground impact in STAMP (Leveson, 2011), a hierarchical control structure was developed by the author, refer to Figure 2-13. It supported the determination and understanding of *the process how higher levels in the control structure contributed to unsafe control actions by considering available information, feedbacks, physical flows and environmental conditions* (rf. (Leveson, Engineering a Safer World, 2011, p. 351)).

The following codings are applied:

- rectangles represent individual controllers;
- continuous lines represent control actions;
- dashed lines indicate information, feedbacks, or physical flows;
- oversized arrow symbols indicate changing environmental conditions.

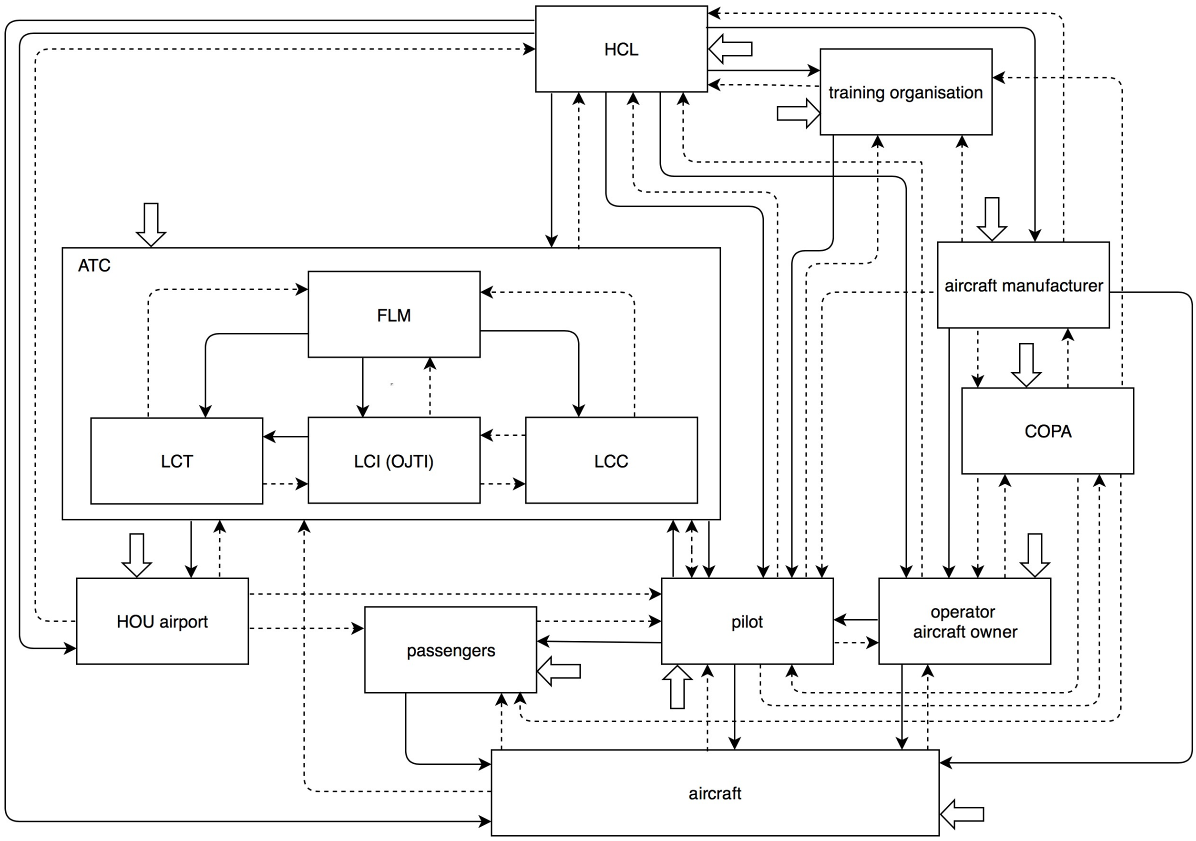


Figure 2-13 General model of hierarchical control structure

2.5 Process Model for each System Component

The potential for inadequate control for each system component – which could ultimately lead to the hazards defined in Chapter 2.3 – was analysed by the author. For a summarized description for each system component, refer to K Appendix.

According to STAMP (Leveson, 2011), accidents are described in such a way that each higher level controls the activity at the level below by means of control hierarchies and adaptation of feedback mechanisms. This adaptation is especially important to avoid future accidents. The understanding of the process and how higher levels in the control structure contributed to unsafe control actions was emphasized. Therefore, the safety control structure of individual system components (Figure 2-14 to Figure 2-22) was simplified to the relevant interactions and the following safety-relevant facts were modeled. Finally, the results were categorized accordingly:

- Unsafe control actions (UCA)
- Dysfunctional Interactions
- Contextual factors
- Identified Safety requirements and constraints (SC) with the link to associated hazards, as defined in Chapter 2.3
- Questions raised (QR)

2.5.1 Higher Control Level (HCL) - Control Structure

The author has defined the HCL as a summarized term for the highest level of the HCS. It describes all higher-level control structures (such components as legislature, government regulatory agencies, aviation authorities, pilot's associations and unions).

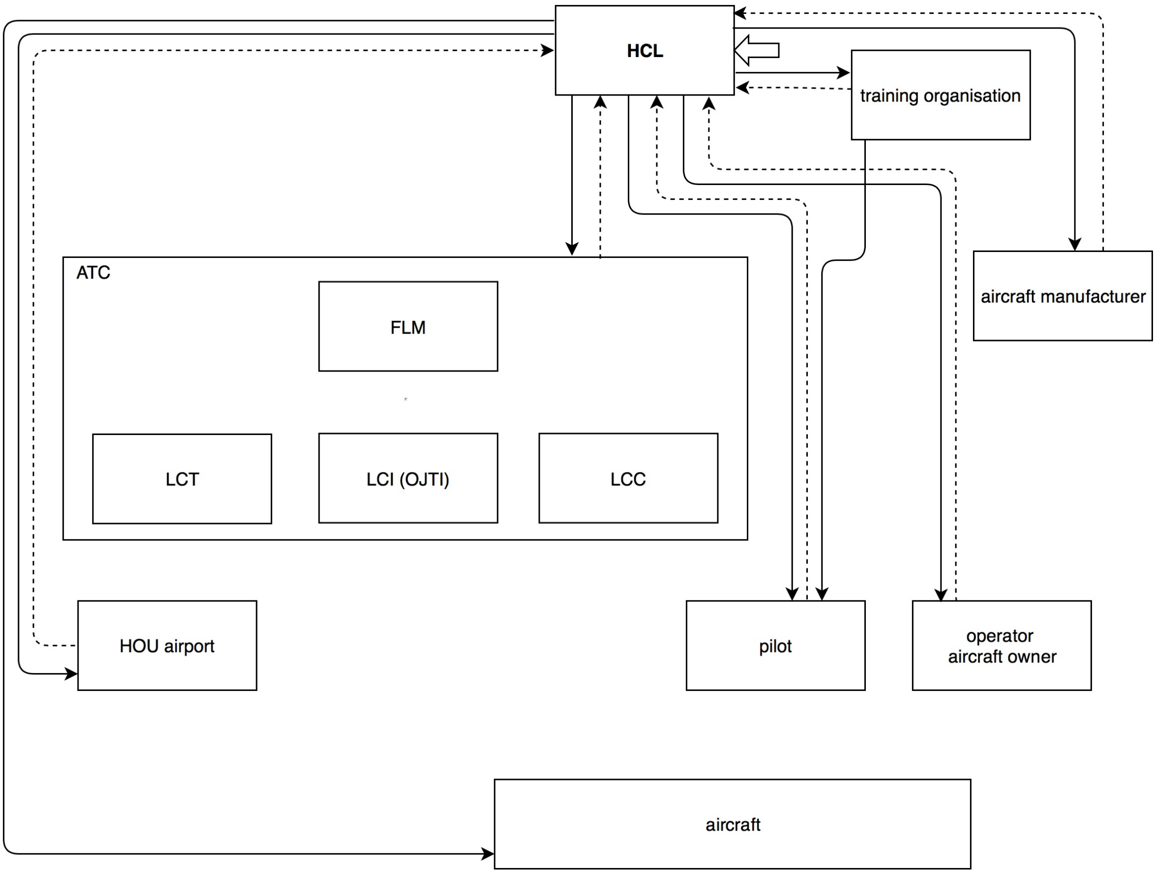


Figure 2-14 HCL - simplified control structure

HCL - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		The legislature has the power to enforce new standards/ regulations. Accident investigation processes are hardly investigated considering system-theoretic principles. Aviation authorities, pilot's associations and unions may disseminate lessons learned and provide experience/ knowledge in respect of flight safety.	[SC-1_HCL] The competent components of the HCL shall emphasize to disseminate lessons learned and enforce flight safety recommendations (considering system-theoretic principles) into standards/ legal law [H-1, H-2, H-3, H-4, H-5].	

HCL - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		US flight training regulations for private pilots are rather maneuver-based than covering real-world challenges, whereas industry standards like FITS provide scenario based training (including SRM, decision making, risk management, etc.).	[SC-2_HCL] Consideration of industry standards and technological possibilities shall be part of the legal enforcement basis for general aviation pilots' training [H-1, H-2, H-3, H-4, H-5].	
		The investigation report incorporates no details of known incidents of the pilot to the authority.		[QR-1] Are there any incidents known to the authority in respect of the accident pilot?
		SRM courses are not obligatory, which may result in a lack of SRM knowledge.	[SC-3_HCL] SRM Courses shall be required for single pilots on a regular base [H-1, H-4].	
		Pilot's licence endorsements have no expiry dates, which may result in pilots exercising their privileges without fulfilling the proficiency requirements.	[SC-4_HCL] Expiry dates of pilot's license endorsements shall be implemented [H-1, H-4, H-6].	
		HCL are not receiving information/ feedback of US pilots exceeding biennial flight reviews.	[SC-5_HCL] Flight review data shall be tracked by the competent authority [H-6].	
		Regular check rides for VFR single-engine piston pilots are not required by regulation.	[SC-6_HCL] HCL shall emphasize to enforce regular check rides for VFR single-engine piston pilots [H-1, H-4].	
		Loss-of-control training is not obligatory for single-engine pilots.	[SC-7_HCL] Loss-of-control training for single-engine pilots shall be required [H-3, H-4].	
		Aircraft parachute system training is not obligatory for flight crews, as actual training requirements are not covering all modern system standards.	[SC-8_JCL] HCL shall emphasize to enforce training requirements based on modern industry standards (e.g. APS training) [H-5].	
		Stress management education, especially for private pilots, is not enforced by the HCL.	[SC-9_HCL] Stress management education for pilots in general shall be required on a regular base [H-7].	
		ATSAP is a reporting program, but on a voluntary base only. Known safety issues might not be resolved, if not reported.	[SC-10_HCL] Reporting programs shall be obligatory for ATC centers [H-7, H-8].	
		Audit procedures raising non-compliances (findings) in respect of communication deficiencies among ATC Centers (requiring instantaneously corrective actions) are not existent.	[SC-11_HCL] Regular audits at ATC centers shall be accomplished as part of the oversight through HCL. Non-compliances shall be analysed for its root causes and respective corrective actions applied [H-8].	

HCL - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		HCL provide no pro-active oversight measures to prohibit flight crews performing their duty under the influence of medications without AME approval.	[SC-12_HCL] Measures must be enforced to prohibit pilots performing their duties under the influence of prescription medications without AME approval [H-1, H-7].	
		Primary accident causal factors that continue to plague the general aviation community had not been explicitly disseminated by HCL as lessons learned.	[SC-13_HCL] Primary accident causal factors that continue to plague the general aviation community shall be explicitly disseminated to the pilots [H-1, H-3, H-4].	

Table 2-2 HCL - CAST analysis

2.5.2 Training Organisation[15] - Control Structure

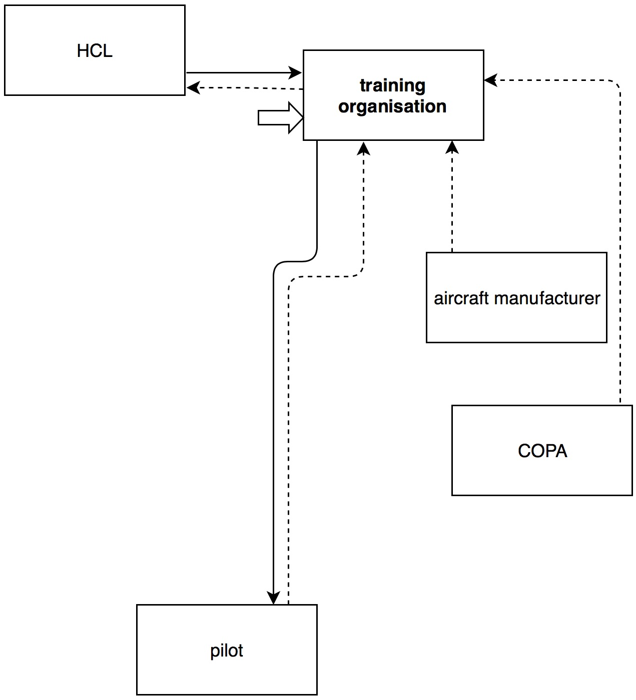


Figure 2-15 Training organisation - simplified control structure

Training Organisation - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
	The prevailing documents provided no information about the initial training of the accident pilot and her progress.	US pilot training is provided either through FAA-certificated pilot schools (rf. Title 14 CFR part 141) or through other training providers (rf. Title 14 CFR part 61). Some training organisations provide scenario based training according industry standards (e.g. FITS).		[QR-2] State details about the initial training of the accident pilot and her progress (type/ duration, types of aircraft, details about descent planning, energy management, busy airport operations, stabilized approach criteria, stall/ spin avoidance, CAPS)?
		The CFI-1 stated that during the first flights of the accident pilot's instrument training every situation was handled comparable to any student the CFI-1 had worked with. The CFI-1 flew three flights with the accident pilot (September, 2015).		[QR-3] What was the status/ progress of the accident pilot's instrument training?

[15]Author's note: Given that the accident report does not describe any details, "training organisation" was defined as generic term substituting all organisations and flight instructors where the accident pilot had received flight training.

Training Organisation - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		The CFI-2 flew with the accident pilot twice. Both flights were recurrent training flights. He stated that the pilot handled it within acceptable levels and retained composure and the ability to fly the airplane.		[QR-4] What had been the weaknesses of the accident pilot in the opinion of the CFIs?
		"Spin entry can be avoided by using good airmanship: coordinated use of controls in turns, proper airspeed control, no accelerated flight control inputs when close to the stall" (POH-SR20, 2015, p. 3-28).		[QR-5] Was good airmanship in respect of spin avoidance (as mentioned in the POH) trained?
		The weather conditions at destination were considered as suitable for landing by the pilot. It is not assured if the pilot had adequate knowledge, that the wind limit was exceeding the personal limits according to the Cirrus FOM (Envelope of Safety).	[SC-14_TrgOrg] Training organisations must assure that pilots are proficient in all relevant aircraft manual contents (POH, FOM) of the aircraft operated [H-7].	[QR-6] Was the FOM with the "Envelope of Safety" taught as part of the initial training for the Cirrus aircraft?
		Risk awareness was a causal factor of the accident.	[SC-15_TrgOrg] Risk awareness tools shall be trained to pilots considering actual influencing factors for instruction flights.	
		Lack of pilot's stress- and workload-management influenced the outcome of the accident.		[QR-7] Did the pilot attend any courses in SRM or related topics and what had been the content?
		Lack of pilot's pro-active safety culture influenced the safety of flight.	[SC-16_TrgOrg] Procedures to keep pro-active, personal Safety Cultures in every pilot's mind shall be enforced [H-6].	[QR-8] How was the pilot's attitude in respect of her own safety culture?
		The CAPS was not activated when the aircraft entered a spin. It is not assured if the pilot had adequate knowledge for procedural behaviour in case of aircraft upset and/ or spin.	[SC-17_TrgOrg] Practical training in acrobatic aircraft/ simulators to maintain proficiency in spin recovery procedures shall be enforced [H-5].	[QR-9] Was the accident pilot trained to recognize loss of control situations and how to escape?

Table 2-3 Training organisation - CAST analysis

2.5.3 ATC - Control Structure

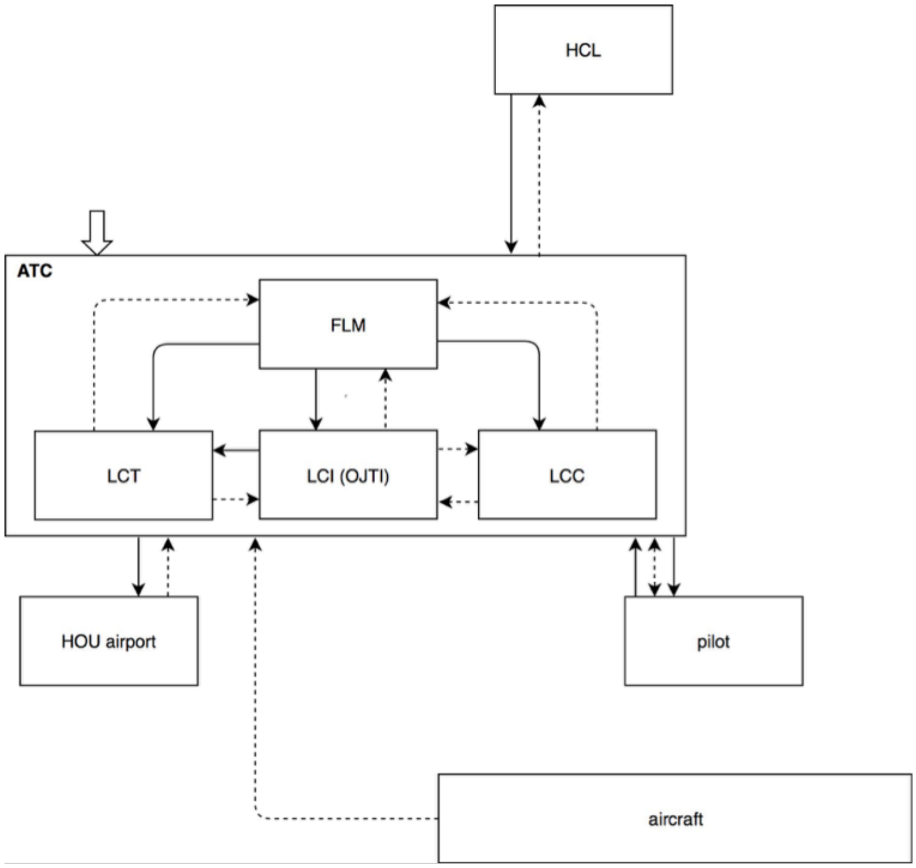


Figure 2-16 ATC - simplified control structure

ATC - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
	The FLM stated that communication throughout the facility in HOU had required improvement.			[QR-10] Which communication processes at the HOU ATC Facility require improvements?
		Reduced number of controllers, as one of the controllers assigned to the shift had been medically disqualified and another controller had already been approved for his annual leave. The activity level placed the facility right in the middle of the ATC 8 levels.	[SC-18_ATC] It must be assured that a minimum number of ATC controllers is available to avoid any degradation in aviation safety [H-7, H-8].	
	The LCT was not sure why the OJTI had taken over the frequency instead of just having him issue the clearance.	The frequency was handed over a few times between the LCT and the OJTI (LCI).	[SC-19_ATC] Operations with ATC trainees being supervised by ATC instructors must follow clear and consistent procedures [H-7, H-8].	[QR-11] Was peer pressure influencing the communication between the ATC trainee and his instructor?

ATC - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		ATC Simulator training was not provided for the LC position, radar training was provided via online learning tools.	[SC-20_ATC] ATC training shall include active ATC simulator sessions rather than online learning tools [H-7, H-8].	
[UCA-1] ATC revised the runway assignments for landing a few times within a short time interval, which resulted in an increased pilot's workload.			[SC-21_ATC] ATC shall not change runway assignments for landing within a short time interval to avoid unnecessarily increasing the workload for the pilot. [H-7, H-8].	
[UCA-2] ATC had no reports of wind shear or other wind issues until the afternoon, which resulted in assignment of runway 4/ 35 instead of runway 12 for arrivals (which was more convenient due to the wind conditions). [UCA-3] ATC did not adapt the runway assignments for the lowest achievable risks, which resulted in an avoidable crosswind component for the active runway 35.		"The tower was not primarily using runway 12 for arrivals because the wind hadn't picked up until the afternoon arrival push was in progress, and that was not a good time to change runways" (rf. (NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 25)).	[SC-22_ATC] Runway assignments shall be adapted for the lowest achievable risk in changing wind conditions [H-7].	
		The aircraft was separated very close to other approaching aircraft.		[QR-12] Which alternative procedures (except visual separation) for re-aligning aircraft in the traffic pattern were common?
[UCA-4] The Cirrus was vectored to runway 35 with the existing crosswind (gusts up to 20 kts), although difficulties for the pilot in handling the aircraft were obvious.		The FLM said that the tower had been using runway 35 all day for a variety of aircraft with no issues.	[SC-23_ATC] Runway assignment procedures for ATC shall be enforced to reduce crosswind components for aircraft approaching with obvious difficulties in aircraft handling [H-7].	
		The LCT stated that the aircraft appeared to be definitely too high to land after both approaches carried out to runway 35.	[SC-24_ATC] ATC tower controllers shall be trained to provide appropriate clearances if the aircraft is in a position ("unstable approach") from which a successful landing cannot be assured [H-9].	
[UCA-5] Non-adherence to ICAO standard phraseology caused misunderstandings between pilot and ATC.	An ATC clearance to turn right without a heading assignment is not according standard ICAO phraseology.	Application of non-standard ICAO phraseology ("keep it tight", "left heading 30 degrees") The LCC was asked about the "low and tight" instruction, he answered he had given instructions like that to other pilots as well.	[SC-25_ATC] Adherence to ICAO standard phraseology shall be regularly evaluated and examined. Importance of clear communication shall be highlighted [H-7, H-8].	[QR-13] Are the ATC controllers trained to follow ICAO standard phraseology and to avoid unnecessarily long ATC clearances, especially during critical phases of flight?

ATC - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
	ATC clearance to 1600 ft MSL for keeping an aircraft in the traffic pattern requires clarificaton.			[QR-14] Do the LC controllers have adequate training for vectoring aircraft in the near proximity of the airport under high-traffic conditions?
[UCA-6] Keeping the aircraft in the traffic pattern instead of handing it over to the Approach Controller increased the pilot's workload.	Non-adherence to the letter of agreement was a very standard alternate plan.	Facility Briefing and a letter of agreement stated to transfer go-around aircraft back to the approach control for resequencing. For the LCI keeping the aircraft in the pattern was the "normal" response. The LCC stated that if a general aviation aircraft went around he would probably have kept the aircraft rather than giving it back to approach. The FLM stated that about 90% of the time if a small VFR aircraft had to be re-sequenced off runway 4, the tower would have kept the aircraft and not handed it off to approach. For the I90 controller it was usual, that VFR traffic was worked back for landing by HOU tower. if they had not been able to do that, then I90 would have taken the go-around aircraft back to re-sequence it for another approach.	[SC-26_ATC] Clear ATC Procedures shall be enforced and adhered to assure that safety has first priority. Handing over of VFR aircraft to approach control must not be categorized as abnormal [H-7, H-8].	
	When the pilot advised about her uncertainty of being correctly lined up, the ATC just cancelled the straight-in approach instead of supporting to regain the situational awareness.		[SC-27_ATC] ATC controllers shall be trained to recognize and support pilots in regaining lost or degraded situational awareness [H-7].	[QR-15] Was LC control ever in doubt, that N4252G might not be able to land the aircraft successfully?
		According the LCT Controller, the pilot never sounded flustered or disoriented. According to the I90 Controller, the pilot of N4252G sounded confident.		[QR-16] How does an ATC controller evaluate the confidence of pilots?

ATC - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
	The approach controller was required to continue to monitor the spacing on final even after aircraft were switched to the tower. The FLM called approach and asked them to slow their next arrival down for more space for the Cirrus. This was not coordinated with LC. The I90 controller didn't think HOU tower could sequence N4252G inside of the traffic.	Approach control (I90) told the FLM that he would take N4252G back, but the FLM saw that N4252G was already turning base, so he told approach that the tower would just work the aircraft. This was not coordinated with LC. The FLM did not give any instruction to LC as they seemed to have the situation under control.	[SC-28_ATC] The internal communication process among ATC stations shall not be impaired [H-7, H-8].	
[UCA-7] ATC transmitted unnecessarily long to the pilot going-around, which resulted in distraction during a critical phase of flight.			[SC-29_ATC] ATC transmissions to an aircraft in a critical phase of flight shall be kept to a minimum [H-7, H-8].	[QR-17] Did the LCC anticipate the high workload and stress that the pilot of N4252G was under at the third go-around?
[UCA-8] The LCI was relieved by the LCC in a busy and critical moment (third go-around of N4252G) after only 2-minutes of overlap (which is the minimum required period). It caused insufficient situational awareness for the controller taking over.		LCIs shift was ending. The FLM had arranged to relieve the LCI. The LCC moved to the monitor position for the required 2-minute position overlap period.	[SC-30_ATC] Overlap periods of ATC controllers shall be adapted to the actual scenario and not be based solely on overlap-time [H-7, H-8].	[QR-18] How was assured, that the LCC taking over had sufficient situational awareness about the ATC traffic situation?
	The FLM had tried to get crew briefings together since he got to HOU, but staffing had been short and briefings had been hard to accommodate. Some controllers had never seen certain situations. Value of these experiences were not taught well enough.	For the LCI, having an aircraft miss the runway twice was the first time he had seen that. The LCI has not participated in any crew briefing since he came to HOU. According to him, there was no practice of discussing incidents and accidents as learning experiences. The LCC stated that he had not attended many crew briefings in the past few years, and that they were not regular events.	[SC-31_ATC] Regular training events to share each ATC controller's experiences shall be accommodated [H-8, H-9].	[QR-19] How is it assured that individual procedures and working practices are shared among every ATC team member?
	The FLM had not completed many PRCs to document controller performance (he admitted it as an error on his part). Poor documentation of performance management by the FLM.			[QR20] How was the performance of ATC controllers assured?

ATC - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		ATSAP reports were not applied in HOU.	[SC-32_ATC] Non-punitive reporting cultures for ATC controllers shall be obligatory for each ATC center for a higher level of experience exchange [H-1, H-7, H-8, H-9].	

Table 2-4 ATC - CAST analysis

2.5.4 Aircraft Manufacturer (Cirrus) - Control Structure

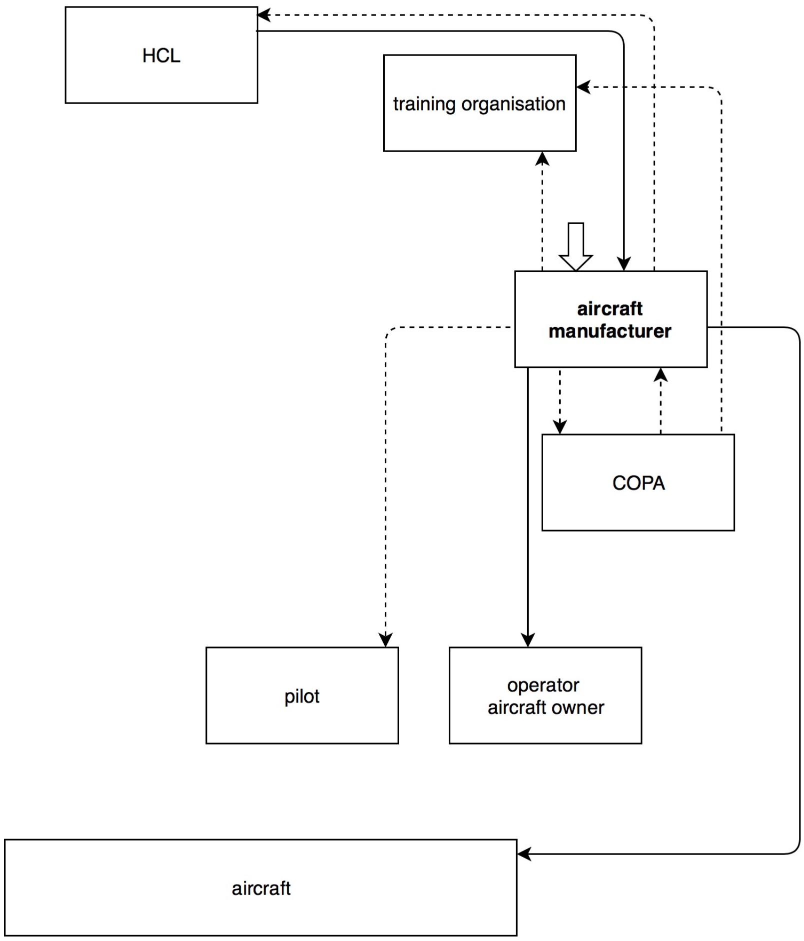


Figure 2-17 Aircraft manufacturer - simplified control structure

Aircraft Manufacturer - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		The POH in Version A1 has been valid and unrevised since December 29, 2015.		[QR-21] What schedules the issue of new POH revisions?
[UCA-9] "The only approved and demonstrated method of spin recovery is activation of the CAPS" (POH-SR20, 2015, p. 3-28). Possible alternative procedures for spin prevention/ recovery are not provided in POH, resulting in limited mental process models for the pilot in case CAPS is not activated/ available.				[QR-22] What is the alternative procedure for pilots if the CAPS system cannot be activated in case of an unintended spin?

Aircraft Manufacturer - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		The POH-SR20 (2015) states, that *the SR20 is trimmed by adjusting the neutral position of the compression spring cartridge* (rf. (POH-SR20, 2015, p. 7-8, 7-10)), which provides an artificial "force against a spring cartridge" on the control yoke. The associated risks of spring-cartridges are not described in the POH.	[SC-33_Cirrus] Unusual artificial feelings on a control yoke and its associated risks shall be described in the POH [H-1, H-2].	[QR-23] Was the pilot aware of the associated risks due artificial aerodynamic forces on the control yoke?
		The flaps were extended above Vfe.	[SC-34_Cirrus] Improper pilot's actions exceeding aircraft limitations or endangering the safety of flight shall be avoided [H-1].	
.	Limited Aircraft Feedback for next flap setting (speed scale on airspeed indicator).	The flaps were retracted below the recommended flap retraction speed causing the aircraft to stall.	[SC-35_Cirrus] The POH shall clearly state a warning that retracting flaps below the recommended stall speeds is of utmost danger of losing control of the aircraft [H-1, H-4].	
	N4252G was lost due to the inability to regain aircraft control.	"Loss of Control is one of the six most critical and common causes of GA [general aviation] accidents" (US Department of Transportation, AC 61-98D (supersedes AC 61-98C), 2018, p. 2-1).		[QR-24] How does the manufacturer assure that LOC is avoided in Cirrus aircraft?

Table 2-5 Aircraft manufacturer - CAST analysis

2.5.5 COPA - Control Structure

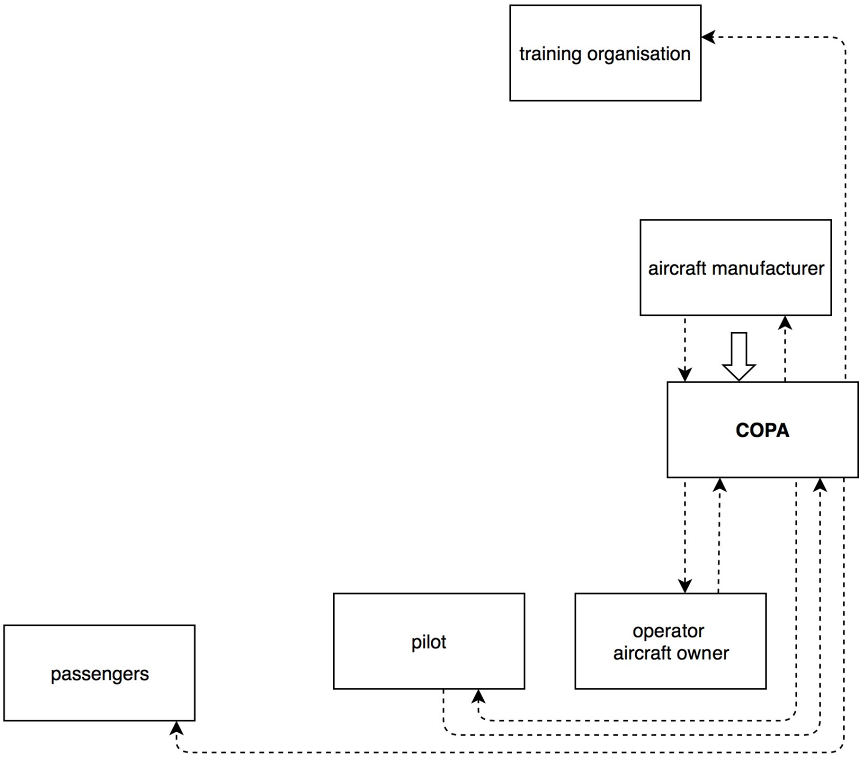


Figure 2-18 COPA - simplified control structure

COPA - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		"The CPPP is designed to expose Cirrus pilots to situations they may encounter while operating their aircraft" (FOM-SR20, 2011, p. 2-4).		[QR-25] Did the accident pilot participate in any CPPP training?
		"The CDM seminar is a facilitated interactive hangar-flying session where the group looks at general aviation and Cirrus accident statistics, reviews case studies of Cirrus accidents, and participates in the reenactment of an actual accident" (FOM-SR20, 2011, p. 2-4).		[QR-26] Did the accident pilot participate in any CDM seminar?
		"The Partner in Command seminar has been designed to give frequent Cirrus passengers more knowledge regarding safety system operations" (FOM-SR20, 2011, p. 2-4).	"	[QR-27] Did any of the passengers participate in a Partner in Command seminar?

Table 2-6 COPA - CAST analysis

2.5.6 HOU Airport - Control Structure

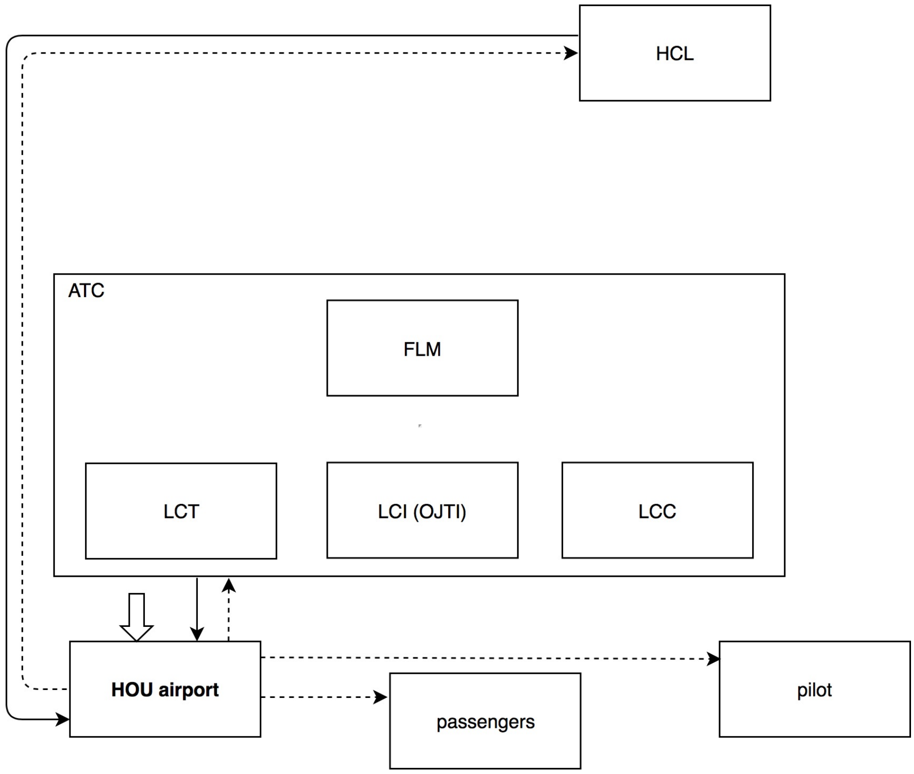


Figure 2-19 HOU airport - simplified control structure

HOU Airport - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		The contents of the actual NOTAMs and weather forecasts on the day of accident is not mentioned in the accident investigation report.		[QR-28] Did the actual NOTAMs at the day of the accident state any deficiencies influencing the safety of flight (e.g. unserviceability of PAPI, displaced thresholds, etc.)?
	The ATC controllers were not informed of the exact location of the wind sensor, therefore an exact wind assignment was not achievable.	The FLM stated that he was not sure where the wind sensor was located on the airport, but noted that there was soon to be a change in the system.	[SC-36_HOU] ATC controllers shall be informed where the wind sensors are located to assign the actual wind properly.	

Table 2-7 HOU airport - CAST analysis

2.5.7 Operator/ Aircraft Owner - Control Structure

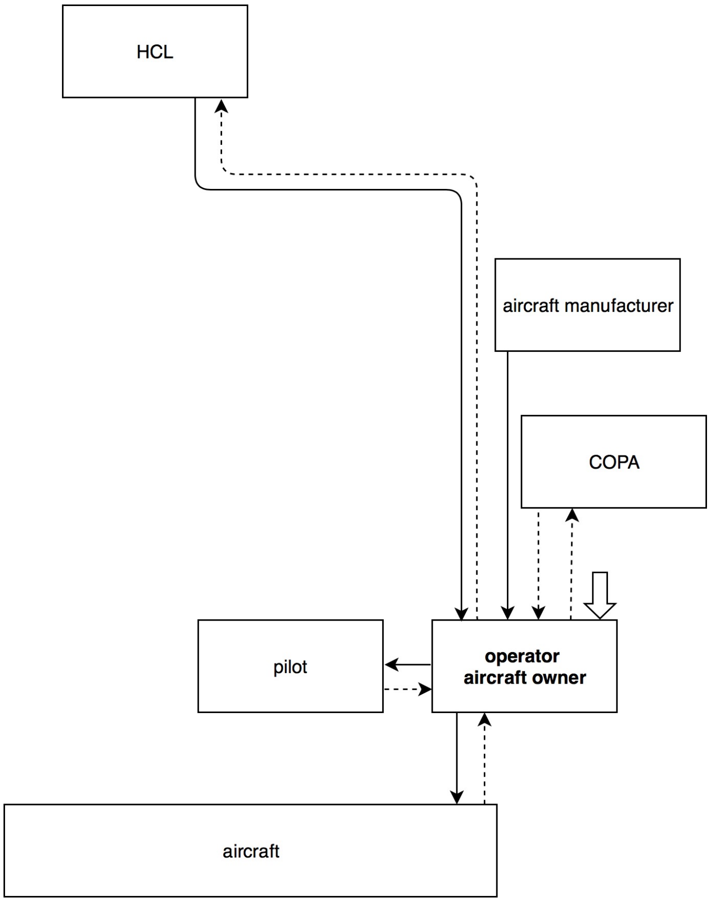


Figure 2-20 Operator/ Aircraft owner - simplified control structure

Operator/ Aircraft Owner - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		Neither the official accident report nor recherches by the author of this thesis provided details about requirements of the owner to permit a pilot to operate N4252G.		[QR-29] Under which pre-requisites did the operator/ aircraft owner permit the pilot to operate the aircraft?
[UCA-10] The operator permitted to operate his aircraft by a pilot without a valid biennial flight review, which caused the potential, that the pilot's lack of proficiency, skills and aeronautical knowledge had been undetected.				[QR-30] What was the operator's/ aircraft owner's safety policy (requirements, currency, training) for pilots operating the aircraft?

Table 2-8 Operator/ Aircraft owner - CAST analysis

2.5.8 Pilot - Control Structure

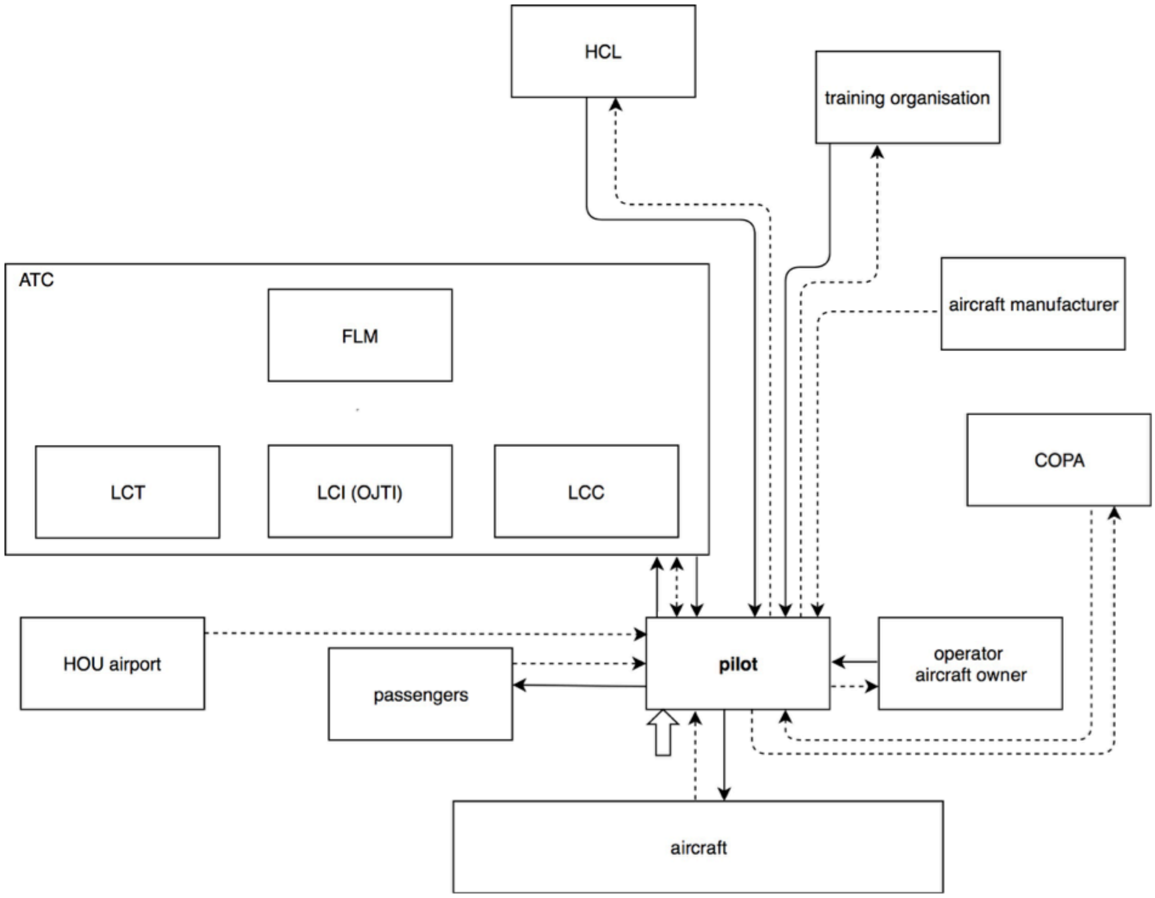


Figure 2-21 Pilot - simplified control structure

Pilot - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		Pilot's general experience on the type and other types of aircraft. Note: The prevailing documentation does neither state details referring to pilot's flight hours/ landings (flight hours within the last 12 months, pilot's landings in total/ within 12 months/ within 3 months) nor to experiences on various types.		[QR-31] What are the details concerning the accident pilot's types of aircraft flown, flight hours and landings.
		Proper flight preparation. Note: No documentations about the flight planning package was found.		[QR-32] Did the pilot have a flight planning package including weather forecast and NOTAMs?

Pilot - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		Risk assessment procedure. Note: No documentations about the application of risk assessment tools through the pilot was found.		[QR-33] Did the accident pilot apply any risk assessment tools?
[UCA11] *The pilot performed active duties under the influence of a prescription medication ("Zolpidem") that may impair mental and/ or physical ability in conducting potentially hazardous tasks such as flying* (NTSB, Aviation Accident Final Report, 2017, p. 8).			[SC-37_Pilot] Performing active flight duties under the influence of prescribed medication, which has not been aeromedically prescribed, shall be strictly prohibited [H-1, H-3, H-4, H-5, H-7, H-9].	[QR-34] Did the pilot wait at least 24 hours after taking Zolpidem before her flying activity (as recommended by the FAA)?
		The pilot had not flown to HOU airport before. HOU is a high-traffic, class-B (airspace) airport.	[SC-38_Pilot] The importance of proper flight planning and preparation shall be emphasized [H-7].	[QR-35] How did the pilot prepare for the flight and what had been the contents of the flight planning package?
[UCA-12] The pilot did not assess the risks for the crosswind condition, which resulted in an exceedance of the recommended wind limit according to the Cirrus FOM (Envelope of Safety).		The POH-SR20 (2015) states that, *operation in direct crosswinds of 20 kts has been demonstrated* (rf. (POH-SR20, 2015, p. 4-21)).	[SC-39_Pilot] Risk assessment shall be performed before and regularly during a flight to be prepared for rapidly changing conditions in the dynamic aviation environment [H-7].	[QR-36] What was the pilot's attitude in respect of risk assessment?
[UCA-13] The pilot did not protest about the permanently changing courses of action by ATC, which resulted in an increased workload.		Lack of Assertiveness.	[SC-40_Pilot] Pilots shall be trained not to accept ATC clearances causing workload, which is exceeding the personal capabilities [H-1, H-8, H-9].	
	No evidence was found that the pilot *had accomplished a satisfactory flight review within the preceding 24 calendar months* (rf. (Title 14 CFR 61.56(c)).	The relatively high experience (> 300 hours within 2 years of flying) on the SR20 aircraft provided the pilot a misleading level of confidence. Skills of performing safety-relevant maneuvers (stabilized approaches, go-around maneuvers, slow flight, stall recognition and recovery, recovery from unusual attitudes, spin recognition and avoidance) had lacked.	[SC-41_Pilot] Safety-relevant maneuvers shall be performed strictly according to procedures [H-1, H-9].	[QR-37] Did the pilot perform any training flights or a flight review before the accident?
	Uncertainty about the ATC intentions existed The pilot got disoriented and lost the clear picture where the runway should be located.	Loss of situational awareness may be influenced by channelized attention (tunnel vision), distraction and task saturation.	[SC-42_Pilot] The importance of sterile cabin procedures shall be emphasized [H-7]. [SC-43_Pilot] Methods and procedures for recognizing and regaining lost situational awareness shall be taught [H-3].	[QR-38] Was the pilot's level of situational awareness impaired by any reason and could the pilot in general be distracted easily when performing tasks?

Pilot - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
[UCA-14] The pilot did not prioritize to stabilize the flight path before communicating with ATC during critical phases of flight, which distracted and increased the workload.			[SC-44_Pilot] Communication announcements shall be performed after the flight path is safely stabilized ("aviate-navigate-communicate" procedure) [H-1, H-7].	
[UCA-15] Pilot tasks were not prioritized correctly, which resulted in a loss of situational awareness. [UCA-16] The pilot accepted, that ATC was keeping the aircraft in the pattern instead of requesting alternative measures to lower her workload.	Pilot's workload was not reduced.	The pilot was subject to high workload ("see and avoid" separation, wake turbulence hazard, changing complex ATC clearances within short time, complex maneuvers, passengers). The pilot lacked assertiveness. Peer pressure to land the aircraft at the planned destination was existent ("third time will be a charm").	[SC-45_Pilot] The importance of SRM training courses shall be emphasized to provide procedures to cope with high workload situations [H-7].	[QR-39] Was the pilot trained in SRM? [QR-40] Had the pilot been subject to time pressure (appointment) on the day of the accident?
[UCA-17] The flaps were extended to 50% at a speed > 10 kts above Vfe, which resulted in exceeding the approved and safe flight envelope.		ATC advised the pilot to keep the speed up. The pilot did not announce the inability to comply.	[SC-46_Pilot] If ATC requests cannot be complied with, procedures for energy and ATC management shall be enforced [H-1, H-9].	
[UCA-18] Safe airspeed control was not achieved, which resulted in exceeding the approved and safe flight envelope. [UCA-19] When the approach speed was deceeding the recommended speed, the pitch angle was not reduced and the speed decreased further until stall.		The pilot might have mistaken procedures/ air speeds with other aircraft flown in the past.	[SC-47_Pilot] Procedures for correct airspeed control and subsequent aircraft trim shall be enforced [H-1, H-7, H-9].	[QR-41] Did the pilot actively operate on other types of aircraft in the recent past? [QR-42] Was the pilot applying correct trim procedures? [QR-43] Are there any RDM data available in regards of aircraft trim?
[UCA-20] The pilot did not start the final descent appropriately in respect of the aiming point, which resulted in ending up too high for the landing.		Visual illusion (false adoption of horizon after long cruise flights) affects stabilized approach criteria and control of aircraft.	[SC-48_Pilot] Procedures to cope with the influence of visual illusions shall be enforced [H-1, H-9]. [SC-49_Pilot] Procedures for the consideration of visual glide slope indications (PAPI) shall be enforced [H-1, H-9].	[QR-44] Was the pilot aware of possible visual illusions?
[UCA-21] Stabilized approach criteria were not fulfilled, which resulted in ending up too high for the landing. [UCA-22] The pilot *did not manage the glide angle with flaps and/ or side-slip as necessary* (rf. (FOM-SR20, 2011, p. 4-11)).	*The aircraft was not slowed to a speed that allowed the pilot to perform a stabilized approach in a timely manner* (rf. (FOM-SR20, 2011, p. 3-58)).	Modern, efficient wing designs produce low drag and speed deduction might suffer. Side-slip maneuvers may be used to increase rate of descent without speed increase.	[SC-50_Pilot] Procedures to perform proper energy management (power control, side-slip maneuvers) to comply with stabilized approach criteria shall be emphasized [H-9].	[QR-45] Had there been any incidents by the pilot in respect of unstabilized approaches at other airports? [QR-46] Was the pilot trained/ assessed for side-slip maneuvers?

Pilot - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
[UCA-23] The pilot overbanked the aircraft, which resulted in exceeding maximum bank angles during visual maneuvering. [UCA-24] The pilot encountered uncertainty about the actual aircraft position (to comply with the assigned ATC clearances), which resulted in uncoordinated and unusual aircraft attitudes in low altitude.	Navigating complex maneuvers distracts pilots from basic aviating.	High-traffic situation in class-B airspace in the close proximity of an airport with crossing runways requires high navigational capabilities to avoid errors. Unusual attitudes in low altitudes may be a sign of uncertain navigation capabilities. Deficiencies in vision may distract the pilot from reading the navigation charts properly. Electronic charts may fail.	[SC-51_Pilot] Pilots shall know to avoid high bank angles in low level flying [H-1, H-9]. [SC-52_Pilot] Navigational charts must be easy to read and have a backup [H-7].	[QR-47] Which charts had been used as reference for navigation? [QR-48] Was the pilot able to read the charts properly?
[UCA-25] The pilot did not recognize the inability to land from the actual position until concerns were raised by ATC ("if that's too high we can put you back […], don't force it if you can't", "you might be too high"), which resulted in a go-around at a late stage.		The late and incorrect initiation of the go-around might be a sign for uncertainty of a go-around procedure.	[SC-53_Pilot] Procedures must be enforced that pilots on control are always aware when and how to initiate a go-around to maintain the highest achievable level of safety margin [H-9].	
[UCA-26] The procedure for balked landings (go-arounds) was not followed correctly (full power not applied, incorrect speeds, inadequate coordination), which resulted in exceeding the approved flight envelope.		The go-around is a complex and demanding procedure, as many actions need to be performed in a short time close to the ground. Reduced power settings were contributing.	[SC-54_Pilot] A pilot must be able to perform a correct go-around procedure in any situation, irrespective of external influences [H-9].	[QR-49] What was the reason for applying reduced power settings for the go-around?
[UCA-27] The increasing tailwind component lowering the energy state of the aircraft was neglected.			[SC-55_Pilot] The influence of wind components in performance shall never be underestimated [H-1].	
[UCA-28] Stall Warnings were neglected by the pilot, which resulted in further speed decrease. [UCA-29] The aircraft was stalled due uncoordinated pitch control and retraction of the flaps.		Lost situational awareness causes even obvious warning signals (stall warning) to be ignored.	[SC-56_Pilot] Measures shall be enforced to maintain the highest level of situational awareness [H-7].	[QR-50] Was the pre-flight check incl. stall warning system check performed properly? [QR-51] Did ATC record any stall warning signals on the transmission tapes? [QR-52] Does the RDM store an active stall warning trigger?
[UCA-30] Control over the aircraft was lost and not recovered until the fatal ground impact.		The pilot "may be disoriented beyond the point where traditional, hand flown recovery techniques are effective" (FOM-SR20, 2011, p. 4-40).	[SC-57_Pilot] Procedures to avoid and escape loss of aircraft control shall always be the first priority of any pilot [H-3, H-4, H-5].	

Pilot - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
[UCA-31] CAPS had not been deployed by the pilot when required, which resulted in a non-decelerated aircraft impact on ground.		Startle Effect may have affected the pilot's ability to cope with the situation on time.	refer to [SC-61_Paxe]	[QR-53] Did the pilot perform any CAPS training?

Table 2-9 Pilot - CAST analysis

2.5.9 Passengers - Control Structure

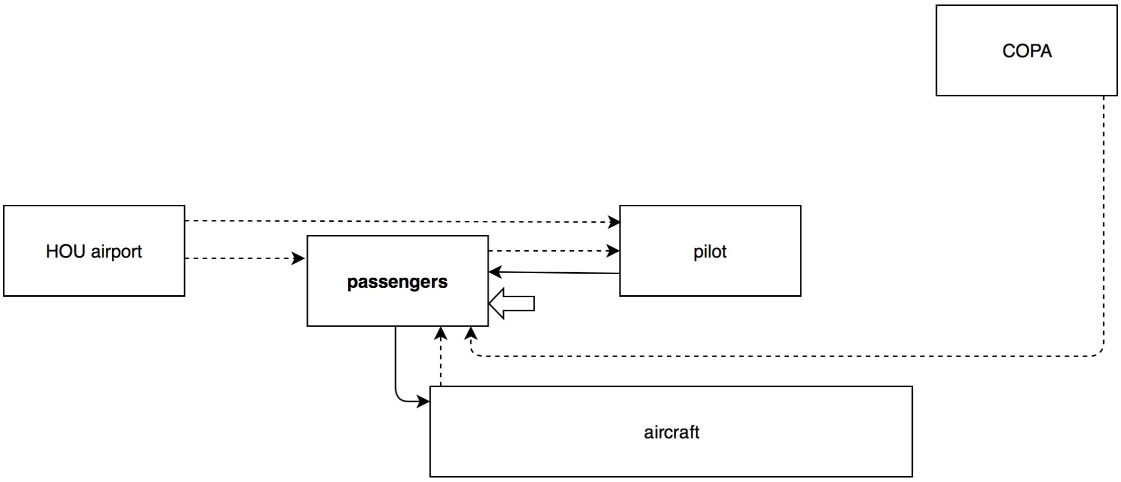


Figure 2-22 Passengers - simplified control structure

Passengers - CAST analysis				
Unsafe control actions	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
		Time pressure influences decision-making.		[QR-54] Were any of the passengers on the flight under time pressure?
		Convective weather causes turbulences. Medical impairment or airsickness of passengers might cause the pilot to be distracted.		[QR-55] Were any of the passengers known for airsickness or other physiological deficiencies?
		The pilot may be distracted by the passengers (e.g. due conversations, airsickness, fear of flying, etc.).	[SC-58_Paxe] Passengers shall be aware of sterile cabin procedures and avoid distracting the pilot [H-7].	[QR-56] Had passengers been briefed on sterile cabin procedures?
		Passengers may support the pilot in high workload environment (airspace scan, awareness of stabilized approach criteria, etc.).	[SC-59_Paxe] Passengers shall be considered as a resource in SRM [H-7].	[QR-57] Did the passengers frequently fly with single-engine piston aircraft and/ or have extensive aviation knowledge?
		Multiple go-arounds, high descent rates, unusual attitudes, gusty crosswind conditions and the recognition of high workload for the pilot may scare passengers and cause distractions for the pilot.	[SC-60_Paxe] Pilots shall be trained in procedures to provide a safe and comfortable atmosphere for passengers [H-7].	
[UCA-32] None of the passengers had considered to activate CAPS when required, which resulted in an non-declerated aircraft impact on ground.		Regarding CAPS activation “no minimum altitude for deployment has been set” (POH-SR20, 2015, p. 10-6).	[SC-61_Paxe] Anybody on board shall know about activating CAPS, if life-threatening situations persist (which requires detailed preflght briefing for passengers) [H-5].	[QR-58] Had the passengers been briefed about life-threatening situations requiring the activation of CAPS?

Table 2-10 Passengers - CAST analysis

2.5.10 Aircraft - Control Structure

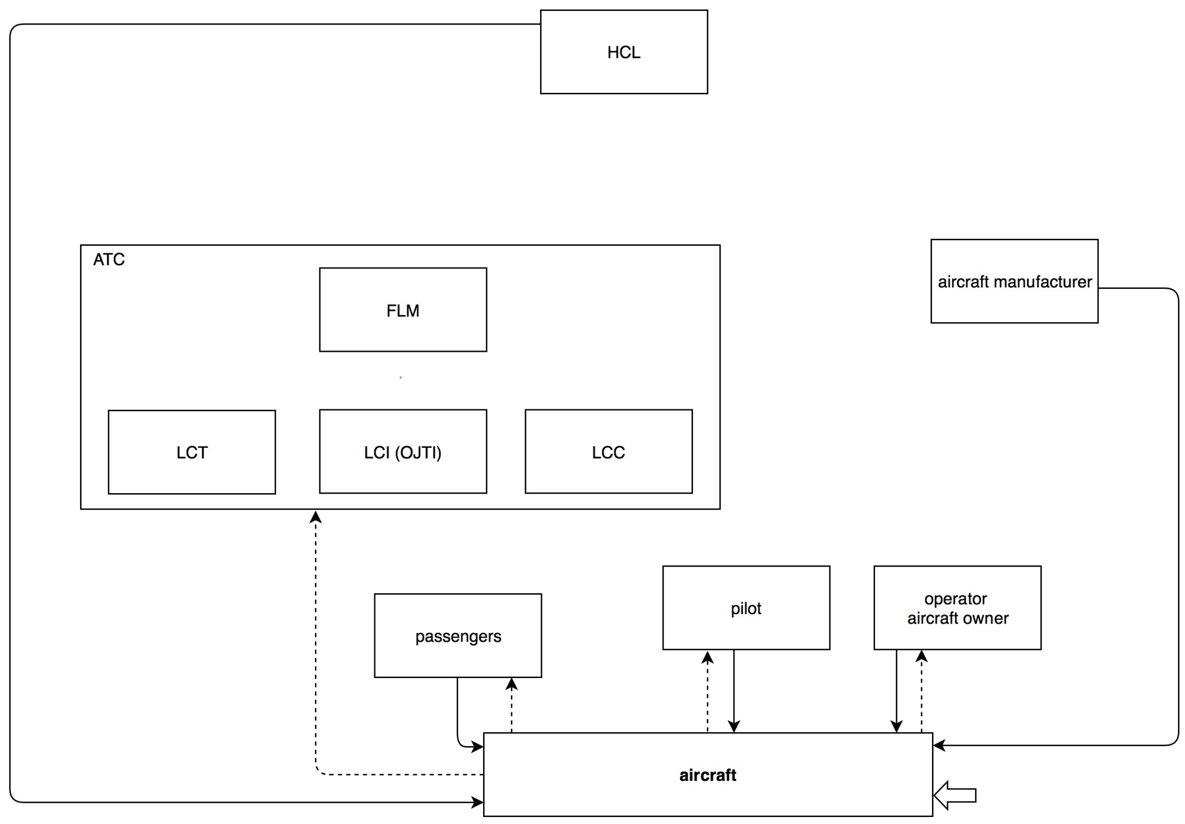


Figure 2-23 Aircraft - simplified control structure

Aircraft - CAST analysis				
Unsafe control	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
[UCA-33] The stall warning system was neglected by the pilot, which resulted in further deceleration and actual stall of the aircraft.				[QR-59] Was the stall warning system functionable on the accident flight? [QR-60] Was the pilot aware of aerodynamic aircraft reactions when approaching stall conditions?
	Safe airspeed control was not achieved.	The inability to read the primary flight information data from the cockpit annunciations may lead to exceedances of the approved flight envelope.		[QR-61] Was there any failure of the primary flight displays logged by the RDM? [QR-62] Did the primary flight display fail or get in an unreadable condition? [QR-63] Did the accident aircraft have alternate indications of the primary flight information (speed, altitude, attitude)?

Aircraft - CAST analysis				
Unsafe control	Dysfunctional interactions	Contextual factors	Safety constraints	Questions raised
	The trim setting of the aircraft on impact was not documented in the investigation report, which would provide an information about forces on the pilot's yoke.			[QR-64] For which speed was the aircraft trimmed before the final impact?
	Data overload through the on-board avionics may impair the ability of pilots to effectively operate the aircraft.		[SC-62_Aircraft] Aircraft system indications shall be simple to understand and read [H-7].	
[UCA-34] The aircraft incorporates no active attention-getter reminding of activating CAPS in life-threatening situations (spin in low altitude), which resulted in a non-decelerated aircraft impact without activated CAPS.		Startle effect impairs the ability to take appropriate action.	[SC-63_Aircraft] Procedures of activating CAPS in life-threatening situations shall be brought to noticeable attention in the cabin [H-5].	

Table 2-11 Aircraft - CAST analysis

3 RESULTS

As Leveson noted “one consequence of the completeness of a STAMP analysis is that many possible recommendations may result - in some cases, too many to be practical to include in the final accident report. A determination of the relative importance of the potential recommendations may be required in terms of having the greatest impact on the largest number of potential future accidents. There is no algorithm for identifying these recommendations, nor can there be. Political and situational factors will always be involved in such decisions. Understanding the entire accident process and the overall safety control structure should help with this identification, however“ (Leveson, Engineering a Safer World, 2011, p. 384).

The prevailing CAST modeling of the N4252G accident was based on available information and detailed recherches by the author. Emphasis was placed on understanding how higher levels in the hierarchical control structure influenced/ allowed unsafe control actions. The following safety recommendations as part of the results of the STAMP-based analysis were created by the author in relation to the developed safety constraints, considering measures to protect them from erosion of safety over time. For details refer to the following Table 3-1 Safety recommendations.

Safety constraints		Safety recommendations	
[SC-1_HCL]	The competent components of the HCL shall emphasize to disseminate lessons learned and enforce flight safety recommendations (considering system-theoretic principles) into standards/ legal law.	[REC-1]	Legal law shall be adapted in a way, that accident investigation processes are investigated considering system-theoretic principles and provide safety recommendations, which are implemented in the standards/ legislation.
[SC-2_HCL]	Consideration of industry standards and technological possibilities shall be part of the legal enforcement basis for general aviation pilots' training.	[REC-2]	Pilot training shall be based on modern equipment used and on real-life scenarios (including SRM, decision making and risk assessment), rather than solely on maneuvers. Training standard syllabi shall be revised on a regular base, considering industry technical standards and lessons learned from recent accidents/ incidents.
[SC-3_HCL]	SRM Courses shall be required for single pilots on a regular base.	[REC-3]	Regular training in single-pilot resource management shall be a requirement for pilots exercising their licenses.
[SC-4_HCL]	Expiry dates of pilot's license endorsements shall be implemented.	[REC-4]	Pilot's license endorsements shall be restricted by expiry dates, which require pre-requisites which can be adapted accordingly by the legislation.
[SC-5_HCL]	Flight review data shall be tracked by the competent authority.	[REC-5]	Check airmen (examiner) shall be provided with a tool to forward proficiency assessments of performed flight reviews to the competent authority, which enables to track the flight crews' proficiency status.

Safety constraints		Safety recommendations	
[SC-6_HCL]	HCL shall emphasize to enforce regular check rides for VFR single-engine piston pilots.	[REC-6]	Check rides shall be required to revalidate VFR single-engine pilot’s license endorsements considering the proficiency of the pilot. For more experienced pilots the interval required to revalidate the license may be extended on discretion of the check airman (examiner).
[SC-7_HCL]	Loss-of-control training for single-engine pilots shall be required.	[REC-7]	Loss-of-control training for pilots shall be required on a regular base and tracked by the authority.
[SC-8_HCL]	HCL shall emphasize to enforce training requirements based on modern industry standards (e.g. APS training).	[REC-8]	Pilots shall be trained in aircraft parachute systems on a regular base and tracked by the authority.
[SC-9_HCL]	Stress management education for pilots in general shall be required on a regular base.	[REC-9]	Stress management education for pilots including coaching shall be required on a regular base.
[SC-10_HCL]	Reporting programs shall be obligatory for ATC centers.	[REC-10]	ATC centers shall apply a formal safety reporting system as well as an independent feedback channel about process safety concerns by employees.
[SC-11_HCL]	Regular audits at ATC centers shall be accomplished as part of the oversight through HCL. Non-compliances shall be analysed for its root causes and respective corrective actions applied.	[REC-11]	Competent authorities shall accomplish regular audits at ATC centers and raise appropriate findings requiring appropriate root cause analyses and corrective action plans (as part of the safety-management-system).
[SC-12_HCL]	Measures must be enforced to prohibit pilots performing their duties under the influence of prescription medications without AME approval.	[REC-12]	Unannounced drug and alcohol test programs of pilots shall be established by the competent authority.
[SC-13_HCL]	Primary accident causal factors that continue to plague the general aviation community shall be explicitly disseminated to the pilots.	[REC-13]	Pilots shall be promoted to engage in incentive proficiency platforms (e.g. WINGS) to enhance their knowledge of primary causal accident factors.
[SC-14_TrOrg]	Training organisations must assure that pilots are proficient in all relevant aircraft manual contents (POH, FOM) of the aircraft operated.	[REC-14]	Measures shall be enforced that relevant aircraft manual contents are refreshed/ reviewed regularly by the pilots.
[SC-15_TrOrg]	Risk awareness tools shall be trained to pilots considering actual influencing factors for instruction flights.	[REC-15]	Establish promotions about the importance of risk assessments at places frequently attended by pilots.
[SC-16_TrOrg]	Procedures to keep pro-active, personal Safety Cultures in every pilot’s mind shall be enforced	[REC-16]	Ensure that every pilot understands that a pro-active, personal Safety Culture is of utmost importance.
[SC-17_TrOrg]	Practical training in acrobatic aircraft/ simulators to maintain proficiency in spin recovery procedures shall be enforced.	[REC-17]	Practical training in acrobatic aircraft/ simulators to maintain proficiency in spin recovery procedures shall be required by regulation.
[SC-18_ATC]	It must be assured that a minimum number of ATC controllers is available to avoid any degradation in aviation safety.	[REC-18]	Ensure that a sufficient number of ATC controllers is available and have alternative measures for unexpected deficiencies.
[SC-19_ATC]	Operations with ATC trainees being supervised by ATC instructors must follow clear and consistent procedures.	[REC-19]	Supervision tasks require clear, established procedures, which shall be briefed to each other before the first duty of the day.
[SC-20_ATC]	ATC training shall include active ATC simulator sessions rather than online learning tools.	[REC-20]	ATC training shall be regularly performed in ATC simulators for maximum benefit of safety.

Safety constraints		Safety recommendations	
[SC-21_ATC]	ATC shall not change runway assignments for landing within a short time interval to avoid unnecessarily increasing the workload for the pilot.	[REC-21]	ATC re-clearances requiring a short-time decision-making process of the pilot over an extended period of time shall be avoided.
[SC-22_ATC]	Runway assignments shall be adapted for the lowest achievable risk in changing wind conditions.	[REC-22]	Runway assignments shall be adapted for continuously achieving the highest level of possible safety.
[SC-23_ATC]	Runway assignment procedures for ATC shall be enforced to reduce crosswind components for aircraft approaching with obvious difficulties in aircraft handling.		refer to [REC-22]
[SC-24_ATC]	ATC tower controllers shall be trained to provide appropriate clearances if the aircraft is in a position ("unstable approach") from which a successful landing cannot be assured.	[REC-23]	ATC controllers shall be trained to recognize unstable approach conditions and provide appropriate clearances to regain a maximum level of safety.
[SC-25_ATC]	Adherence to ICAO standard phraseology shall be regularly evaluated and examined. Importance of clear communication shall be highlighted.	[REC-24]	Adherence of ATC controllers to ICAO standard phraseology shall be monitored (regular standard phraseology exams) and appropriate training measures taken if needed.
[SC-26_ATC]	Clear ATC Procedures shall be enforced and adhered to assure that safety has first priority. Handing over of VFR aircraft to approach control must not be categorized as abnormal.	[REC-25]	ATC habits shall be monitored for compliance to applicable procedures. In case of deviations re-evaluations to regain the highest level of safety shall be applied.
[SC-27_ATC]	ATC controllers shall be trained to recognize and support pilots in regaining lost or degraded situational awareness.	[REC-26]	ATC controllers shall be trained to recognize lost or degraded levels of situational awareness of pilots and how to support them to regain a maximum level of safety.
[SC-28_ATC]	Internal communication processes among ATC stations shall not be impaired.	[REC-27]	For internal communication among ATC stations, it shall be assured that information concerning the actual task is forwarded to the controllers in charge.
[SC-29_ATC]	ATC transmissions to an aircraft in a critical phase of flight shall be kept to a minimum.	[REC-28]	ATC controllers shall be trained not to distract pilots with unnecessarily long transmissions in critical phases of flight.
[SC-30_ATC]	Overlap periods of ATC controllers shall be adapted to the actual scenario and not be based solely on overlap-time.	[REC-29]	ATC overlaps shall not be finished as long as a sufficient level of situational awareness of the ATC controller taking over is not achieved.
[SC-31_ATC]	Regular training events to share each ATC controller's experiences shall be accommodated.	[REC-30]	It shall be assured that regular training events of ATC controllers are accommodated to share individual experiences.
[SC-32_ATC]	Non-punitive reporting cultures for ATC controllers shall be obligatory for each ATC center for a higher level of experience exchange.		refer to [REC-10]
[SC-33_Cirrus]	Unusual artificial feelings on a control yoke and its associated risks shall be described in the POH.	[REC-31]	It must be assured that a pilot is warned of aircraft systems with unusual characteristics and associated risks in a proper manner.
[SC-34_Cirrus]	Improper pilot's actions exceeding aircraft limitations or endangering the safety of flight shall be avoided.	[REC-32]	Referring to FOM-SR20 (2011), pilots shall be disciplined to *follow standard procedures during flight operations, as they will develop habit patterns through repetition that allows to be most efficient while completing tasks and configuring the aircraft for various phases of flight* (rf. (FOM-SR20, 2011, p. 3-3)).

Safety constraints		Safety recommendations	
[SC-35_Cirrus]	The POH shall clearly state a warning that retracting flaps below the recommended stall speeds is of utmost danger of losing control of the aircraft.	[REC-33]	It must be assured that a pilot is warned of actions that could lead to an immediate loss of control. Alternative measures shall be enforced to avoid initiating unsafe actions.
[SC-36_HOU]	ATC controllers shall be informed where the wind sensors are located to assign the actual wind properly.	[REC-34]	ATC controllers shall be informed about the location of meteorological sensors and the applicability of its data.
[SC-37_Pilot]	Performing active flight duties under the influence of prescribed medication, which has not been aeromedically prescribed, shall be strictly prohibited.		refer to [REC-12].
[SC-38_Pilot]	The importance of proper flight planning and preparation shall be emphasized.	[REC-35]	Pilots shall be disciplined that the preparation of a proper flight planning including risk assessment is of utmost importance for the safety of flight.
[SC-39_Pilot]	Risk assessment shall be performed before and regularly during a flight to be prepared for rapidly changing conditions in the dynamic aviation environment.	[REC-36]	Pilots decision-making pre-flight and in-flight (with emphasize to rapidly changing conditions in the dynamic aviation environment) shall be related to a risk assessment process, which is trained regularly.
[SC-40_Pilot]	Pilots shall be trained not to accept ATC clearances causing workload, which is exceeding the personal capabilities.	[REC-37]	Pilots shall be disciplined that the PIC has the final authority for the safety of flight. Therefore, clearances shall always be verified in respect of safety deficiencies. Regular scenario-based training events in decision-making and assertiveness shall be a requirement.
[SC-41_Pilot]	Safety-relevant maneuvers shall be performed strictly according to procedures.	[REC-38]	Pilots shall be strictly disciplined that it is each airman's personal responsibility to maintain skills to be prepared in performing safety-relevant maneuvers any time they are needed.
[SC-42_Pilot]	The importance of sterile cabin procedures shall be emphasized.	[REC-39]	Pilots shall be aware that distractions may severely impair the situational awareness. Passengers must be briefed about sterile cabin procedures. Placards to remind in the aircraft cabin shall be considered.
[SC-43_Pilot]	Methods and procedures for recognizing and regaining lost situational awareness shall be taught.	[REC-40]	Pilots operating in single-pilot operation shall be aware that "staying ahead of the aircraft" all the time is of utmost importance. If a lack of situational awareness is recognized procedures to regain SA shall be known and applied accordingly.
[SC-44_Pilot]	Communication announcements shall be performed after the flight path is safely stabilized ("aviate-navigate-communicate" procedure).	[REC-41]	It must be the golden rule for any pilot, that first stabilizing the flight path and second navigation (adherence to ATC clearances) has priority over communication.
[SC-45_Pilot]	The importance of SRM training courses shall be emphasized to provide procedures to cope with high workload situations.	[REC-42]	Consideration of all available resources must be performed. Regular scenario-based training to enhance the highest achievable level of competence shall be emphasized. Workload shall always be managed in a way so as to maintain sufficient personal capacities for safe completions of primary flight duties.

Safety constraints		Safety recommendations	
[SC-46_Pilot]	If ATC requests cannot be complied with, procedures for energy and ATC management shall be enforced.	[REC-43]	Stabilized approach criteria shall be monitored by the pilot. Appropriate warnings ("attention-getters") shall be triggered by the on-board avionics equipment in case of parameters deviating.
[SC-47_Pilot]	Procedures for correct airspeed control and subsequent aircraft trim shall be enforced.	[REC-44]	Pilots shall be aware that irrespective of the level of automation of an aircraft, the discipline to strictly follow approved procedures and maintain basic skills in flying is required for a safe operation.
[SC-48_Pilot]	Procedures to cope with the influence of visual illusions shall be enforced.	[REC-45]	Pilots shall be aware that visual perception influences the pilot's basic flying capability. Vigilance and regular training shall be ensured.
[SC-49_Pilot]	Procedures for the consideration of visual glide slope indications (PAPI) shall be enforced.	[REC-46]	Effects of visual illusions in respect of stabilized approach criteria shall not be underestimated and regularly trained.
[SC-50_Pilot]	Procedures to perform proper energy management (power control, side-slip maneuvers) to comply with stabilized approach criteria shall be emphasized.		refer to [REC-44]
[SC-51_Pilot]	Pilots shall know to avoid high bank angles in low level flying.	[REC-47]	High bank awareness systems shall be integrated in the aircraft's avionics system, to warn pilots exceeding defined bank angles.
[SC-52_Pilot]	Navigational charts must be easy to read and have a backup.	[REC-48]	Pilots shall assure that the navigational charts used can be read and understood under all expected conditions.
[SC-53_Pilot]	Procedures must be enforced that pilots on control are always aware when and how to initiate a go-around to maintain the highest achievable level of safety margin.		refer to [REC-38]
[SC-54_Pilot]	A pilot must be able to perform a correct go-around procedure in any situation, irrespective of external influences.		refer to [REC-38]
[SC-55_Pilot]	The influence of wind components in performance shall never be underestimated.	[REC-49]	Pilots shall be trained how to deal with environmental factors instantaneously influencing the energy state of the aircraft.
[SC-56_Pilot]	Measures shall be enforced to maintain the highest level of situational awareness.		refer to [REC-26]
[SC-57_Pilot]	Procedures to avoid and escape loss of aircraft control shall always be the first priority of any pilot.	[REC-50]	Pilots shall always have full control of the aircraft. For the case of inadvertent loss of control, the pilot shall be trained regularly to apply the safest courses of action.
[SC-58_Paxe]	Passengers shall be aware of sterile cabin procedures and avoid distracting the pilot.		refer to [REC-39]
[SC-59_Paxe]	Passengers shall be considered as a resource in SRM.	[REC-51]	Designated passengers shall be considered to assist the pilot in resource management (e.g. reading checklists, announcing deviations of basic flight parameters, etc.).
[SC-60_Paxe]	Pilots shall be trained in procedures to provide a safe and comfortable atmosphere for passengers.	[REC-52]	Passengers shall be briefly kept informed about the progress of flight with avoiding any means of scare.
[SC-61_Paxe]	Anybody on board shall know about activating CAPS, if life-threatening situations persist (which requires detailed preflght briefing for passengers).	[REC-53]	Passengers shall be briefed about life-threatening situations requiring CAPS activation and/ or regularly complete a CAPS training.
[SC-62_Aircraft]	Aircraft system indications shall be simple to understand and read.	[REC-54]	Aircraft systems shall be designed in a way that they support the decision-making process rather than impair it by an overload of data.

[SC-63_Aircraft]	Procedures of activating CAPS in life-threatening situations shall be brought to noticeable attention in the cabin.	[REC-55]	Options to activate applicable passive safety equipment shall always be considered and mentioned in personal pilot briefings. Appropriate indications by the on-board avionics system may reduce the time of possible startle effects.

Table 3-1 Safety recommendations

The existing accident report does not contain all necessary information to gain a holistic understanding of the prevailing loss. Through the STAMP (Leveson, 2011) modeling subsequently questions emerged (refer to Table 3-2 Questions raised). Its answers would need to be considered for further clarification in the CAST (Leveson, 2011) analysis and would probably involve revising already-defined safety constraints and recommendations.

Questions raised	
[QR-1]	Are there any incidents known to the authority in respect of the accident pilot?
[QR-2]	State details about the initial training of the accident pilot and her progress (type/ duration, types of aircraft, details about descent planning, energy management, busy airport operations, stabilized approach criteria, stall/ spin avoidance, CAPS)?
[QR-3]	What was the status/ progress of the accident pilot's instrument training?
[QR-4]	What had been the weaknesses of the accident pilot, in the opinion of the CFIs?
[QR-5]	Was good airmanship in respect of spin avoidance (as mentioned in the POH) trained?
[QR-6]	Was the FOM with the "Envelope of Safety" taught as part of the initial training for the Cirrus aircraft?
[QR-7]	Did the pilot attend any courses in SRM or related topics and what had been the content?
[QR-8]	How was the pilot's attitude in respect of her own safety culture?
[QR-9]	Was the accident pilot trained to recognize loss of control situations and how to escape?
[QR-10]	Which communication processes at the HOU ATC Facility require improvements?
[QR-11]	Was peer pressure influencing the communication between the ATC trainee and his instructor?
[QR-12]	Which alternative procedures (except visual separation) for re-aligning aircraft in the traffic pattern were common?
[QR-13]	Are the ATC controllers trained to follow ICAO standard phraseology and avoid unnecessarily long ATC clearances, especially during critical phases of flight?
[QR-14]	Do the LC controllers have adequate training for vectoring aircraft in the near proximity of the airport under high-traffic conditions?
[QR-15]	Was LC control ever in doubt, that N4252G might not be able to land the aircraft successfully?
[QR-16]	How does an ATC controller evaluate the confidence of pilots?
[QR-17]	Did the LCC anticipate the high workload and stress that the pilot of N4252G was under at the third go-around?
[QR-18]	How was assured, that the LCC taking over had sufficient situational awareness about the ATC traffic situation?
[QR-19]	How is it assured that individual procedures and working practices are shared among every ATC team member?
[QR-20]	How was the performance of ATC controllers assured?
[QR-21]	What schedules the issue of new POH revisions?
[QR-22]	What is the alternative procedure for pilots if the CAPS system cannot be activated in case of an unintended spin?
[QR-23]	Was the pilot aware of the associated risks due artificial aerodynamic forces on the control yoke?
[QR-24]	How does the manufacturer assure that LOC is avoided in Cirrus aircraft?
[QR-25]	Did the accident pilot participate in any CPPP training?

Questions raised	
[QR-26]	Did the accident pilot participate in any CDM seminar?
[QR-27]	Did any of the passengers participate in a Partner in Command seminar?
[QR-28]	Did the actual NOTAMs at the day of accident state any deficiencies influencing the safety of flight (e.g. unserviceability of PAPI, displaced thresholds, etc.)?
[QR-29]	Under which pre-requisites did the operator/ aircraft owner permit the pilot to operate the aircraft?
[QR-30]	What was the operator's/ aircraft owner's safety policy (requirements, currency, training) for pilots operating the aircraft?
[QR-31]	What are the details concerning the accident pilot's types of aircraft flown, flight hours and landings?
[QR-32]	Did the pilot have a flight planning package including weather forecast and NOTAMs?
[QR-33]	Did the accident pilot apply any risk assessment tools?
[QR-34]	Did the pilot wait at least 24 hours after taking Zolpidem before her flying activity (as recommended by the FAA)?
[QR-35]	How did the pilot prepare for the flight and what had been the contents of the flight planning package?
[QR-36]	What was the pilot's attitude in respect of risk assessment?
[QR-37]	Did the pilot perform any training flights or a flight review before the accident?
[QR-38]	Was the pilot's level of situational awareness impaired by any reason and could the pilot in general be distracted easily when performing tasks?
[QR-39]	Was the pilot trained in SRM?
[QR-40]	Had the pilot been subject to time pressure (appointment) on the day of the accident?
[QR-41]	Did the pilot actively operate on other types of aircraft in the recent past?
[QR-42]	Was the pilot applying correct trim procedures?
[QR-43]	Are there any RDM data available regarding aircraft trim?
[QR-44]	Was the pilot aware of possible visual illusions?
[QR-45]	Had there been any incidents by the pilot in respect of unstabilized approaches at other airports?
[QR-46]	Was the pilot trained/ assessed for side-slip maneuvers?
[QR-47]	Which charts had been used as reference for navigation?
[QR-48]	Was the pilot able to read the charts properly?
[QR-49]	What was the reason for applying reduced power settings for the go-around?
[QR-50]	Was the pre-flight check incl. stall warning system check performed properly?
[QR-51]	Did ATC record any stall warning signals on the transmission tapes?
[QR-52]	Does the RDM store an active stall warning trigger?
[QR-53]	Did the pilot perform any CAPS training?
[QR-54]	Were any of the passengers on the flight under time pressure?
[QR-55]	Were any of the passengers known for airsickness or other physiological deficiencies?
[QR-56]	Had passengers been briefed on sterile cabin procedures?
[QR-57]	Did the passengers frequently fly with single-engine piston aircraft and/ or have extensive aviation knowledge?

Questions raised	
[QR-58]	Had the passengers been briefed about life-threatening situations requiring the activation of CAPS?
[QR-59]	Was the stall warning system functionable on the accident flight?
[QR-60]	Was the pilot aware of aerodynamic aircraft reactions when approaching stall conditions?
[QR-61]	Was there any failure of the primary flight displays logged by the RDM?
[QR-62]	Did the primary flight display fail or get in an unreadable condition?
[QR-63]	Did the accident aircraft have alternate indications of the primary flight information (speed, altitude, attitude)?
[QR-64]	For which speed was the aircraft trimmed before the final impact?

Table 3-2 Questions raised

Figure 2-24 summarizes the results (unsafe control actions (UCA), safety constraints (SC), questions raised (QR)) categorized for the individual components in the HCS.

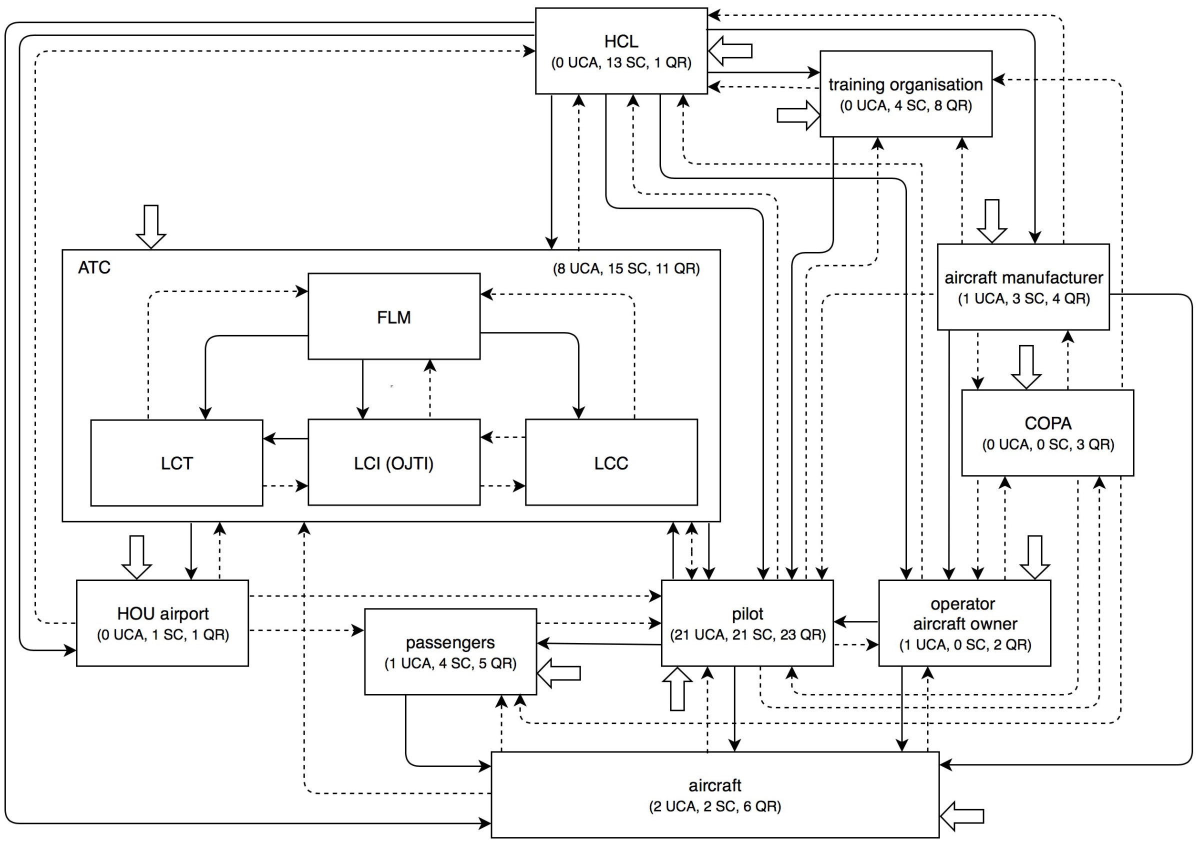


Figure 3-1 General model of hierarchical control structure including results

The modeling of the prevailing accident of N4252G emerged 34 unsafe control actions, 63 safety constraints, 64 raised questions and 55 safety recommendations.

4 DISCUSSION

The interaction of many factors was crucial for this accident. The hierarchical control structure in Chapter 2.4 visually illustrates the complexity of a system-theoretical accident investigation, which a linear simplification - as traditionally used in many cases - cannot provide. The comparison of the results of the linear analysis (refer to F Appendix) against a STAMP/ CAST (Leveson, 2011) based analysis clearly shows the different results.

The complexity in aviation is steadily increasing and the multitude of relevant terms (refer to A Appendix) illustrates only a fraction of the necessary expertise that today's pilots need. Despite the constantly improved technical aids, aviation accidents continue to happen, although these are rarely given public importance in general aviation. That was also one of the reasons why the author chose this accident as a topic for the master thesis.

The aircraft in this accident was flown into an undesired aircraft state, which eventually caused the loss. Referring to the official accident report, the question emerged concerning what aspects contributed a pilot with more than 300 flight hours of type experience in just over 2 years being involved in such an accident. The question of whether a flight review could have avoided the accident cannot be clearly answered.

Despite the fact that the safety recommendations of this thesis include changes in standards and regulations, the author believes that the safety of aviation is not solely governed by laws and regulations. Anyone who is actively involved in aviation - not only pilots - must be made aware that regulations are only the foundation upon which decisions must be continually built. "Good airmanship" requires much more than compliance with legal regulations and the avoidance of "dirty dozen". It requires a strong emphasis on discipline to continuously improve skills and permanently assess decisions with the risks to finally execute safe flight operations.

The implementation of safety recommendations into standards/ legal law is often considered as an unnecessary restriction. However, when it is recognized that every single aviation operator can contribute to a safer aviation, it is ultimately up to the attitude of individuals to inspire others to act safely and make aviation safer in the future.

Finally, the author hopes that researchers and practitioners in aviation accident investigations can obtain valuable insights from this research method and findings, and that the use of STAMP/ CAST will be established as best practice in aviation accident investigation.

5 CONCLUSIONS

This thesis provides an insightful investigation of this specific accident by applying Leveson's STAMP model and CAST methodology (Leveson, 2011). Compared with a conventional method of investigation, the insights gained and lessons learned from this study, although only limited sources of information had been available to the author, highlight the potential in applying STAMP in modern accident investigations.

The influences of individual components were analysed and described. It was emphasized that complex, system-theoretical models can also be justified by means of short and simple statements. The large number of identified recommendations illustrates the existing potential for revising procedures in aviation. The questions raised describe that the present aviation accident could be investigated and understood in further detail by answering these open questions.

The existing accident report was substantiated by the investigating party through contributing factors but did not elaborate recommendations for preventing future aircraft accidents. The higher control levels had influenced the outcome by a variety of contextual factors. It was not possible to investigate in detail for what reason the owner of the aircraft permitted the operation by the pilot without a valid flight review. Despite the high workload and external influences, the pilot applied his habits, which he obviously did not classify as unsafe and therefore continued. Similarly, it was also not obvious to ATC that applied habits deviating from known procedures would limit safety. Information from the training organisation was limited to statements made by two of the pilot's flight instructors and a number of questions remained unanswered. The extent to which the manufacturer's flight control system took effect remains questionable, and the extent to which COPA provided training courses to the pilot and passengers was not apparent due to the lack of information. Restrictions from HOU airport could not be researched. Finally, when aircraft control was lost, the passive safety aid CAPS was not activated.

The assumption is confirmed that the accident was still favored by the interaction of individual controllers. This concludes that regular adapting the aviation system is required in so far that it does not blame the mistakes of an individual. Recommendations are to be implemented to ensure that in the interaction of unsafe control actions under worst-case environmental conditions through individual components, the result is not an accident.

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A APPENDIX

Definition of Relevant Terms

In order to understand the terms used in this thesis, this appendix provides a list of descriptions of the most common terms used. It is important to note that these terms and their definitions are typically not self-explanatory and do not have any accepted dictionary definitions, and hence they are only applicable in the document in which they are defined.

Accident. "An occurrence associated with the operation of an aircraft which, in the case of a manned aircraft, takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, or in the case of an unmanned aircraft, takes place between the time the aircraft is ready to move with the purpose of flight until such time as it comes to rest at the end of the flight and the primary propulsion system is shut down, in which:

a) a person is fatally or seriously injured as a result of:

- being in the aircraft, or
- direct contact with any part of the aircraft, including parts which have become detached from the aircraft, or
- direct exposure to jet blast, except when the injuries are from natural causes, self-inflicted or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers and crew; or

b) the aircraft sustains damage or structural failure which:

- adversely affects the structural strength, performance or flight characteristics of the aircraft, and
- would normally require major repair or replacement of the affected component, except for engine failure or damage, when the damage is limited to a single engine (including its cowlings or accessories), to propellers, wing tips, antennas, probes, vanes, tires, brakes, wheels, fairings, panels, landing gear doors, windscreens, the aircraft skin (such as small dents or puncture holes), or for minor damages to main rotor blades, tail rotor blades, landing gear, and those resulting from hail or bird strike (including holes in the radome); or

c) the aircraft is missing or is completely inaccessible.

Note 1 - For statistical uniformity only, an injury resulting in death within 30 days of the date of the accident is classified, by ICAO, as a fatal injury.

Note 2 - An aircraft is considered to be missing when the official search has been terminated and the wreckage has not been located" (ICAO, Annex 13, 2016, p. 1-1).

Airmanship. "Airmanship is the consistent use of good judgement and well-developed skills to accomplish flight objectives. This consistency is founded on a cornerstone of uncompromising flight discipline and is developed through systematic skill acquisition and proficiency. A high state of situational awareness completes the airmanship picture and is obtained through knowledge of one's self, aircraft, environment, team and risk" (Kern, 1996, p. 22).

Assertiveness. "Assertiveness is a communication and behavioral style that allows us to express feelings, opinions, concerns, beliefs and needs in a positive and productive manner. […] Being both unable to express our concerns and not allowing other to express their concerns creates ineffective communications and damages teamwork. Unassertive team members can be forced to go with a majority decision, even when they believe it is wrong and dangerous to do so"
(Skybrary.aero, retrieved from
https://www.skybrary.aero/index.php/The_Human_Factors_%22Dirty_Dozen%22#Lack_of_assertiveness, 2019).

Causes. "Actions, omissions, events, conditions, or a combination thereof, which led to the accident or incident. The identification of causes does not imply the assignment of fault or the determination of administrative, civil or criminal liability" (ICAO, Annex 13, 2016, p. 1-2).

Control Structure. "A control structure captures functional relationships and interactions by modeling the system as a set of feedback control loops. The control structure usually begins at a very abstract level and is iteratively refined to capture more detail about the system" (Leveson, STPA Handbook, 2018, p. 14).

Dirty Dozen. "The Dirty Dozen related to aviation refers to twelve of the most common human error preconditions, or conditions that can act as precursors, to accidents or incidents. These twelve elements influence people to make mistakes. […]

- Lack of Communication: Poor communication often appears at the top of contributing and causal factors in accident reports, and is therefore one of the most critical human factor elements […]
- Complacency: Complacency can be described as a feeling of self-satisfaction accompanied by a loss of awareness of potential dangers […]
- Lack of Knowledge: […]
- Distraction: Distraction could be anything that draws a person's attention away from the task […]

- Lack of Teamwork: In aviation many tasks and operations are team affairs; no single person (or organisation) can be responsible for the safe outcomes of all tasks. However, if someone is not contributing to the team effort, this can lead to unsafe outcomes [...]
- Fatigue: Fatigue is a natural physiological reaction to prolonged physical and/ or mental stress […]
- Lack of Resources: […]
- Pressure: Pressure is to be expected when working in a dynamic environment. […] Pressure can be created by lack of resources, especially time; and also from our own inability to cope with a situation [...]
- Lack of Assertiveness: […] Assertiveness is a communication and behavioral style that allows us to express feelings, opinions, concerns, beliefs and needs in a positive and productive manner [...]
- Stress: There are many types of stress. Typically in the aviation environment there are two distinct types - acute and chronic. Acute stress arises from real-time demands placed on our senses, mental processing and physical body; such as dealing with an emergency, or working under time pressure with inadequate resources. Chronic stress is accumulated and results from long-term demands placed on the physiology by life's demands, such as family relations, finances, illness, bereavement, divorce, or even winning the lottery […]
- Lack of Awareness: Working in isolation and only considering one's own responsibilities can lead to tunnel vision; a partial view, and a lack of awareness of the affect our actions can have on others and the wider task. Such lack of awareness may also result from other human factors, such as stress, fatigue, pressure and distraction […]
- Norms: […] It is important to understand that most Norms have not been designed to meet all circumstances, and therefore are not adequately tested against potential threats"

(Skybrary.aero, retrieved from
https://www.skybrary.aero/index.php/The_Human_Factors_%22Dirty_Dozen%22, 2019).

FITS (FAA Industry Training Standards). "FITS is focused on the redesign of general aviation training. Instead of training pilots to pass practical test, <u>FITS focuses on expertly manage real-world challenges</u>. Scenario based training is used to enhance the GA pilots' aeronautical decision making, risk management, and single pilot resource management skills" (FAA.gov, retrieved from https://www.faa.gov/training_testing/training/fits/more/, 2019).

Flight Review. “The purpose of the flight review required by [Title] 14 CFR part 61, § 61.56 is to provide for a regular evaluation of pilot skills and aeronautical knowledge. Consequently, a flight review is a routine evaluation of a pilot’s ability to conduct safe flight. In effect, it is a proficiency-based exercise in which the airman is required to demonstrate the safe exercise of the privileges of his or her pilot certificate. […] the flight review is not a test or checkride, but rather a training event in which proficiency is evaluated. […] Under § 61.56(c) no person may act as PIC of an aircraft, except as provided in § 61.56(d), (e), and (g), unless within the preceding 24 calendar-months that person has accomplished a satisfactory flight review in an aircraft for which that pilot is appropriately rated. An authorized instructor or other person approved must conduct the flight review. […] a person who has satisfactorily completed one or more phases of the FAA-sponsored WINGS within the preceding 24 calendar-months does not need to accomplish the flight review requirements of this section. […] Pilots and flight instructors should be aware that, under § 61.56(d), there is no requirement for pilots who have completed certain proficiency checks and ratings within the preceding 24 calendar-months to accomplish a separate flight review. [...] Before beginning the flight portion of the bi-annually [biennially] required flight review, the flight instructor should discuss various operational areas with the pilot. This oral review should include, but not be limited to, areas such as aircraft systems, speeds, performance, meteorological and other hazards (e.g. wind shear and wake turbulence), operations in controlled airspace, and abnormal and emergency procedures. The emphasis during this discussion should be on practical knowledge of recommended procedures and regulatory requirements. […] Regardless of the pilot’s experience, the flight instructor should review at least those maneuvers considered critical to safe flight, such as: takeoffs, stabilized approaches to landings, slow flight, stall recognition, stalls, and stall recovery, spin recognition and avoidance, recovery from unusual attitudes and operating the aircraft by sole reference to instruments under actual or simulated conditions” (US Department of Transportation, AC 61-98D (supersedes AC 61-98C), 2018, p. 4-1, 4-2, 4-6, 4-7).

General Aviation Operation. “An aircraft operation other than a commercial air transport operation or an aerial work operation” (ICAO, Annex 6, Part II, 2016, p. 1.1-4).

Hazard. “A hazard is a system state or set of conditions that, together with a particular set of worst-case environmental conditions, will lead to a loss” (Leveson, STPA Handbook, 2018, p. 17).

IMSAFE. "One of the best ways single pilots can mitigate risk is to use the IMSAFE checklist to determine physical and mental readiness for flying. [...] IMSAFE, which stands for Illness, Medication, Stress, Alcohol, Fatigue, and Emotion" (US Department of Transportation, Pilot's Handbook of Aeronautical Knowledge, 2016, p. 2-8, 17-18).

Investigation. "A process conducted for the purpose of accident prevention which includes the gathering and analysis of information, the drawing of conclusions, including the determination of causes and/ or contributing factors and, when appropriate, the making of safety recommendations" (ICAO, Annex 13, 2016, p. 1-2).

Loss. "A loss involves something of value to stakeholders. Losses may include a loss of human life or human injury, property damage, environmental pollution, loss of mission, loss of reputation, loss or leak of sensitive information, or any other loss that is unacceptable to the stakeholders" (Leveson, STPA Handbook, 2018, p. 16).

Loss of Control. "LOC refers to aircraft accidents that result from situations in which a pilot should have maintained (or should have regained) aircraft control, but failed to do so" (US Department of Transportation, AC 61-98D (supersedes AC 61-98C), 2018, p. 2-1).

Notices to Airmen (NOTAMs). "Notices to Airmen, or NOTAMs, are time-critical aeronautical information either temporary in nature or not sufficiently known in advance to permit publication on aeronautical charts or in other operational publications. The information receives immediate dissemination via the National Notice to Airmen (NOTAM) System. NOTAMs contain current notices to airmen that are considered essential to the safety of flight, as well as supplemental data affecting other operational publications" (US Department of Transportation, Pilot's Handbook of Aeronautical Knowledge, 2016, p. 1-12).

PAVE checklist. "By incorporating the PAVE checklist into preflight planning, the pilot divides the risks of flight into four categories: Pilot-in-command (PIC), Aircraft, enVironment, and External pressures (PAVE) which form part of a pilot's decision-making process" (US Department of Transportation, Pilot's Handbook of Aeronautical Knowledge, 2016, p. 2-8).

Pilot's Operating Handbook/ Airplane Flight Manual (POH/ AFM)[16]. "FAA-approved documents published by the airframe manufacturer that list the operating conditions for a particular model of aircraft" (US Department of Transportation, Pilot's Handbook of Aeronautical Knowledge, 2016, p. G23).

Pilot in Command (PIC). "The pilot designated by the operator, or in the case of general aviation, the owner, as being in command and charged with the safe conduct of a flight" (ICAO, Annex 2, 2005, p. 1-7). The Code of Federal Regulations declares that "*the pilot in command of an aircraft is directly responsible for, and is the final authority as to, the operation of that aircraft. […] In an in-flight emergency requiring immediate action, the pilot in command may deviate from any rule of this part to the extent required to meet that emergency"* (rf. Title 14 of the Code of Federal Regulations (14 CFR) part 91, § 91.3).

Precision Approach Path Indicator (PAPI). Referring to the AIM (2017) a PAPI is defined as *a visual aid of one row of lights in two- or four-light systems arranged to provide descent guidance information during the approach to the runway. A pilot on the correct glideslope will see two white lights and two red lights* (rf. (US Department of Transportation, Aeronautical Information Manual, 2017, p. 2-1-1, 2-1-4)).

Safety constraint. "A system-level safety constraint specifies system conditions or behaviors that need to be satisfied to prevent hazards (and ultimately prevent losses)" (Leveson, STPA Handbook, 2018, p. 20).

Safety recommendation. "A proposal of an accident investigation authority based on information derived from an investigation, made with the intention of preventing accidents or incidents and which in no case has the purpose of creating a presumption of blame or liability for an accident or incident. In addition to safety recommendations arising from accident and incident investigations, safety recommendations may result from diverse sources, including safety studies" (ICAO, Annex 19, 2013, p. 1-3).

Safety risk. "The predicted probability and severity of the consequences or outcomes of a hazard" (ICAO, Annex 19, 2013, p. 1-3).

[16]Title 14 of the Code of Federal Regulations (14 CFR) part 91, § 91.9 requires *that pilots comply with the operating limitations specified in the approved flight manuals, markings, and placards.*

Single-Pilot Resource Management (SRM). "It is the ability to manage all the resources available to a single pilot to ensure that the successful outcome of the flight is never in doubt" (FOM-SR20, 2011, p. 3-2).

Situational Awareness (SA). Referring to Endsley (2000), *situational awareness is the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future*[17]*. SA is the real-world changing knowledge that is critical for effective decision-making and action. The formal definition of SA breaks down into three separate levels:*

Level 1 – perception of elements in the environment[18]

Level 2 – comprehension of the current situation[19]

Level 3 – projection of future status

(rf. (Endsley, Situation Awareness Analysis and Measurement, 2000, p. 13-14)).

Stabilized Approach Criteria. "[…] the airplane should be stabilized by 500 ft above airport elevation during straight-in approaches in visual meteorological conditions (VMC). Pilots should monitor at least seven major elements that define a stabilized approach in a GA airplane. The FAA considers an approach to touchdown to be stabilized when the airplane meets all of the following criteria, with only minor deviations:

[…] Glidepath. The airplane is on the correct flightpath. Typically, the glidepath is 3 degrees to the runway touchdown zone (TDZ) (obstructions permitting).

[…] Heading. The airplane is tracking the extended centerline to the runway with only minor heading/ pitch changes necessary to correct for wind or turbulence to maintain alignment. Bank angle should not exceed 15 degrees on final approach.

[…] Airspeed. The pilot maintains a constant target airspeed within +10/ -5 kts indicated airspeed (KIAS), which is usually at, but no lower than, the recommended landing speed specified in the POH […] Note: […] Pilots generally select an appropriate approach speed for the prevailing weather, aircraft, traffic, and performance conditions, but not less than 1.3 Vs0. However, aircraft are usually slowed to a normal landing speed when on the final approach just prior to landing.

[17] pilots usually call it to "stay ahead of the aircraft"

[18] *influences may be channelized attention (tunnel vision), distraction and task saturation* (rf. (Kern, 1996, p. 234))

[19] *new pilots might have difficulties developing SA at this level or beyond, as they have few experiential patterns on which to place new information of events* (rf. (Kern, 1996, p. 236))

[…] Configuration. The airplane is in the correct landing configuration with flaps as required, landing gear extended, and the airplane in trim.

[…] Rate of Descent. Descent rate is a constant and generally no greater than 500 fpm. If a descent greater than 500 fpm is required due to approach considerations, it should be reduced prior to 300 ft above ground level (AGL) and well before the landing flare and touchdown phase.

[…] Power Setting. Power setting is appropriate for the airplane configuration and is not below the minimum power for approach as defined by the POH/ AFM.

[…] Checklists/ Briefings. All briefings and checklists (except the landing checklist) are completed prior to initiating the approach.

Note: For a typical GA piston airplane in a traffic pattern, if the approach becomes unstabilized below 300 ft AGL, the pilot should initiate an immediate go-around" (US Department of Transportation, AC 61-98D (supersedes AC 61-98C), 2018, p. 2-3, 2-4).

Startle Effect. "In aviation, startle effect can be defined as an uncontrollable, automatic reflex that is elicited by exposure to a sudden, intense event that violates a pilot's expectations. […] The startle effect includes both the physical and mental responses to a sudden unexpected stimulus. While the physical responses are automatic and virtually instantaneous, the mental responses - the conscious processing and evaluation of the sensory information - can be much slower. In fact, the ability to process the sensory information - to evaluate the situation and take appropriate action - can be seriously impaired or even overwhelmed by the intense physiological responses. […] performance of more complex motor tasks may be impacted for up to 10 seconds" (Skybrary.aero, retrieved from https://www.skybrary.aero/index.php/Startle_Effect, 2019).

System. "A set of things (referred to as system components) that act together as a whole to achieve some common goal, objective, or end" (Leveson, STPA Handbook, 2018, p. 169).

TAA. "Technologically Advanced Aircraft (TAA) are equipped with new-generation avionics that take full advantage of computing power and modern navigational aids to improve pilot situational awareness, system redundancy and dependence on equipment, and to improve in-cockpit information about traffic, weather, airspace and terrain" (AOPA Technologically Advanced Aircraft, 2007, p. 2).

Traffic Pattern. A visual traffic pattern is a maneuver flown by aircraft taking-off or landing while maintaining visual contact with the airfield. It comprises crosswind, downwind, base and final-leg elements.

Unsafe Control Action. “An Unsafe Control Action (UCA) is a control action that, in a particular context and worst-case environment, will lead to a hazard” (Leveson, STPA Handbook, 2018, p. 35).

Vigilance. “Vigilance is a term that refers to an individual’s ability to pay close and continuous attention to a field of stimulation for a period of time and being watchful for any particular changing circumstances”
(Skybrary.aero, retrieved from https://www.skybrary.aero/index.php/Vigilance_in_ATM, 2019).

Wake turbulence. “When an airplane generates lift, air spills over the wingtips from the high pressure areas below the wings to the low pressure areas above them. This flow causes rapidly rotating whirlpools of air called wingtip vortices or wake turbulence” (US Department of Transportation, Pilot’s Handbook of Aeronautical Knowledge, 2016, p. G34).

WINGS. “The objective of the WINGS - Pilot Proficiency Program is to reduce the number of accidents in General Aviation (GA) by assisting airmen to find educational opportunities designed to help them apply the principles of risk assessment and risk management (RM). When properly applied, these principles will help mitigate accident causal factors associated with common pilot errors, lack of proficiency, and faulty knowledge. The Federal Aviation Administration’s (FAA) purpose is to encourage the majority of GA pilots, through WINGS, to engage in ongoing, targeted flying tasks and learning activities keyed to identified risks and which are designed to mitigate those risks” (US Department of Transportation, AC61-91J, 2011, p. 1).

B APPENDIX

Loss of Control in General Aviation

“While maneuvering an airplane at low altitude in visual meteorological conditions (VMC), many pilots fail[20]

- to avoid conditions that lead to an aerodynamic stall,
- to recognize the warning signs of a stall onset, and
- to apply appropriate recovery techniques.

Many stall accidents that occur in VMC result when a pilot is momentarily distracted from the primary task of flying, such as while maneuvering in the airport traffic pattern, during an emergency, or when fixating on ground objects. Aerodynamic stall accidents fall into the “loss of control in flight” category“ (NTSB, Safety Alert 019, 2013, p. 1).

“The GAJSC cites LOC as one of the six most critical and common causes of GA accidents. […] The FAA reminds pilots and flight instructors to regularly evaluate (and elevate) procedures and skills to avoid, recognize, and recover from emergencies such as LOC. […] LOC usually occurs when pilots lack proficiency. Conditions exceeding personal skill limitations can present themselves at any time and can occur unexpectedly. In this event, the pilot should be able to avoid being startled, make appropriate decisions in a timely manner, and be able to exercise skills at a proficiency level he or she may not have maintained or attained since acquired during initial training. This makes personal currency programs and proficiency training essential. […] LOC accidents often occur while pilots are maneuvering at low altitude and airspeed, such as in an airport traffic pattern” (US Department of Transportation, AC 61-98D (supersedes AC 61-98C), 2018, p. 2-1, 2-2).

[20]Author’s note: “fail“ in respect of humans focuses on blame, which contradicts systemic analyses of why human errors appeared to be right at the time they had occured

C APPENDIX

General Information about STAMP

"For centuries complexity has been handled by traditional methods breaking the system into smaller components, examining and analysing each component in isolation, and then combining the results in order to understand the behavior of the composed components. […] The success of this type of decompositional or reductionist approach relies on the assumption that the separation and individual analysis does not distort the phenomenon or property of interest. […] Complexity is creating "unknowns" that cannot be identified by breaking the system behavior into chains of events. In addition, complexity is leading to important system properties (such as safety) not being related to the behavior of individual system components but rather to the interactions among the components. Accidents can occur due to unsafe interactions among components that have not failed and, in fact, satisfy their requirements. […] STAMP (System-Theoretic Accident Model and Processes) is an accident causality model based on systems theory. […] Systems theory was developed after World War II to cope with the increasingly complex systems with advanced technology that were being created. […]

Some unique aspects of systems theory are:

- The system is treated as a whole, not as the sum of its parts. […]
- A primary concern is emergent properties, which are properties that are not in the summation of the individual components but "emerge" when the components interact. Emergent properties can only be treated adequately by taking into account all their technical and social aspects.
- Emergent properties arise from relationships among the parts of the system, that is, by how they interact and fit together. […]

It expands the traditional model of causality beyond a chain of directly-related failure events or component failures to include more complex processes and unsafe interactions among system components, […]. The two most widely used STAMP-based tools today are STPA (System-Theoretic Process Analysis) and CAST (Causal Analysis based on STAMP). STPA is a pro-active analysis method that analyses the potential cause of accidents during development so that hazards can be eliminated or controlled. CAST is a retroactive analysis method that examines an accident/ incident that has occurred and identifies the causal factors that were involved" (Leveson, STPA Handbook, 2018, p. 5, 7, 4, 10, 12, 13).

"CAST can be used to identify the questions that need to be answered to fully understand why the accident occurred. It provides the basis for maximizing learning from the events. The use of CAST does not lead to identifying single causal factors or variables. Instead it provides the ability to examine the entire sociotechnical system design to identify the weaknesses in the existing safety control structure and to identify changes that will not simply eliminate symptoms but potentially all the causal factors, including the systemic ones. One goal of CAST is to get away from assigning blame and instead to shift the focus to why the accident occurred and how to prevent similar losses in the future. To accomplish this goal, it is necessary to minimize hindsight bias and instead to determine why people behaved the way they did, given the information they had at the time" (Leveson, Engineering a Safer World, 2011, p. 349).

"STPA and STAMP were found to be more efficient and effective than traditional methods, but they can be combined with traditional methods, too. […] They have a solid theoretical background and a practical applicability to complex problems" (Koglbauer, 2018, p. 131-133).

Hierarchical Control Structure (HCS) in STAMP

Referring to Levesson (2018), *a HCS comprises overlapping and interacting control loops, which help to manage the complexity. This is one of the main investigations in every hazard analysis. In general, a controller may provide control actions to control some process and enforce constraints on the behavior of the controlled process. The control algorithms (also called operating procedures or decision-making rules) determine the control actions to provide. Controllers have process models (also called mental models) that represent the human controller's internal beliefs used to make decisions. Process models may include beliefs about the process being controlled or other relevant aspects of the system or the environment, and they may be updated in part by feedback used to observe the controlled process* (rf. (Leveson, STPA Handbook, 2018, p. 22, 23)).

Leveson (2011) describes that *applying the CAST analysis method entails understanding the dynamic process that led to the loss. The accident process is documented by showing the sociotechnical safety control structure for the system involved and the safety constraints that were violated at each level of this control structure, as well as why. The analysis results in multiple views of the accident, depending on the perspective and level from which the loss is being viewed. Moving up the levels of the safety control structure determines how and why each successive higher level in the control structure allowed or contributed to the inadequate control at the current level* (rf. (Leveson, Engineering a Safer World, 2011, p. 350, 351)).

D APPENDIX

In this appendix, the author collects and summarizes essential information and data from various available documents about the basic events of the flight N4252G. Its knowledge and understanding is relevant for the modeling of the accident based on STAMP (Leveson, 2011).

History of Flight N4252G

“On June 9, 2016, about 13:09 central daylight time, a Cirrus SR20 single-engine airplane, N4252G, was substantially damaged after it impacted terrain following a loss of control during initial climb at the William P. Hobby Airport (HOU), Houston, Texas” (NTSB, Cockpit Display(s) - Recorded Flight Data, 2017, p. 1). “Witnesses saw the airplane at a low altitude when it turned to the left and descended. A security camera video showed that the airplane spun to the left and was about 45° nose down in a slightly left-wing-low attitude before impact with terrain. The airplane impacted an unoccupied automobile in a hardware store parking lot about half-mile north of runway 35. The video showed that the airplane’s airframe parachute rocket motor activated during the impact; however, the parachute remained stowed in the empennage and did not deploy” (NTSB, Aviation Accident Final Report, 2017, p. 4). “The private pilot and the two passengers were fatally injured. The airplane was registered and operated […] under the provisions of 14 Code of Federal Regulations Part 91 as a personal flight. Visual meteorological conditions prevailed and a visual flight rules (VFR) flight plan had been filed. The airplane departed from University of Oklahoma Westheimer Airport (OUN), Norman, Oklahoma […] and was destined for HOU” (NTSB, Cockpit Display(s) - Recorded Flight Data, 2017, p. 1).

Summary of Basic Events of Flight N4252G

Factual accident information retrieved from the NTSB Aviation Accident Final Report, 2017 and the HOU Tower Accident Package N4252G, 2018 are listed as follows:

Destination:	*HOU, Texas/ USA*
Date and time:	*June 09, 2016, 13:09 local time (CDT)*
Aircraft:	*CIRRUS DESIGN CORP SR20*
Airframe total time[21]:	*429 hours, 42 hours since last inspection (January 16, 2016)*
Avionics[22]:	*Garmin G1000 Integrated Flight Deck with RDM*
Defining event:	*Loss of control in flight*
Registration:	*N4252G*
Serial number:	*2217*
Aircraft damage:	*substantial*
Persons on board:	*1 pilot (female, age 46), 2 passengers*
Injuries:	*3 fatal*
NTSB number:	*CEN16FA211*
Position of sun:	*Solar position at date/ time of accident was azimuth/ elevation 158°/ 83°*

(rf. (NTSB, Aviation Accident Final Report, 2017, p. 1-10), (HOU-ATCT-0064, 2018, p. 40)).

The following data were researched and summarized by the author:

Runways in use[23]:	Runway 4, LDA 6000 ft x 150 ft, 4-Light PAPI (3.0°), threshold elevation 42ft
	Runway 35, LDA 7602ft x 150 ft, 4-Light PAPI (3.0°), threshold elevation 43ft
Weather[24]:	At 09:53 CDT (approximate departure time), visibility 10 miles, lowest clouds were scattered at 2400 ft AGL, broken at 18000 ft AGL, wind direction 070° with 8 kts, temperature 30°C, dew point 23°C, Altimeter Setting 29.95 inches Hg, no precipitation;
	At 12:53 CDT (approximate accident time), visibility 10 miles, lowest clouds were broken at 3600 ft AGL, wind direction 100° with speeds/ gusts 12/ 16

[21]at the time of accident
[22]Electronic systems used on aircraft.
[23]Runway data were retrieved from https://www.airnav.com/airport/KHOU and verified with the HOU Tower Accident Package (HOU-ATCT-0064 2018, p. 40). Restrictions on LDA and serviceability of PAPI could not be verified, as the NTSB Final Report and the available NTSB DMS documents of the N4252G accident do not state NOTAMs and general servicabilities at HOU at the time of accident.
[24]Observed at HOU airport, 1NM distant from accident site. Source: Weather Summary File (p. 1) as retrieved from NTSB DMS Website:
https://dms.ntsb.gov/pubdms/search/hitlist.cfm?docketID=60618&CFID=2395938&CFTOKEN=81732fd00bba5423-5AB1BC7B-CB39-E91F-3732EB517FD2FBDB

	kts, temperature 32°C, dew point 22°C, Altimeter Setting 29.94 inches Hg, no precipitation;
	Available weather forecasts on the day of accident are not mentioned in the official NTSB accident report and its accompanying documents.
Mass and balance[25]:	The mass and balance envelope was recalculated by the author for the time of takeoff and impact. The results showed that the center of gravity was within safe limits[26] for the whole progress of flight.
Flight preparation:	There was no information mentioned in the official NTSB accident report and its accompanying documents regarding details of the flight preparation package from the pilot.
Remaining fuel[27]:	left wing tank: 13 US-gal, right wing tank: 8.8 US-gal (equals a remaining endurance[28] of approximately 2 hours)
Max. glide ratio[29]:	9:1 (equals 6.34°) with best glide speed

[25]Author's note: As the actual basic-empty-mass of N4252G was not available in the prevailing documents, the author applied the basic-empty-mass/ -moment data of a similar SR20 aircraft (2144 lbs/ 303561 lbs-inch) for the recalculation.
For pilot and passengers the following numbers were used: female pilot with 155 lbs, two male passengers with 175 lbs each (one of them occupying the front seat). The amount of carried baggage could not be confirmed. Therefore, two calculations with and without an assumed total baggage mass of 65 lbs were considered. Fuel on board (28 US-gal in both the left and right wing tank for takeoff; 13 US-gal in the left and 8.8 US-gal in the right wing tank before the impact) was considered as retrieved from the stored onboard data record (Attachment 1 - Cockpit Displays Factual Report.csv) from NTSB DMS website:
https://dms.ntsb.gov/pubdms/search/hitlist.cfm?docketID=60618&CFID=2395938&CFTOKEN=81732fd00bba5423-5AB1BC7B-CB39-E91F-3732EB517FD2FBDB
[26]For details regarding safe loading limits refer to POH-SR20 (2015), Section 6, Weight and Balance Data.
[27]Retrieved by the author from the last stored onboard data record before the impact at 13:09:02 CDT from NTSB DMS website:
https://dms.ntsb.gov/pubdms/search/hitlist.cfm?docketID=60618&CFID=2395938&CFTOKEN=81732fd00bba5423-5AB1BC7B-CB39-E91F-3732EB517FD2FBDB
[28]Recalculated by the author with POH-SR20 2015, Section 5, Range Endurance Profile for 65% Power (Fuel Flow 10,5 US-gal per hour).
[29]Retrieved by the author from POH-SR20, 2015, Section 3, Chapter Emergency Descent, p. 3-14.

Pilot - Information

This section lists factual pilot information retrieved from the NTSB Aviation Accident Final Report (2017):

Pilot:	*Female, age 46*
Pilot License:	*Private Pilot Certificate (single engine land) was received on May 2, 2014, no other ratings*[30]
Medical certification:	*Class 3 without waivers/ limitations,* *last FAA medical exam October 10, 2014*
Pilot hours:	*332.6 hours (Total, all aircraft), 303.6 hours (Total, this make and model), 253 hours (Pilot In Command, all aircraft), 28 hours (Last 90 days, all aircraft), 7 hours (Last 30 days, all aircraft), 0 hours (Last 24 hours, all aircraft)*
Pilot's airport experience:	*According to the logbook, she had landed within class-B airspace at least four times. Her most recent flight in class-B airspace was to Dallas Love Field (DAL), Dallas, Texas, and consisted of a landing on May 30, 2016, and a takeoff on June 3, 2016. There was no evidence that she had flown to HOU before the accident flight.*
Flight review:	*Her last flight review or equivalent was on May 2, 2014.* *Interviews with the pilot's flight instructors and review of her logbook did not find evidence that the pilot had completed a flight review in the previous 24 calendar months, as required by 14 CFR 61.56(c).*[31]
Pathological information:	*An autopsy on the pilot was performed. The cause of death was multiple blunt force injuries, and the manner of death was ruled an accident. Forensic toxicology on specimens from the pilot detected the following substances: Ibuprofen, Naproxen, Zolpidem.*

The use of Ibuprofen and Naproxen would generally not present a hazard to aviation safety. Zolpidem is a prescription medication used to treat insomnia and may impair mental and/ or physical ability required for the performance of potentially hazardous tasks, such as driving, flying and operating heavy machinery. Due to adverse side effects, the FAA recommends waiting at least 24 hours after use of Zolpidem before flying (rf. (NTSB, Aviation Accident Final Report, 2017, p. 5, 8)).

[30]Ratings in this context means other aircraft ratings, instrument ratings (IFR) or instructor ratings.
[31]Title 14 CFR part 61.56(c) states that *a person may not act as pilot-in-command of an aircraft unless that person has accomplished a satisfactory flight review within the preceding 24 calendar months*.

Pilot - Experience Level

The on-type and general experience of the accident pilot gained in a relatively short time of just over two years, as mentioned previously, provides the impression of a well-experienced pilot. For the process of modeling the prevailing accident in STAMP (Leveson, 2011), the author decided to determine the Pilot's Capability Category in reference to the pilot's experience according to the Envelope of Safety provided by the aircraft manufacturer Cirrus in its FOM-SR20 (2011) and summarized in L Appendix, Figure 6-2 Guidance for establishing Personal Weather Minimums and Figure 6-3 Envelope of Safety. The grading (total rating points added up: 27) for the accident pilot was calculated by the author anticipating the following facts: *2-5 years actively flying (3 points), last training > 24 months (5 points), private pilot certificate (4 points), total time < 500 hours (5 points), exact number of hours logged in the last 12 months not documented (therefore, anticipated as 4 points), 28 hours in Cirrus in the last 90 days (3 points), no pilot mishap (0 points), and Cirrus Landings during the last 30 days not documented (therefore, anticipated as 3 points). There was no documentation found concerning whether the pilot had successfully completed a Cirrus Transition Training* (rf. (FOM-SR20, 2011, p. 2-6)).

It concluded to define the Pilot's Capability Category of the accident pilot as "infrequent flyer".

In respect of the defined Pilot's Capability Category, the aircraft manufacturer Cirrus recommends the following Personal Weather Minimums (for details, refer to L Appendix, Figure 6-2 Guidance for establishing Personal Weather Minimums).

wind limit 15 kts, x-wind limit 5 kts, maximum gust 5 kts

E APPENDIX

In this appendix, the author summarizes the most relevant aspects of the SR20 Pilot Operating Handbook (POH) and the SR20 Flight Operations Manual (FOM) for modeling the accident with STAMP (Leveson, 2011).

Relevant Aspects - SR20 Pilot Operating Handbook (POH)

A1 was the actual revision number (revised December 29, 2015) at the time of the accident and it was still unrevised and valid at the time of publication of this thesis:

POH, Section 2 – Limitations *describes that the aircraft is certified in the normal category and not designed for aerobatic operations. Only those operations incidental to normal flight are approved. These operations include normal stalls, chandelles, lazy eights, and turns in which the angle of bank is limited to 60°. Aerobatic maneuvers and spins are prohibited.*
The maximum flap extended speed Vfe is the highest speed permissible with wing flaps extended, it is limited to 119 KIAS for Flaps 50%, and 104 KIAS for Flaps 100%. The maximum structural cruising speed Vno is the speed that should not be exceeded except in smooth air, and then only with caution. The never-exceed speed Vne of 200 KIAS is the speed limit that may not be exceeded at any time.
The airspeed indications are marked as follows: WHITE-arc[32] *- 61-104 KIAS - Full Flap Operating Range, GREEN-arc*[33] *- 69-163 KIAS - Normal Operating Range, YELLOW-arc*[34] *- Caution Range - 163-200 KIAS, RED line*[35] *- 200 KIAS - Never-exceed speed* (rf. (POH-SR20, 2015, p. 2-11, 2-4, 2-5)).

POH, Section 3 – Emergency Procedures *warns that in all cases if the aircraft enters an unusual attitude following or in connection with a stall, a spin condition should be assumed and immediate deployment of the CAPS is required. Under no circumstances should spin recovery other than CAPS deployment be attempted. The aircraft is not approved for spins and has not been certified for traditional spin recovery characteristics. The only approved and demonstrated method of spin recovery is the activation of the CAPS. Accordingly, if the aircraft enters a spin, CAPS must be deployed immediately. While the stall characteristics of the aircraft make inadvertent entry into a*

[32]"[The] lower limit is the most adverse stall speed in the landing configuration. [The] upper limit is the maximum speed permissible with flaps extended" (POH-SR20 29.12.2015, p. 2-5).
[33]"[The] lower limit is the maximum weight stall speed at most forward CG with flaps retracted. [The] upper limit is the maximum structural cruising speed" (POH-SR20 29.12.2015, p. 2-5).
[34]"Operations must be conducted with caution and only in smooth air" (POH-SR20 29.12.2015, p. 2-5).
[35]"Maximum speed for all operations" (POH-SR20 29.12.2015, p. 2-5).

spin extremely unlikely, it is possible. Spin entry can be avoided by using good airmanship, including coordinated use of controls in turns, proper airspeed control following the recommendations of the POH, and never abusing the flight controls with accelerated inputs when close to the stall. If the controls are misapplied and abused aggressive inputs are made to the elevator, rudder and/ or ailerons at the stall, an abrupt wing drop may be felt and a spin may be entered.
The CAPS should also be used in other life-threatening emergencies where CAPS deployment is determined to be safer than continued flight and landing. Several possible scenarios in which the activation of the CAPS would be appropriate include mid-air collisions, structural failures, loss of control, landing in inhospitable terrain and pilot incapacitation (rf. (POH-SR20, 2015, p. 3-28, 3-33, 3-34)).

POH, Section 4 – Normal Procedures *advises that normal landings are to be made with full flaps with power on or off. The speeds for landing approach are as follows: Normal Approach Flaps - Up 88 KIAS, Normal Approach - Flaps 50% 83 KIAS, Normal Approach - Flaps 100% 78 KIAS. The Go-Around Speed with Flaps 50% is 78 KIAS. Surface winds and air turbulence are usually the primary factors in determining the most comfortable approach speeds.*
Crosswind landings are made with full flaps and prolonged slips to be avoided. The maximum allowable crosswind velocity is dependent upon the pilot capability as well as aircraft limitations. Operation in direct crosswinds of 20 kts has been demonstrated.
The procedures for balked landings (go-arounds) state to climb, disengage the autopilot, apply full power, and then reduce the flap setting to 50%. If obstacles must be cleared during the go-around, a climb at the best angle of climb speed (81-83 KIAS) with 50% flaps has to be achieved. After clearing any obstacles, the procedure states to retract the flaps and accelerate to the normal flaps-up climb speed.
Aircraft stall characteristics are conventional. Power-off stalls may be accompanied by a slight nose bobbing if full aft stick is held. Power-on stalls are marked by a high sink rate at full aft stick. Power-off stall speeds at maximum weight for both forward and aft CG positions are as follows: for Flaps UP (0%) – 69 KIAS with wings level (0° bank), for Flaps 50% - 63-66 KIAS with wings level (0° bank), for Flaps FULL (100%) - 59-61 KIAS with wings level (0° bank). The altitude loss for a wings level stall is defined as 250 ft or more. KIAS values may not be accurate at stall.
When practicing stalls at altitude, it is noted that as the airspeed is slowly reduced, a slight airframe buffet will be noticed, the stall speed warning horn is activated between 5 and 10 kts before the stall, and the Crew Alerting System displays a STALL warning annunciation. Normally, the stall is marked by a gentle nose drop while the wings can easily be held level or in the bank with the coordinated use of

the ailerons and rudder. Upon stall warning in flight, recovery has to be accomplished by immediately reducing back pressure to maintain safe airspeed, adding power if necessary and rolling wings level with the coordinated use of the controls.
A warning refers to extreme care to be taken to avoid uncoordinated, accelerated or abused control inputs when close to the stall, especially when close to the ground (rf. (POH-SR20, 2015, p. 4-21, 4-3, 4-22, 4-23. 5-12)).

POH, Section 7 – Airplane and Systems Description *describes the various aircraft systems:*
Avionics System - The Perspective Integrated Avionics System provides advanced cockpit functionality and improved situational awareness through the use of fully-integrated flight, engine, communication, navigation and monitoring equipment. The Primary Flight Display, located directly in front of the pilot, is intended to be the primary display of flight parameter information (attitude, airspeed, heading, and altitude) during normal operations.
Flight Controls *- The airplane uses conventional flight controls for ailerons, elevator and rudder. The control surfaces are pilot controlled through either of two single-handed side control yokes mounted beneath the instrument panel. The location and design of the control yokes allow easy, natural use by the pilot. The control system uses a combination of push rods, cables and bell cranks for control of the surfaces.*
Pitch trim is provided by adjusting the neutral position of the compression spring cartridge in the elevator control system by means of an electric motor. It is possible to easily override full trim or autopilot inputs by using normal control inputs.
Roll trim is provided by adjusting the neutral position of a compression spring cartridge in the aileron control system by means of an electric motor. The electric roll trim is also used by the autopilot to position the ailerons. It is possible to easily override full trim or autopilot inputs by using normal control inputs.
Yaw trim is provided by spring cartridge attached to the rudder pedal torque tube and console structure. The spring cartridge provides a centring force regardless of the direction of rudder deflection. The yaw trim is ground-adjustable only.
Engine *- The airplane is powered by a Teledyne Continental IO-360-ES, six-cylinder, normally aspirated, fuel-injected engine de-rated to 200 horsepower at 2700 RPM.*
The single-lever throttle control on the console adjusts the engine throttle setting in addition to automatically adjusting propeller speed. The lever is mechanically linked by cables to the air throttle body/ fuel-metering valve and to the propeller governor. Moving the lever towards MAX opens the air throttle butterfly and meters more fuel to the fuel manifold. A separate cable to the propeller

governor adjusts the governor oil pressure to increase propeller pitch to maintain engine RPM. The system is set to maintain approximately 2500 RPM throughout the cruise power settings and 2700 RPM at full power.

Percent power is shown in the upper left corner of the synoptic ENGINE page as both a simulated gage and a digital value. The digital percent power value is displayed in white numerals below the gage. The display units calculate the percentage of maximum engine power produced by the engine based on an algorithm employing manifold pressure, indicated air speed, outside air temperature, pressure altitude, engine speed, and fuel flow.

***Wing Flaps** - The electrically-controlled, single-slotted flaps provide low-speed lift enhancement. The flaps are selectively set to three positions: 0%, 50% (16°) and 100% (32°) by operating the FLAP control switch. The FLAP control switch positions the flaps through a motorized linear actuator mechanically connected to both flaps by a torque tube. Proximity switches in the actuator limit flap travel to the selected position and provide position indication. An airfoil-shaped FLAPS control switch is located at the bottom of the vertical section of the center console. The control switch is marked and has detents at three positions: UP (0%), 50% and 100%. <u>The appropriate Vfe speed is marked at the flap 50% and 100% switch positions.</u> Setting the switch to the desired position will cause the flaps to extend or retract to the appropriate setting. An indicator light at each control switch position illuminates when the flaps reach the selected position. <u>The UP (0%) light is green and the 50% and 100% lights are yellow.</u>*

***Stall Warning System** - The airplane is equipped with an electro-pneumatic stall warning system to provide audible warning of an approach to aerodynamic stall. The system comprises an inlet in the leading edge of the right wing, a pressure switch and associated plumbing.*

As the airplane approaches a stall, the low pressure on the upper surface of the wings moves forward around the leading edge of the wings. As the low-pressure area passes over the stall warning inlet, a slight negative pressure is sensed by the pressure switch. The pressure switch then provides a signal to cause the warning horn to sound, the red STALL warning crew-alerting-system annunciation to illuminate, and, if engaged, the autopilot system to disconnect.

<u>The warning sounds at approximately 5 kts above stall with full flaps and power off in wings level flight and at slightly greater margins in turning and accelerated flight.</u>

The system operates on 28 volts of direct-current supplied though the 2-amp STALL WARNING circuit breaker. <u>A stall warning system pre-flight check is explained in the POH</u> (rf. (POH-SR20, 2015, p. 7-8, 7-10, 7-12, 7-35, 7-39, 7-25, 7-76)).

***POH, Section 10 – Safety Information CAPS** describes that CAPS is designed to lower the aircraft and its passengers to the ground in the event of a life-threatening emergency. CAPS deployment is likely to result in damage to the airframe and possible injury to aircraft occupants. Its use should not be taken lightly. Instead, possible <u>CAPS activation scenarios should be well thought out and mentally practiced by every Cirrus pilot.</u> Pilots who regularly conduct CAPS training and think about using CAPS will often have a higher probability of deploying CAPS when necessary. Cirrus also recommends that pilots discuss CAPS deployment scenarios with instructors as well as fellow pilots through forums such as the Cirrus Owners and Pilots Association. <u>In the event of a spin or loss of aircraft control, immediate CAPS activation is required.</u> In other situations, CAPS activation is at the informed discretion of the pilot in command. CAPS has been activated by pilots at speeds in excess of 180 KIAS on multiple occasions with successful outcomes. While the best speed to activate CAPS is below 133 KIAS, a timely activation is most important for loss-of-control situations.*

Loss of control may result from many situations, such as a control system failure (disconnected or jammed controls), severe wake turbulence, severe turbulence causing upset, severe airframe icing or pilot disorientation caused by vertigo or panic. If loss of control occurs, the CAPS should be activated immediately. The POH further warns that in the event of a spin, immediate CAPS activation is mandatory and that <u>under no circumstances should the pilot attempt to recover from a spin other than by CAPS activation</u>.

Regarding pilot incapacitation, which may be the result of anything from a pilot's medical condition to a bird strike that injures the pilot, if the passengers are not trained to land the aircraft, CAPS activation by the passengers is highly recommended. This scenario should be discussed with passengers prior to flight and all appropriate passengers should be briefed on CAPS operation so they could effectively deploy CAPS if required.

<u>General Deployment Information states that no minimum altitude for deployment has been set.</u> This is because the actual altitude loss during a particular deployment depends upon the airplane's airspeed, altitude and attitude at deployment as well as other environmental factors. However, in all cases, the chances of a successful deployment increase with altitude. In the event of a spin, immediate CAPS activation is mandatory regardless of altitude. In other situations, the pilot in command may elect to troubleshoot a mechanical problem or attempt to descend out of icing conditions if altitude and flight conditions permit. <u>As a data point, altitude loss from level flight deployments has been demonstrated at less than 400 ft.</u> Deployment at such a low altitude leaves little or no time for the aircraft to stabilize under the canopy or for the cabin to be secured. A low-altitude deployment increases the risk of injury or death and should be avoided. If circumstances permit, it is advisable to activate the CAPS at or above 2000 ft AGL. After a CAPS deployment, the

airplane will descend at less than 1700 fpm with a lateral speed equal to the velocity of the surface wind. The CAPS landing touchdown is equivalent to ground impact from a height of approximately 10 ft. While the airframe, seats, and landing gear are designed to accommodate the stress, occupants must be prepared for the landing. The overriding consideration in all CAPS deployed landings is to prepare the occupants for the touchdown to protect them from injury as much as possible
(rf. (POH-SR20, 2015, p. 10-4, 10-5, 10-6, 10-7)).

Relevant Aspects - SR20 Flight Operations Manual (FOM)

Reissue A was the actual revision number (revised February 2011) at the time of the accident and it was still unrevised and valid at the time of publication of this thesis:

***FOM, Section 1 - Introduction** describes that procedures in the FOM are derived from procedures in the FAA-approved Airplane Flight Manual (AFM). Cirrus Aircraft has attempted to ensure that the data contained agrees with the data in the AFM. If there is any disagreement, the Airplane Flight Manual is the final authority* (rf. (FOM-SR20, 2011, p. 1-1)).

***FOM, Section 2 - General Operating Procedures** describes in the Currency Requirements section that it is recommended that all pilots operate in accordance with the policies and procedures prescribed within the FOM. In no case does it relieve the PIC from the responsibility of making safe decisions regarding the operation of the aircraft. Regarding initial training, Cirrus pilots should satisfactorily complete the Cirrus Transition Training Course, Advanced Transition Training Course, Avionics Differences, Airframe and Power Plant Differences, or the Cirrus Standardized Instructor Pilot (CSIP) Course prior to acting as pilot in command of a Cirrus aircraft.*
In respect of recurrent training, Cirrus pilots should complete recurrent training at a Cirrus Training Center (CTC) or with a CSIP under the guidance found in the Cirrus Syllabus Suite. Recurrent training emphasizes aeronautical decision-making, risk management, and airmanship, which leads to increased proficiency. <u>The recurrent training program provides an opportunity to meet the requirements of a biennial flight review or instrument proficiency check.</u>
Cirrus pilots should maintain VFR currency by completing each of the following items in a Cirrus aircraft: Cirrus Transition Training course, three takeoffs and three landings to a full stop within the previous 60 days, and 10 hours as the PIC within the previous 60 days. <u>Cirrus pilots should fly with a Training Center Instructor (TCI) or with a CSIP to meet the flight currency requirement if currency lapses</u>.

Regarding personal minimums and risk assessment, all Cirrus pilots should regularly assess their personal risk factors and use them to develop personal minimums for wind, ceiling and visibility. A matrix in the FOM is available to establish the risk category (Author's note: refer to L Appendix). *Pilots should re-evaluate their risk category on a quarterly basis or any time that a major milestone occurs. This category should be applied to the recommended personal minimums found in the Envelope of Safety. Note that the "Envelope of Safety" Table describes recommended personal minimums for wind, ceiling, and visibility based on the pilot's risk category, time of day, and pilot rating. These minimums are followed by company pilots at Cirrus Aircraft* (rf. (FOM-SR20, 2011, p. 2-2, 2-3, 2-8, 2-4, 2-5)). *Regarding takeoff and landing wind proficiency, the FOM describes that a Cirrus pilot should not attempt to takeoff or land when the wind speed and crosswind component exceed the individual's capabilities. A decision should be made to postpone the flight if the weather is not acceptable* (rf. (FOM-SR20, 2011, p. 2-5, 2-11)).

A sterile cabin should be observed during departure, arrival and abnormal/ emergency operations, and during sterile cabin operations all distractions such as satellite radio, non-flight related activities and unnecessary communication with passengers should be minimized (rf. (FOM-SR20, 2011, p. 2-19)).

***FOM, Section 3 - Standard Operating Procedures** describes the recommended procedures when operating a Cirrus aircraft. Cirrus pilots are encouraged to follow the procedures outlined in the FOM, use their best judgment, and adapt the procedures when handling non-standard situations. The majority of Cirrus aircraft operations are conducted on a single-pilot basis. The workload associated with flying the aircraft, configuring and monitoring avionics, communicating with air traffic control, and decision-making requires pilots to efficiently manage all tasks while maintaining positive aircraft control at all times. The following SRM procedures have been adapted from cockpit procedures common to dual pilot transport category aircraft. In order to ensure the highest levels of safety, it is strongly recommended that these single-pilot operating procedures are incorporated into the operation of the aircraft:*

Priority of Tasks - The number one priority of the pilot is to maintain aircraft control. Pilots should maintain a high level of vigilance during periods of high and low workload to ensure that aircraft control is always maintained. Once aircraft control is assured, pilots should set and verify that the avionics are correctly configured for navigation. This includes creating and modifying flight plans, selecting proper navigation sources and/ or tuning navigation frequencies. Use of the autopilot may assist the pilot with accomplishing these tasks. Communication is an important task in the aircraft but *it follows aircraft control and navigation as a priority. This task includes setting assigned frequencies, controlling communication volume and responding to ATC instructions.*

The use of standard operating procedures will allow for single-pilot operations with higher levels of safety and efficiency. Following standard procedures during flight operations will develop habit patterns through repetition that allow pilots to be most efficient while completing tasks and configuring the aircraft for various phases of flight.

The use of all available resources during flight in single-pilot operations will allow pilots to make better and more timely decisions. Many resources are available to pilots, such as ATC, Flight Watch or Flight Service Stations, on-board weather displays, on-board chart displays, and even passengers.

When used properly, checklists enhance the safety of flight by confirming that the aircraft is appropriately configured for the flight condition. At the same time, checklists expedite the completion of procedures that are necessary to transition to subsequent phases of flight.

Regarding to passenger flight briefing, the pilot should provide a safety briefing, referencing the passenger briefing card, to all passengers prior to each flight. As a minimum, passengers should be briefed on the following items: CAPS, smoking, seatbelts, doors, emergency exits/ egress hammer and the use of oxygen. The pilot should also discuss sterile cabin procedures and other information as necessary (rf. (FOM-SR20, 2011, p. 3-1, 3-2, 3-3, 3-21)).

A go-around should be executed any time that an approach does not meet the stabilized approach criteria. A go-around should be completed from memory since it is a time-critical maneuver. The first priority of executing a go-around is to stop the aircraft's descent. It is necessary to smoothly and promptly apply full power (increase power lever to the full forward position, ensure full power is used and do not stop at any detents along power lever travel) while simultaneously leveling the wings and pitching the aircraft to stop the descent. The flaps should be retracted to 50%, but not fully retracted at this point in the go-around because it may lead to excessive altitude loss.

Regarding normal landings, the FOM says that they should be made with 100% flaps. Final approach speeds should be adjusted to account for gusts exceeding 10 kts by adding half of the gust factor. Referring to "crosswind landings", they should be made with 100% flaps (rf. (FOM-SR20, 2011, p. 3-77, 3-81)).

FOM, Section 4, Abnormal and Emergency Procedures - CAPS Deployment *describes that emergency situations in an aircraft are always stressful and pilots may overlook all available options for surviving the emergency. Pilots who regularly conduct CAPS training and think about using CAPS will often have a higher probability of deploying CAPS when necessary. Performing CAPS training in a Cirrus flight training device or simulator is highly recommended. It is also recommended that frequent flying* *passengers complete CAPS training in a Cirrus simulator to develop the ability to properly activate CAPS. Regarding "unusual attitudes" it is advised that they are most likely to be encountered by pilots who lack instrument skills, VFR pilots who have inadvertently entered IMC, or pilots experiencing an abnormally high workload. Pilots who have entered an unusual attitude have temporarily lost aircraft control or failed to maintain aircraft control. At the moment of recognition, the pilot must make an immediate decision regarding whether the aircraft can be recovered using traditional recovery techniques such as a manual recovery, engaging the autopilot (if within limitations), or activating CAPS. Immediate action by the pilot is required to recover the aircraft regardless of which recovery method is chosen. It is important to note that pilots who have lost aircraft control may be disoriented beyond the point where traditional, hand flown recovery techniques are effective. CAPS activation may be the best recovery option available. Preventing unusual attitudes is the best course of action. Pilots are encouraged to use the autopilot during periods of high workload, but should not become overly-dependent on the autopilot for aircraft control* (rf. (FOM-SR20, 2011, p. 4-2, 4-40)).

F APPENDIX

Results Raised by the NTSB Final Report

This appendix describes the probable causes from the official Aviation Accident Final Report published on December 12, 2017 to be compared with the final results of this thesis:

- *The pilot's improper go-around procedure that did not ensure that the airplane was at a safe airspeed before raising the flaps, which resulted in an exceedance of the critical angle of attack and an accelerated aerodynamic stall and spin into terrain.*
- *The initial local controller's decision to keep the pilot in the traffic pattern, and the second local controller's issuance of an unnecessarily complex clearance during a critical phase of flight contributed to the accident.*
- *The pilot's lack of assertiveness was also a contributing factor*

(rf. (NTSB, Aviation Accident Final Report, 2017, p. 2)).

In addition to the final report, fifteen documents[36] related to the N4252G accident have been published via the Docket Management System (DMS) on the NTSB public website[37] for unrestricted download. For the purpose of modeling the prevailing accident with STAMP (Leveson, 2011), the author has retrieved these documents and further analysed them in more detail.

[36]Air Traffic Control Factual Report, HOU Tower Accident Package, OUN Tower Accident Package, HOU Tower Operating Procedures, N4252G Radar Target File - HOU ASR Google Earth KML Target File, Houston Approach Control Radar File (Shelf Item), Cockpit Displays - Specialist's Factual Report, Attachment 1 - Cockpit Displays Factual Report, Pilot Toxicology, Statement of Party Representatives to NTSB Investigation, Weather Summary, Wreckage Diagram (Courtesy of Houston PD), CFI Statements, Photos, Stall Speeds

[37]https://dms.ntsb.gov/pubdms/search/hitlist.cfm?docketID=60618&CFID=2395938&CFTOKEN=81732fd00bba5423-5AB1BC7B-CB39-E91F-3732EB517FD2FBDB

G APPENDIX

Chain of Events

The NTSB, Air Traffic Control, Group Chairman's Factual Report (2016) desribes the chain of events as follows:

*N4252G departed from University of Oklahoma Westheimer airport at **10:09 CDT** en route to HOU. The pilot contacted Houston Approach at **12:27:48**, reporting that she had received automated terminal information service (ATIS) information Hotel for HOU[38]. The controller instructed the pilot to descend to 5000 ft and maintain VFR[39]. The flight received routine VFR handling and subsequently descended to 1800 ft.*

*At **12:38:40**, the controller told the pilot to expect a left base to the traffic pattern for runway 4 at HOU. Vectoring and traffic advisories continued, and at **12:51:38**, the controller advised the pilot, "... you're following a Boeing 737 about 1:00 o'clock and 5 miles - on a four mile final at 2000, caution for wake turbulence". The pilot reported the other aircraft in sight.*

*At **12:52:20**, the controller instructed the pilot to fly heading 095 to follow the traffic, issued another wake turbulence advisory, and transferred communications to HOU tower. The pilot acknowledged.*

*The pilot contacted the HOU tower LC position at **12:52:47** and reported at 1600 ft. The position was being worked by a trainee (LCT) and an instructor (LCI). The trainee missed the source of the call and thought it was a Southwest Airlines (SWA) flight. He responded as if the SWA pilot had called, then realized that it had actually been the pilot of N4252G. After resolving the confusion, the LCT controller transmitted, "Cirrus 4252G Hobby tower, you're number 2 following a 737 on a 3 mile final, caution wake turbulence, runway 4 cleared to land". The pilot read back the instructions correctly. The controller then asked where the aircraft would be parking, and the pilot responded, "We'll be parking at MillionAir, 4252G".*

*At **12:53:51**, the LCI controller transmitted, "Cirrus 4252G proceed direct to the numbers, you're going to be inside a 737 intercepting a 10 mile final". The pilot asked, "OK, you'd like me to proceed direct to the numbers, 4252G?" The LCI controller responded, "November 52G, what did approach tell you*

[38] *Information Hotel was broadcasted after 11:53 CDT, and reported HOU weather conditions as wind with 100 degrees at 8 kts, visibility of 10 miles, scattered clouds at 3,500 feet, and a broken ceiling at 18000 feet*
(The author of this thesis recalculated the wind components considering Figure 6-4 Wind component diagram as follows: 100°/ 8 kts equals 2 kts tailwind and 8 kts crosswind for runway 35 (356° runway track) versus 4 kts headwind and 7 kts crosswind for runway 4 (041° runway track)).

[39] *"Maintain VFR" is an instruction issued to pilots to remain in flight conditions suitable for visual flight rules (VFR).*

before?" The pilot answered, "Um, to left base runway 4 and follow the Boeing, 4252G". The LCI controller again instructed the pilot to, "... proceed direct the numbers for runway 4, direct to Hobby".

At ***12:54:24****, the Hobby Final controller called the LC controllers to ask that they have the Cirrus proceed direct to the numbers, and the LCI controller responded that the pilot had been directed to do so.*

At ***12:54:39****, the LCT controller asked the pilot to maintain maximum forward speed and proceed direct to the numbers, advising her that there was a 737 on 9 mile final following the Cirrus that was overtaking it by 80 kts. The pilot responded that she would proceed direct to the numbers and keep her speed up.*

At ***12:55:49****, the LCT controller broadcasts to all aircraft that HOU ATIS information India was current, altimeter 29.94. The pilot was not required to acknowledge the updated ATIS announcement and did not do so.*

At ***12:55:59****, SWA235 contacted HOU, reporting that they were on 5 mile final for runway 4. The LCT controller responded that they were number 2 following a Cirrus on 2 mile final, cleared the pilot to land, and instructed him to slow to final approach speed.*

At ***12:56:19****, the LCT controller broadcasts a wind check, 080 degrees at 13 kts gusting to 18 kt.*

At ***12:56:58****, the LCI controller called N4252G, and the pilot responded. The LCI controller then continued, "Yeah, I've got traffic behind you, just go-around and fly runway heading for now, maintain VFR, and I'm going to put you back on the downwind for runway 35. The winds are 090 at 13 gusts 18 [kt]. Can you accept runway 35?" The pilot responded, "We're to and line up for runway 35 downwind". The LCI controller then told the pilot to fly runway heading for runway 4 "for right now". The pilot responded, "We'll fly runway heading for 4, 4252G". The LCI controller then cleared SWA235 to land.*

At ***12:57:34****, the LCI controller transmitted, "N52G when able go ahead and make a right downwind now for runway 35 and then we'll just go ahead and keep that right turn, runway 35 cleared to land". The pilot read back, "OK, make a right downwind for runway 35?" The LCI controller continued, "N52G yes and just keep the right turn all the way around, you're just going to roll right into the base for runway 35, cleared to land. I've got another 737 on 5 mile final to runway 4 and you're going to be in front of him". The pilot acknowledged with, "... turning around for runway 35"*

At ***12:58:10****, the LCI controller said, "... just enter the downwind for runway 35," and the pilot acknowledged.*

At ***12:58:16****, the LCI controller told the pilot that he would call the right base turn.*

At ***12:58:48****, the LCT controller provided a traffic advisory to the pilot of N4252G about another 737 inbound to runway 4, and the pilot reported the 737 in sight. The LCT controller instructed the pilot to* *make a right base to follow [pass behind] the 737, and again cleared the pilot to land on runway 35. The pilot read back, "we're going to make a right base following them... for runway 35, N4252G".*

*At **12:59:20**, the LCT controller told the pilot to "turn left heading 30 degrees". This was to resolve a perceived conflict between N52G and SWA235. The pilot read back, "turn left heading 30 degrees".*

*At **12:59:30**, the LCI controller asked the pilot if she, "... wanted to follow the 737 to runway 4?" The pilot responded, "Yes, that would be great". The controller then told her to follow the 737 to runway 4 and cleared her to land. The pilot then asked, "Am I turning a right base now, 4252G?" The LCI controller continued, "N52G roger, just maneuver back for the straight-in, I don't know which way you're going now, so just turn back around to runway 35". The pilot replied, "Turning to 35, I'm so sorry for the confusion, 4252G". The LCI controller responded, "That's OK, we'll get it".*

*At **13:00:13**, the LCI controller asked the pilot which direction she was turning. She responded, "I thought I was turning a right base for 35, 4252G". The LCI controller continued, "... that's fine 52G, uh, just make it uh, you say you're in a right turn, keep it tight, I need you to make it tight". The pilot answered, "Keeping turn tight, 4252G".*

*At **13:00:31**, the controller provided a traffic alert to "0GA" about traffic 1 mile away at 900 ft, which was N4252G. That pilot reported that he was "looking," and the LCI controller continued, "N52G I need you to uh there you go, straight in to runway 35, cleared to land". The pilot read back, "Straight in to runway 35 and I don't believe I'm lined up for that". The LCI controller acknowledged and instructed the pilot to, "... turn to the right and climb and maintain 1600, right turn". The pilot acknowledged, and the LCI controller continued, "Yes, ma'am, heading about 040," which the pilot read back correctly.*

*At **13:01:16**, the LCI controller transmitted, "OK 52G, let's do this. Can you do a right turn back to join the straight-in to 35? Could you do it like that?" The pilot replied, "Yes, right turn back to 35, N4252G". The LCI controller instructed the pilot to make a right turn, "all the way around to runway 35," and again cleared the pilot to land. The pilot acknowledged.*

At the same time, the Hobby Final controller was calling the tower to offer a space to put N4252G behind another aircraft, N4JJ, inbound on the runway 4 final. The LCI controller did not respond to that call.

*At **13:01:44**, N4JJ contacted the tower on a visual approach to runway 4. The LCI controller told the pilot to reduce to minimum speed, and advised that he would be number 2 for the airport following a Cirrus on 1 mile final for runway 35. The pilot of N4JJ acknowledged the information.*

*At **13:02:02**, the LCI controller transmitted, "Cirrus 52G, OK, you're looking good just continue a right turn for runway 35. Do you see runway 35 still?" The pilot responded, "Yes, 35, 4252G have it in sight, continuing my roll around". The LCI controller continued, "Yes, ma'am, yeah you're good so you can* *start your descent to runway 35 there, and uh cleared to land on 35". The pilot replied, "Cleared to land on 35, 52G, thank you very much". The controller then provided a wind check, "... winds[40] are 100 at 15 gusts to 20". The pilot responded, "OK, thank you, trying to lose altitude 4252G". The LCI controller continued, "No problem, little bit of wind off the right".*

*At **13:03:01**, the LCI controller transmitted, "N52G if you don't want to land – if that's too high, we can put you back around the downwind, don't force it if you can't". The pilot answered, "OK - we'll see, thank you, 4252G". At 1303:25, the LCI controller told her, "OK, I think you're too high, Cirrus 52G, you might be too high". The pilot replied, "OK - we'll go-around then, N4252G". The LCI controller told the pilot to make right traffic for runway 35. The pilot replied, "Sounds perfect, right traffic runway 35, 4252G".*

*At **13:04:38**, the LCI controller cleared N4252G to land, stating, "... make right downwind to runway 35, and you are cleared to land - there will be no other traffic for runway 4 so this one will be easy". The pilot read back, "Making right traffic for downwind for runway 35, 4252G". The controller continued, "N52G affirmative, and cleared to land on runway 35 via the right downwind and right base". The pilot then read back, "Thank you – right downwind, right base, 4252G".*

*At **13:06:00**, the LCI controller issued a traffic advisory to the pilot of N4252G, stating, "... there's a 737 on short final runway 4 touching down right in front of you so just caution wake turbulence right there at that intersection". The pilot responded, "OK, I've got that in sight, N4252G".*

*At **13:07:03**, the LCI controller asked if the pilot of N4252G had runway 35 in sight. The pilot answered that she did, and the controller provided a wind check[41], "090 at 13 gust 18, runway 35 again, cleared to land". The pilot replied, "35 cleared to land trying to get [laugh] down again, 4252G".*

*At **13:07:49**, a position relief briefing occurred on the LC position and a new controller took over.*

*At **13:08:21**, the pilot reported, "... going around, third time will be a charm". The new controller responded, "OK, Cirrus 52G, just go ahead and make the left turn now to enter the downwind, midfield downwind for runway 4, if you can just keep it in a nice tight low pattern, I'm going to have traffic 4 miles behind you so I need you to just kind of keep it in tight if you could". The pilot responded, "OK, this time will be runway 4, turning left, 4252G". The controller continued, "And actually I might end up sequencing you behind that traffic, he's on 4 miles a minute, um it is gonna be*

[40] The author of this thesis recalculated the wind components considering Figure 6-4 Wind component diagram as follows: 100°/ 15 kts steady (gusts up to 20 kts) equals 4 kts (gusts up to 5 kts) tailwind and 14 kts (gusts up to 19 kts) crosswind for runway 35 (356° runway track).

[41] The author of this thesis recalculated the wind components considering Figure 6-4 Wind component diagram as follows: 090°/ 13 kts steady (gusts up to 18 kts) equals 1 kt (no gusts) tailwind and 13 kts (gusts up to 18 kts) crosswind for runway 35 (356° runway track).

a bit tight with the one behind it so when you get on the downwind, stay on the downwind and advise me when you have that 737 in sight. We'll either do 4 or we might swing you around to 35 uh uh ma'am, ma'am uh straighten up straighten up!"

There were no further contacts with the pilot. N4252G crashed northwest of the airport in a commercial parking lot, and the tower supervisor reported the accident to emergency services (rf. (NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 4, 5, 6, 7)).

H APPENDIX

Interviews with ATC Controllers held by NTSB

This appendix summarizes relevant facts of personal interviews held by the NTSB with involved ATC controllers as described in the NTSB, Air Traffic Control, Group Chairman's Factual Report (2016). For this thesis, names have been erased and replaced by the short form of their positions by the author.

HOU LCI (OJTI) - Controller

The ATC group interviewed the LCI on June 15, 2016.

He began working for the FAA in December 2002 at Longview ATCT (GGG). In February 2012, the LCI transferred to HOU. He was certified on all positions at HOU by December 2012, and held a current FAA medical certificate.

On the day of the accident, the LCI was working his regular assigned shift of 05:30 to 13:30 CDT, assigned to provide on-the-job training (OJT) to a trainee (LCT) on the LC position. On a scale of 1 to 5, the LCI described the traffic during period before the accident as "around a 3". There were no personal or operational issues affecting his performance, and he did not feel fatigued during the shift. During the preceding month, he had worked "a couple" of overtime shifts, and typically worked one midnight shift every week.

The LCI did not feel that he needed to intervene much during the training session until N4252G was inbound. He said that normally aircraft are sequenced by approach control and the tower just clears them to land. If the spacing were to diminish unacceptably, then he would either send one of the aircraft around or send them back to approach to be re-sequenced. He stated that approach normally gives a "good feed" to the airport and it is not common for the tower to have to pull someone off the approach or switch them to a different runway. He described the relationship between the tower and approach control as good.

The LCI recalled first seeing N4252G inbound from the west on a modified base to runway 4. When the pilot checked in, his trainee thought the call was from a Southwest B737 on final. They corrected the confusion and cleared the pilot of N4252G to land on runway 4. The LCI asked the pilot if approach had issued any restrictions and then told her to proceed direct to the runway numbers. He saw N4252G join the final and then slow down.

He noticed the spacing decreasing between N4252G and the following 737, so he told N4252G to go-around. He made that decision due to the "flow" in use at the airport and the knowledge that runway 35 was also available for landing. This was a common "out" that he had used many times to resolve a spacing issue rather than sending the aircraft back to approach for resequencing. He stated that if the *approach controller called to take an aircraft back for sequencing, he would not question it and would send the aircraft back to approach.*

The LCI told the pilot to enter right downwind for runway 35. N4252G overshot the final and was not properly lined up for runway 35. The overshoot started to look like a problem with the aircraft on the runway 4 final, so the LCT issued a 30-degree left turn for traffic. The pilot seemed confused about what to do, so the LCI took over the frequency and began working LC on his own. After N4252G was lined up for runway 35, the aircraft looked high ("a couple hundred ft above the runway at midfield"), so he again instructed the pilot to go-around and enter the right downwind. He added that there was no further traffic on the runway 4 final, so the next try "should be easy". He subsequently cleared N4252G to land on runway 35. The aircraft ended up too high again, and the pilot reported going around.

The FLM had been monitoring the local frequencies and coordinating on the landlines.

The LCI did not recall hearing any specific landline coordination between the FLM and approach, but generally when LC became busy the FLM handled the coordination with approach control. The LCI knew that the FLM was aware of N4252G's multiple go-arounds. The FLM did not intervene at any time during the incident and did not ask questions about the event afterwards.

The LCI's shift was almost over, so another LC controller (LCC) had come to LC to complete a relief briefing and take over the position. The LCC moved to the monitor position for the required 2-minute position overlap period. He saw N4252G turn left crosswind off runway 35 and then "nose the aircraft straight down". Based on radar and visual observation, the LCI estimated that N4252G was approximately 500 ft above ground just before the accident. He saw the FLM pick up the crash phone, but was not aware which emergency services responded to the scene. The LCC continued working the LC position, but departures at HOU were stopped due to the accident.

While he was dealing with the spacing issue between N4252G and the trailing SWA flight, the approach controller called and the LCI replied that he would take care of [the spacing]. He stated that spacing issues requiring a go-around or a runway change only occurred about once a week.

A facility briefing item provided to the group stated that it was a "best practice" to handle go-arounds by transferring them back to the approach control for resequencing, while the I90/ HOU letter of agreement stated that go-arounds should be handled as a satellite airport departure[42] that is transferred back to I90. Asked about the disagreement, the LCI said that keeping go-around aircraft in the pattern was frequently coordinated with I90 and was a very standard alternate plan. It was

[42]Title 14 CFR part 91.129(c)(2)(ii) states that *departing flight from a satellite airport without an operating control tower must establish and maintain two-way radio communications with the ATC facility having jurisdiction over the Class D airspace area as soon as practicable after departing*.

common for FLMs to coordinate with I90 on behalf of LC, but that would not necessarily lead to a conversation between LC and the FLM about what had been discussed.
In the LCI's experience, having an aircraft miss the runway twice was unusual, and this was the first time that he had seen such an occurrence. As the aircraft was VFR, keeping it in the pattern was the "normal" response.
There were about five developmentals at HOU, and they were generally well prepared for OJT after completing their classroom training. The LCI said that he would not have done anything differently in this situation, and that if a local assist position had been open it would not have changed anything. Overall, the LCI felt that HOU does a very good job and uses good procedures, but noted that there was always room for improvement.
The LCI had been on administrative leave until Wednesday, June 15, 2016, and had not participated in any discussions with facility management about the accident. He has not participated in any crew briefings since he came to HOU, and said there was no practice of discussing incidents and accidents as learning experiences. He was not aware of the specific membership of the facility safety council (rf. (NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 20, 21, 22)).

HOU FLM - Controller

The ATC group interviewed the FLM on June 15, 2016.
He began working for the FAA in February 1991 at the FAA Academy, and was first assigned to Burbank ATCT. He later transferred to Chicago Center, Rockford ATCT, Chicago Midway ATCT, Las Vegas ATCT, Dayton ATCT, and Dallas Fort Worth International ATCT before coming to HOU as an FLM in June 2015. He was certified on all positions at HOU and held a current medical certificate. He typically worked 12 to 16 hours a month on the LC and ground control (GC) positions, and otherwise spent almost 40 hours a week in the cab supervising the operation.
On the date of the accident, the FLM was working his regular assigned shift of 06:30 to 14:30 CDT and performing his regular FLM duties. The day started with seven controllers, including one trainee, but around noon he was notified that one of the controllers assigned to the shift had been medically disqualified. Another controller had already been approved for annual leave, so only five controllers were available. There were no unusual equipment issues affecting the operation. The winds started out variable from 050 to 110 degrees, and increased in strength as the day went on. There were no reports of wind shear or other wind issues during the shift. The FLM was unsure where the wind sensor was located on the airport, but noted that there was soon to be a change in the system.
In the period leading up to the accident, HOU was landing runways 4/ 35, and departing runways 4, 12L/ R, and 35. Most of the traffic was landing on runway 4 and departing from runway 12R. There

was training in progress on the LC position, which he was monitoring to the maximum extent possible along with his other duties at the supervisory position in the back of the cab.

The FLM first became aware of N4252G when he saw the aircraft on radar on a left base for runway 4, with other jet traffic inbound on final. The training team on LC decided to turn N4252G direct to the runway. At the same time, he heard approach call and ask the tower to turn N4252G direct to the runway. When the LCT controller issued the instruction, N4252G made a slow turn and proceeded directly to the end of runway 4.

The FLM noticed that the B737 traffic behind N4252G was slowing but still overtaking the aircraft. LC told the pilot of N4252G to go-around and fly runway heading. N4252G overflew about 3⁄4 of runway 4 before LC instructed the pilot to enter right downwind for runway 35. After N4252G turned downwind, it started drifting towards the other traffic on final for runway 4. The FLM heard the LCT controller tell N4252G to turn left 20 degrees[43]*, and then the LCI controller took over the position.*

The LCI told the pilot of N4252G to make a gradual 270 degree turn around to runway 35. The plan was to put the Cirrus on runway 35 through a gap between the runway 4 arrivals. The Cirrus was not descending very much. The LCI then told the pilot that the aircraft looked too high and to go-around. The LCI then sequenced N4252G on to another downwind for runway 35 and cleared the pilot to land.

<u>While N4252G was on downwind to runway 35 for the second time, the FLM called approach and asked them to slow their next arrival down to build in a little more space for the Cirrus. The approach controller told the FLM that he would take N4252G back, but the FLM saw that N4252G was already turning base, so he told approach that the tower would just work the aircraft. The FLM did not coordinate with LC about the call.</u> Although the spacing between the runway 4 arrivals looked adequate, the FLM saw N4252G coming in high on final again (around the height of the tower), and the pilot reported that they were going around.

<u>The LCI's shift was ending, so the FLM had the LCT move to GC and send a controller (LCC) from GC to LC to relieve the LCI.</u> After the relief briefing was completed, the FLM heard the LCC calmly talking to the pilot, who by then was on the upwind following the go-around. The FLM was on the phone, so he did not hear exactly what was said, although both the controller and pilot sounded calm. The FLM then heard LCC saying "straighten it out, straighten it out!" and realized that there had been an accident. He put the regular phone down and activated the crash phone, reporting that the crash was about half a mile up Airfield Road. Emergency vehicles responded.

[43]Author's note: The official NTSB report and ATC transcript describes 30 degrees, therefore it is considered to be an ambiguity error.

The FLM also told the flight data/ clearance delivery controller to call the other controller up from lunch immediately. The air traffic manager came up to the cab to assist with emergency notifications. The FLM got the LCC off the LC position about five minutes after the accident. He was unable to get the other controllers off position for about 15 minutes due to staffing. The FLM spent the next two hours up in the tower cab.

He did not discuss the events of the accident with the controllers involved. He was mostly concerned for the controller's well-being and did not want to talk to about the accident with them. The controllers were given some administrative leave in addition to their regular days off to decompress and participate in stress counseling. The FLM contacted them over the weekend to ensure that they were coping after the accident.

When asked about the LCC's instruction to N4252G to "keep turn in tight", the FLM said that it was not standard phraseology.

The FLM said that the speeds of the aircraft coming in on final are a "hit or miss". Sometimes the aircraft come in fast and other times slower. HOU does not normally put restrictions on the final unless unusual conditions at the airport are affecting runway occupancy times or other operational issues. On occasions, HOU has to break an aircraft out on final, but it was not a systemic issue. If an aircraft goes around, there are two choices: to either go back to approach or come into runway 35. About 90 percent of the time if a small VFR aircraft had to be re-sequenced off runway 4, the tower would keep the aircraft and not hand it off to approach. This was normal handling following a go-around. The FLM said that he did not give any instructions to LC because they had the situation under control. As far as the FLM could tell, both approaches to runway 35 were good and should have worked: the aircraft simply did not descend. The first approach to runway 4 would not have worked and sending N4252G around was the best option. If they had not pulled N4252G out, they would have potentially had to send two other aircraft around.

The FLM has tried to get crew briefings together since he got to HOU, but staffing has been short and briefings have been difficult to accommodate. He tries to meet with his crew when he can, but the priority is the operation over crew briefs. The FLM organised two all-hands briefings scheduled for the following week. The supervisors and training specialist were to cover the operation so all the controllers could meet with the ATM and the facility NATCA representative.

The FLM had not completed many Performance Records of Conference (PRCs) to document controller performance, and admitted that it was an error on his part. With the recent events that they have had, PRCs have become more common. The FLM stated that he has undertaken performance management from day one but his documentation was poor. The FLM said that the new ATM has addressed performance management with the FLMs and has stressed documentation within the *allowable time constraints. He said that it was difficult documenting this due to his workload with the schedule. He attended FLM training at the end of 2015, which helped him to better understand performance management. He had not completed any PRCs related to this accident as of the date of this interview. He will be discussing the accident and ATC communications with the ATM to see how he wants to handle it. The FLM reported receiving no specific personal training on performance management or quality control in the past month, although he received some training on resource management.*

The FLM could not explain why HOU had their recent issues, but has found that some people were not engaged like they should have been. Some controllers have never seen certain situations and that opened up opportunities to coach them. If he had to grade[44] the facility management efforts to brief employees about issues and events, he would give them a "C to C minus". He felt that the value of these experiences are not taught sufficiently well. He has not been involved in the Air Traffic Safety Action Program (ATSAP[45]) event review and skill enhancement training process yet as a supervisor, and he did not file an ATSAP report for this accident. He was unsure whether any of the controllers did so. The local safety council had not been very active prior to a recent visit from the central service area Quality Control Group. While their activity level had recently increased, he had still not seen much information coming out of the group.

If the FLM had the opportunity to do anything at HOU, he would improve the communication throughout the entire facility. Controllers may be briefed about an occurrence, but there is too little time available to ensure that understanding and learning occurs. When he talks to his crew, if there is a specific topic to address, all seven of his controllers receive the same briefing. If it is a week during which a more generic discussion is possible, he has sessions that are more of a coaching nature.

Management staffing at HOU was one ATM, three supervisors, and one training specialist. The activity level placed the facility right in the middle of the ATC 8 levels.

The tower was not primarily using runway 12 for arrivals because the wind had not picked up until the afternoon arrival push was in progress, and it was not a good time to change runways. Landing on the 12s while also landing on runway 4 was difficult due to the airport layout.

The approach control was usually cooperative about restrictions requested by the tower.

[44]Author's note: common grades in US schools are scaling from A (excellent) via B (good), C (average), D (below average) to E (insufficient).

[45]Author's note: FAA modeled ATSAP as *a voluntary safety reporting program that helps to resolve safety issues that otherwise might not have been identified or resolved. No punitive or disciplinary actions will be taken as a result, provided those errors are not the result of gross negligence or illegal activity* (rf. (retrieved from https://www.natca.org/index.php/insider-articles/2183-atsap-what-you-need-to-know)).

When asked if he had ever participated in a System Service Review process, the FLM said he had temporarily filled a slot on the local safety council for an event involving a runway crossing without using visual aids. The whole process took 60 to 90 minutes. He also participated in the last half of the "services rendered teleconference" for this event.

When asked about the decision to put the Cirrus on runway 35 with the existing crosswind, FLM said that the tower had been using runway 35 all day for a variety of aircraft with no issues. He thought that the controllers were making good decisions and the sequencing with the runway 4 arrivals looked good both times. He never felt a need to intervene. The problem seemed to be that the pilot never descended sufficiently to reach the runway (rf. (NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 22, 23, 24, 25)).

HOU LC - Controller

The ATC group interviewed the LC controller (herein called LCC) on June 16, 2016.

The LCC began working for the FAA in November 1988 at the FAA Academy. He worked at various facilities including Santa Maria ATCT, San Jose ATCT, and HOU since then, arriving at HOU in 1998. He also worked seven temporary details at Oshkosh ATCT during the annual EAA event. He was certified on all positions at HOU. He held a current ATC medical certificate.

On the date of the accident, the LCC was working his regularly-assigned shift of 05:30 to 15:30 CDT. There were no unusual personal or equipment issues affecting his performance.

The LCC was working GC when he became aware of N4252G inbound to HOU. He recalled seeing the aircraft on radar about five miles out and again on short final to runway 4. He did not observe anything unusual up to that point. He heard one of the LC controllers send N4252G around, but was unsure whether it was the developmental (LCT) or the trainer (LCI) who issued the instructions. He then heard the local control controller sequence N4252G to runway 35. He was generally aware that the Cirrus was in the pattern, but was mainly occupied with his GC duties. The LCC was relieved from GC by the developmental controller who had been training on LC. He observed N4252G high and south of runway 35. When the LCC went to LC to relieve the LCI, he noticed N4252G over the runway and still high. He could not really estimate the altitude of the aircraft, but it just seemed high. He was hoping that the pilot was not going to try to land because the aircraft was at least midfield and looked like it was going to touch down at the far end of the runway.

The LCC heard the pilot of N4252G report that she was going around. She commented: "third time's a charm". He felt confident that she was comfortable based on that comment. The LCC told the pilot to make a "close-in pattern" to runway 4 and then told her that he might have to amend that or perhaps take the aircraft to runway 35 based on other traffic.

The LCC then saw the aircraft "winging ... over" and "going steep". He estimated N4252G was probably close to a 90-degree bank before the aircraft started to fall. He transmitted "Straighten it out, straighten it out," wanting the pilot to level the wings, although the airplane crashed. After the accident, the LCC recalled someone calling on the frequency asking about departure. The LCC advised the FLM of what had happened with N4252G but did not recall the specifics of the conversation.

When asked about the "low and tight" instruction that he gave the pilot, he said he had given instructions like that to other pilots but did not recall the specifics. His plan was to have the Cirrus follow a 737 on the runway 4 final, so he asked the pilot to report the 737 in sight and then added that he might have to put the Cirrus back on runway 35.

The LCC said approach does a pretty good job on final and they don't "jam them up too often". If a general aviation aircraft went around, he would probably keep the aircraft rather than give it back to approach, and depending on traffic would take the aircraft to runway 4 or runway 35. The flow in this case was to runways 4 and 35, so that was where he would have kept the Cirrus even with the existing crosswind. The aircraft looked high during both approaches to runway 35.

The FLM is his supervisor. The LCC stated that he has not been to many crew briefings in the past few years, and they were not regular events. He did recall receiving some training on incidents occurring at other facilities, but not the specific content (rf. (NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 25, 26)).

HOU LCT - Controller

The ATC group interviewed the LCT on June 17, 2016.

He began working for the FAA in December 2010 at the FAA Academy. After completing initial training, he reported to David Wayne Hooks airport (DWH) in March 2010. The LCT transferred to HOU in January 2016. He was qualified on the FD/ CD and GC positions, and was training on the LC, helicopter, and local assist positions. The LCT has received approximately 19 hours of OJT on the LC position. He held an ATC medical certificate. He had Saturday and Sunday off. On the day of the accident, he was working his regularly-assigned shift of 07:00 to 15:00 CDT and receiving training on the LC position from his secondary OJTI, herein called the LCI. He was unsure how long he had been on position before the accident.

The LCT first became aware of N4252G when the aircraft was eight miles west of the airport. When the pilot called, he was talking to his instructor and missed the call sign. He thought the transmission was from an inbound Southwest flight, so he cleared the Southwest jet to land before realizing that N4252G had checked in. He then cleared the pilot of N4252G to land. He noticed that the Southwest flight was overtaking N4252G when the SWA flight was on approximately a 9 mile final. The LCT *instructed N4252G to fly directly to the numbers and keep their speed up. The approach controller called at about the same time and asked the tower to have N4252G fly directly to the airport. The LCT stated that aircraft speeds on final could be adjusted without coordination with the I90 Hobby final controller. He stated that N4252G and the following SWA jet were advised of the overtake situation.*

The LCT and his OJTI (LCI) had been discussing whether the spacing between the jet and the Cirrus would work. When N4252G was between one and two miles from runway 4, the OJTI took over the frequency and instructed the pilot to go-around. He was unsure why the OJTI had taken over the frequency instead of simply having him issue the clearance. The OJTI told the pilot to enter a right downwind for runway 35. The LCT then took the frequency back. He noticed that N4252G had gone past the runway 35 final and was approaching the runway 4 final. He instructed the pilot to turn left heading 030 to stay away from traffic landing on runway 4. The heading was based on both radar and visual observation of the aircraft's track.

The OJTI took the frequency back and issued instructions to the pilot in an attempt to get the aircraft lined up with runway 35. The LCT stated that the OJTI advised N4252G that they appeared to be too high and issued go-around instructions. On the next approach to runway 35, the aircraft was again too high and the pilot initiated a go-around. The aircraft appeared to be about the same altitude on both approaches to runway 35, and definitely too high to land.

The FLM told the LCT to relieve the ground controller, so he moved to the GC position, and the LCC took over the LC position. He heard the LCC sequence N4252G to runway 4. His attention was then diverted by GC duties. He did not observe N4252G turn left crosswind, but saw the aircraft when it was between 50 and 75 ft above the ground.

The FLM activated the crash phone. Departures were stopped due to the accident, although arrivals continued to land. One of the airport fire trucks requested control of the discrete emergency frequency.

The LCT was relieved from the ground control position about 15 minutes after the accident. After a ten-minute break, he returned to the tower to work ground control.

The LCT stated that he had not had any discussions with anyone following the event. He had not spoken to the event crisis team but planned to do so.

OJT debriefs took place after each training session if warranted, and were normally completed by the end of each day.

The LCT stated the new procedural changes being implemented by the facility are good, such as requiring adherence to standard procedures and minimizing runway changes.

The LCT had not seen very many go-arounds in training. The usual procedure was for jets to proceed straight down the runway, then turn to heading 160, maintain 3000 ft, and contact departure. In *classroom instruction, controllers are taught to treat go-arounds as a satellite airport departure. He had not yet received any simulator training, although a simulator is available at Houston Intercontinental. He noted that simulator training was not provided for the LC position, but was provided as part of GC training. Radar training was provided via online learning modules.*

Based on his experience at DWH, the LCT was asked how he would characterize the handling of N4252G's arrival. Having the Cirrus mixed in with the jets meant that the situation needed to be watched, but it was not a major issue. The pilot never sounded flustered or disoriented. After the accident, the airport fire crews asked to use frequency 120.2 and responded to the far NW corner of the airport.

The LCT was uncertain about the type of separation being applied between the SWA flight and the Cirrus on final. He realized that it was not going to work when his trainer took over the position. The intent was to prevent a flyover on the runway (rf. (NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 27, 28)).

I90 - Approach Controller

The ATC group interviewed the I90 – Approach Controller via telephone on June 17, 2016.

The I90 – Approach Controller began working for the FAA in October 1989. His first facility was San Juan center/ approach control in Puerto Rico. Before being assigned to I90 in 2008, he worked at Isla Grande ATCT, San Juan ATCT, and San Juan Center. He held an ATC medical certificate.

On the date of the accident, he was working his regularly-assigned shift of 07:00 to 15:00 CDT.

The I90 – Approach Controller had been working the Hobby Final position for about 45 minutes when he first became aware of N4252G. He recalled taking a handoff from the "Lakeside" sector when N4252G was approximately 20 miles west of HOU. N4252G came in on a base leg to runway 4. The aircraft's ground speed was about 130 kts with a head wind. The pilot of N4252G sounded confident.

Some of the arrivals into HOU were being vectored around heavy weather south-west of the airport. He sequenced N4252G behind a Boeing 737 and gave the pilot a wake turbulence advisory. At that point, the pilot seemed fine. The I90 – Approach Controller had other traffic behind N4252G on final, so he issued the aircraft a heading to shorten the approach and switched the aircraft to HOU tower. He advised the aircraft sequenced behind N4252G to reduce speed to 150 kts or less and switched the aircraft to HOU tower. After both aircraft were on HOU tower frequency, the spacing appeared to be diminishing between N4252G and the trailing B737. The approach controller was required to continue to monitor spacing on final even after aircraft were switched to the tower. He was working five or six other aircraft, and noticed that N4252G still seemed to be headed toward the outer marker, so he called the tower to have them turn the aircraft direct to the runway. N4252G showed a 120 kts

groundspeed to about 3 mile final, then started reducing speed. He told the next jet arrival to reduce speed to 150 kts, and told the pilot to contact the tower.
After N4252G went around on runway 4, the I90 – Approach Controller received a call from HOU tower asking him to slow the next arrival to runway 4 due to N4252G landing. The final was fairly full out to about 20NM. <u>The I90 – Approach Controller advised the HOU controller that he would work N4252G, but HOU said they would keep the aircraft.</u>
The I90 – Approach Controller told the tower he could not issue the reduction, and did not slow the next arrival because the aircraft was already at the final approach fix and <u>he did not think that HOU tower could sequence N4252G inside of the traffic</u>. He switched the next arrival to HOU tower. He first recognized that N4252G was landing runway 35 when he saw the aircraft turning final for that runway, prior to which he thought the tower was going to have N4252G land on runway 4.
The I90 – Approach Controller said that HOU tower has control for speed changes of aircraft on contact, with no requirement for HOU tower to coordinate the speed changes with approach control. It is normal practice to restrict arrivals to 170 kts on final.
In the event of a go-around by an aircraft operating under instrument flight rules, most of the time the tower would switch the aircraft back to approach. <u>If the aircraft was operating VFR, HOU tower would usually work the aircraft back in for landing. If they could not do that, then I90 would take the go-around aircraft back and re-sequence it for another approach.</u>
The I90 – Approach Controller was first informed about the accident by another controller who heard about it while on a break (rf. (NTSB, Air Traffic Control, Group Chairman's Factual Report, CEN16FA211, 2016, p. 29, 30)).

I APPENDIX

Summary of CFI Statements

Referring to the published document in the NTSB DMS called "CFI Statements" (2016), the content of the information from two CFIs that had flown with the pilot of N4252G in the past (in this context solely called the pilot) was summarized by the author as follows:

CFI-1:

Recent flights with the pilot: September 15, 23 and 28, 2015

These three flights were considered the first flights of her instrument training. They had a pre- and post-flight discussion with every lesson. Specifically, before the lesson on September 15, 2015, they talked about checklists, pre-flight, basic instrument control and reviewed the PAVE and IMSAFE checklists. On September 15, 2015 they did climbs, turns, descents, instrument scan, pre- and post-flight and discussed collision avoidance and runway incursions. On September 23, 2015, they did more of the same and added compass turns, timed turns and introduced VORs. On September 28, 2015, they did VOR intercepting and tracking.

NTSB asked the CFI-1 whether these three flights could be considered a biennial flight review, which was answered as no.

When asked about the experience of CFI-1 in the Cirrus, it was answered that the CFI-1 had been a Cirrus Trained Instructor and had over 1100 hours of dual given, 80 hours of which was in a Cirrus.

The final question asked was whether the CFI-1 had seen the pilot in a stressful situation. The CFI-1 answered that every situation in which they had been was handled by the pilot with composure and the control of the airplane was maintained, comparable with any student with whom the CFI-1 has worked.

CFI-2:

Recent flights with the pilot: once on August 4, 2014 and once on September 24, 2014

The CFI-2 flew with the pilot only twice after being certificated. Both flights were recurrent training flights, but neither flight would complete the requirements of Title 14 CFR part 61.56 for a flight review.

Regarding the pilot's ability to handle stressful environments, the CFI-2 only flew a handful of times, and the few times when a stressful situation was observed the pilot handled it within acceptable levels and retained composure and the ability to fly the airplane.

In terms of qualifications, the CFI-2 has been a Chief Instructor for a Cirrus Training Center, and a qualified Cirrus Standardized Instructor Pilot. The experience of the CFI-2 is 400 hours in dual given in Cirrus aircraft, 500 hours Cirrus total hours and 2900 hours overall (rf. (retrieved from https://dms.ntsb.gov/pubdms/search/hitlist.cfm?docketID=60618&CFID=2395938&CFTOKEN=81732 fd00bba5423-5AB1BC7B-CB39-E91F-3732EB517FD2FBDB, CFI Statements, 2016, p. 1, 2)).

J APPENDIX

Recorded Flight Data

Referring to the NTSB, Cockpit Display(s) – Recorded Flight Data (2017) document, *the Garmin G1000 Integrated Flight Deck in N4252G included a data-logging feature. The SD memory card was recovered and in good condition and the data records were extracted. It contained 820 log files. The accident flight recording was the last file recorded and it contained approximately 3 hours and 10 minutes of data records. Additionally, a Heads-Up Technologies RDM data recorder was mounted in the tail of the aircraft, which is a lightweight impact and fire-hardened recorder. It is capable of recording approximately 150 hours of aircraft data at a rate of one record per second. Each record includes approximately 105 positional, aircraft flight and engine parameters. An exterior examination revealed that the unit had not sustained any impact or heat/ fire damage. The unit powered up normally and the recorded information was extracted using the manufacturer's software, without difficulty.*

"The data extracted included 522220 total data records. The accident flight was the last session recorded (approximately 12000 total data records (seconds)) (rf. (NTSB, Cockpit Display(s) - Recorded Flight Data, 2017, p. 2, 3)).

For the STAMP (Leveson, 2011) modeling of this accident, the availability of flight data in an electronic coded format supported the author in the analysis. For this reason, the data was downloaded via the DMS of the NTSB website and analysed in detail, in both the raw data tables and subsequently graphically in the form of diagrams. For details refer to the Chapter 2.2.

K APPENDIX (SYSTEM COMPONENTS)

This appendix provides basic descriptions of each individual system component, which was considered in modeling of the N4252G accident:

Training Organisation

"Pilot training is available on-site at most airports in the USA, either through an FAA-certificated[46] (approved) pilot school or through other[47] training providers. […] Enrollment in an FAA-approved pilot school usually ensures a high quality of training. Approved schools must meet prescribed standards with respect to equipment, facilities, personnel, and curricula. However, individual flight instructors and training companies that are not certificated by the FAA as "pilot schools" may also offer high quality training, but find it impractical to qualify for FAA certification. Another difference between training provided by FAA-approved pilot schools and other providers is that fewer flight hours are required to be eligible for a pilot certificate when the training is received through an approved school"
(FAA.gov, retrieved from https://www.faa.gov/training_testing/training/pilot_schools/, 2019).

ATC Control Service

"Air traffic control service is a service provided for the purpose of preventing collisions between aircraft and on the manoeuvring area between aircraft and obstructions and for the purpose of expediting and maintaining an orderly flow of air traffic" (ICAO, Annex 11, 2016, p. 1-3).

Aircraft Manufacturer (Cirrus)

"As of April 2018, the company had delivered over 7,000 SR-aircraft in nearly 19 years of production, and has been the world's largest producer of piston-powered aircraft since 2013" (Wikipedia.org, retrieved from https://en.wikipedia.org/wiki/Cirrus_Aircraft, 2019).

COPA

"Cirrus Owners and Pilots Association (COPA) is an organisation that welcomes the membership of Cirrus owners, pilots, and enthusiasts with an interest in aviation and Cirrus aircraft issues and events. Three main training and safety related events provided by COPA are the Cirrus Pilot

[46]Author's note: for details, refer to Title 14 CFR part 141 - Pilot Schools
[47]Author's note: for details, refer to Title 14 CFR part 61 - Certification Pilots, Flight Instructors […]

Proficiency Program (CPPP), the Critical Decision Making (CDM) seminar, and the Partner in Command seminar.

The CPPP is designed to expose Cirrus pilots to situations they may encounter while operating their aircraft. Topics such as weather, accident review, advanced avionics, emergency procedures, and engine management are discussed and applied during a CPPP.

The CDM seminar is a facilitated interactive hangar-flying session where the group looks at general aviation and Cirrus accident statistics, reviews case studies of Cirrus accidents, and participates in the reenactment of an actual accident.

The Partner in Command seminar has been designed to give frequent Cirrus passengers more knowledge regarding safety system operations in the unlikely event that the pilot in command should become incapacitated. Procedures include using basic radio communication and CAPS activation" (FOM-SR20, 2011, p. 2-3, 2-4).

HOU Airport

"William P. Hobby Airport […] HOU is an international airport in Houston. […] Hobby is Houston's oldest commercial airport and was its primary commercial airport until Houston Intercontinental Airport […] opened"

(Wikipedia.org, retrieved from https://en.wikipedia.org/wiki/William_P._Hobby_Airport, 2019).

Operator/ Aircraft Owner

It could not be verified under which pre-requisites the operator/ aircraft owner permitted the pilot to operate the aircraft.

Pilot

For personal details regarding the pilot of the accident aircraft, refer to D Appendix.

Passengers

The official NTSB accident report provided no details about the passengers on board the accident aircraft. Recherches[48] by the author of this thesis revealed *that the passengers (two males, age 52 and 27) were family members of the pilot, with the purpose of visiting a close relative who was*

[48]Retrieved from http://www.kathrynsreport.com/2016/06/cirrus-sr20-n4252g-safe-aviation-llc.html and https://www.dailymail.co.uk/news/article-3636188/Ma-ma-straighten-straighten-Tragic-words-woman-piloting-plane-husband-brother-filmed-crashing-killing-three.html

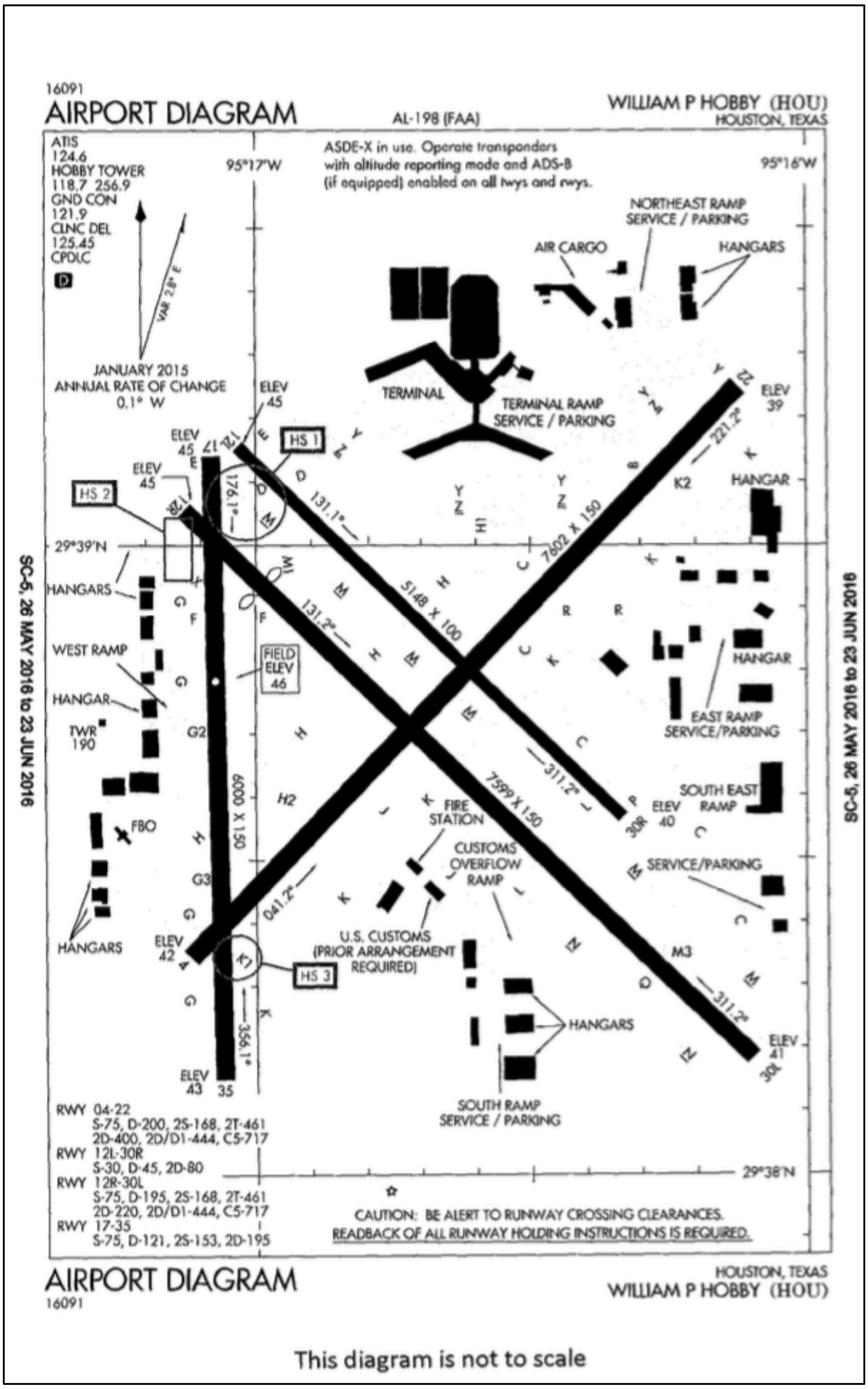
receiving cancer treatment in Houston (rf. (Passenger Recherches, 2019)). It could not be ascertained whether any of the passengers had been a licensed pilot or possessed pilot-related knowledge.

Aircraft SR20

“The Cirrus SR20 is an American piston-engine four-or-five-seat, composite monoplane built by Cirrus Aircraft of Duluth, Minnesota since 1999. The SR20 was the first production general aviation aircraft equipped with a parachute to lower the airplane safely to the ground after a loss of control, structural failure or mid-air collision. It was also the first manufactured light aircraft with all-composite construction and flat-panel avionics” (Wikipedia.org, retrieved from https://en.wikipedia.org/wiki/Cirrus_SR20, 2019).

L APPENDIX (ILLUSTRATIONS)

Figure 6-1 illustrates a schematic of the HOU Airport.



(HOU-ATCT-0064, 2018, p. 40)

Figure 6-1 HOU airport diagram

Figure 6-2 illustrates the Guidance for establishing personal weather minimums for Cirrus Pilots, which was retrieved from SR20 Flight Operations Manual (2011).

Guidance for Establishing Personal Weather Minimums

General Flight Guidelines

	1	2	3	4	5	Your Rating
Years Actively Flying (Maintained FAA req. currency)	>10	6-10	2-5		<2	
Last Recurrent Training Event	<6 months		6mo-12mo		12mo-24mo	
Certificate Held	ATP or CFI	Commercial w/instrument	Private w/instrument	Private Pilot	Solo Student Pilot	
Total Time	2000	1000-2000	750-1000	500-750	<500	
Hours logged last 12 months	>200	150-200	100-150	50-150	<50	
Hours in Cirrus last 90 days	>50	35-50	25-35	10-25	<10	
Pilot Mishap Last 24 months				Incident	Accident	
Cirrus Landings last 30 days	>10	6-9	3-5	1-2	0	
					Total	

Age: Add 2 pts for 65 years or older
Time to Achieve Private Pilot: Add 2 pts for 100+ hours
Time to Complete Transition Training: Add 2 pts for 30+ hours
Crew: Subtract 1 pt for flying with licensed pilot
Training: Add 2 pts for not completing Cirrus Transition Training

Pilot Category	
● (green circle)	≥ 23
■ (blue square)	14-22
◆ (diamond)	≤13

Category ◆ Not Applicable for pilots in first 100 hours of aircraft operation.

Instrument Flight Guidelines

	1	2	3	4	5	Your Rating
Years Actively Flying IFR (Maintained FAA req. currency)	>5		1-5		<1	
Hours flown IFR last 90 days	>35	25-35	10-25	5-10	<5	
Simulated/Actual instrument hours in Cirrus in last 90 days	>3		1-3		<1	
Instrument Approaches with use of Autopilot last 90 days	>4		1-4		0	
Hand-flown Instrument Approaches last 90 days	>2		1		0	
Recieved avionics specific IFR training from CSIP/CTC	Yes				No	
					Total	

Crew: Subtract 1 pt for flying with licensed pilot
Training: Subtract 2 pts for completing avionics specific IPC from CSIP/CTC in last 12 months.

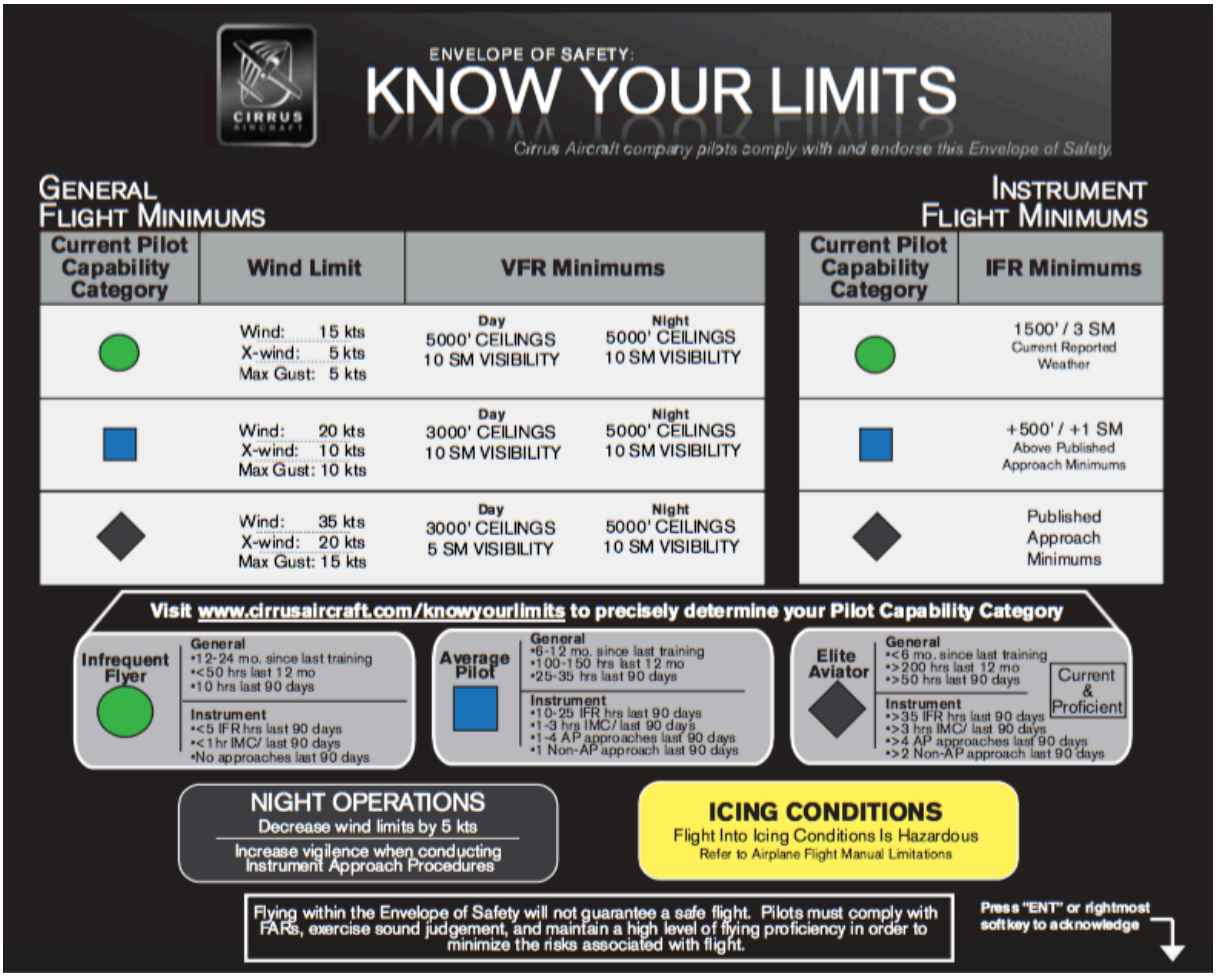
Pilot Category	
● (green circle)	≥ 19
■ (blue square)	8-18
◆ (diamond)	≤7

CIRRUS AIRCRAFT

(FOM-SR20, 2011, p. 2-6)

Figure 6-2 Guidance for establishing Personal Weather Minimums

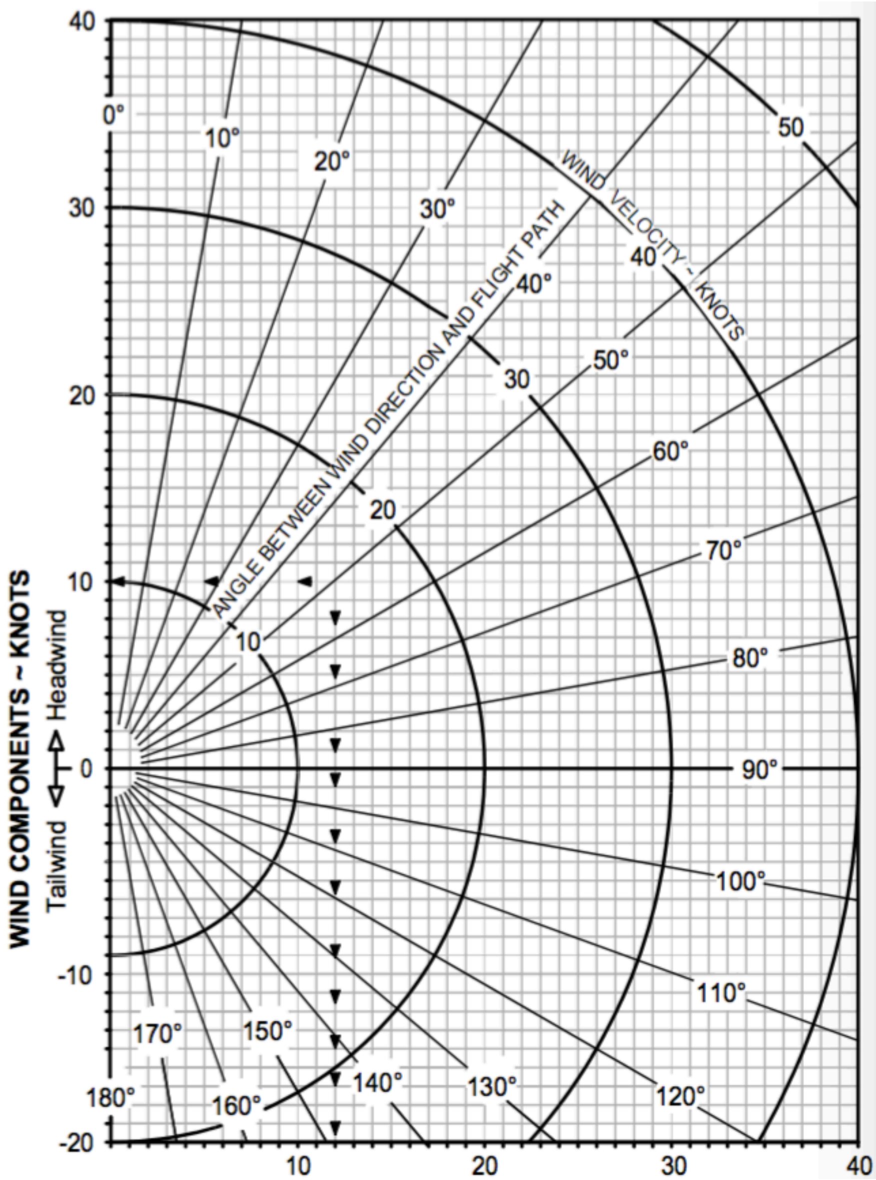
Figure 6-3 illustrates the Envelope of Safety for Cirrus Pilots, which was retrieved from SR20 Flight Operations Manual (2011).



(FOM-SR20, 2011, p. 2-7)

Figure 6-3 Envelope of Safety

Figure 6-4 illustrates a diagram to calculate the wind components, which was retrieved from SR20 Pilot's Operating Handbook (2015).



(POH-SR20, 2015, p. 5-13)

Figure 6-4 Wind component diagram

M APPENDIX (ATC TRANSCRIPT)

The following Table 6-1 summarizes the ATC transmissions from the first go-around until the accident as retrieved from HOU Tower Accident Package N4252G (2018).

CDT	COM	ATC Transmission/ Note	RY
12:57:02	*LCI*	*"just go-around and fly runway heading for now, maintain VFR, and I'm going to put you back on the downwind for runway 35. The winds are 090 at 13 gusts 18. Can you accept runway 35?"*	*4*
12:57:15	*52G*	*"We're to go-around and line up for runway 35 downwind"*	*35*
12:57:20	*LCI*	*"N4252G, fly runway heading for runway 4 for right now"*	*35*
12:57:23	*52G*	*"We'll fly runway heading for 4, 4252G"*	*35*
12:57:34	*LCI*	*"N52G when able go ahead and make a right downwind now for runway 35 and then we'll just go ahead and keep that right turn, runway 35 cleared to land"*	*35*
12:57:46	*52G*	*"OK, make a right downwind for runway 35?"*	*35*
12:57:50	*LCI*	*"N52G yes and just keep the right turn all the way around, you're just going to roll right into the base for runway 35, cleared to land. I've got another 737 on 5 mile final to runway 4 and you're going to be in front of him"*	*35*
12:58:06	*52G*	*"... turning around for runway 35"*	*35*
12:58:10	*LCI*	*"... just enter the downwind for runway 35,"and the pilot acknowledged*	*35*
12:58:16	*LCI*	*"I'll call your right base now"*	*35*
12:58:48	*LCT*	*"Cirrus 52G 737 at your 2:00 o'clock and 3 miles at 900 ft inbound for runway 4 advise that traffic in sight"*	*35*
12:58:56	*52G*	*"I have traffic sight, 4252G"*	*35*
12:58:58	*LCT*	*"52G make a right base behind that traffic runway 35 cleared to land you're going to be landing the crossing runway prior to your arrival"*	*35*
12:59:07	*52G*	*"We'll make a right base following them 4252G for 35"*	*35*
12:59:20	*LCT*	*"Cirrus 52G make a turn left heading 30 degrees"*	*35*
12:59:26	*52G*	*"Left heading 30 degrees 4252G"*	*35*
12:59:30		*LCI asks the pilot if she, "... wanted to follow the 737 to runway 4?"*	*35*
12:59:35	*52G*	*"yes that would be great, 4252G"*	*35*
12:59:38	*LCI*	*"Follow the 737 and to runway 4 cleared to land"*	*4*
12:59:45	*52G*	*"Am I turning a right base now, 4252G?"*	*4*
12:59:48	*LCI*	*"N52G roger, just maneuver back for the straight-in, I don't know which way you're going now, so just turn back around to runway 35".*	*35*
12:59:56	*52G*	*"Turning to 35, I'm so sorry for the confusion, 4252G".*	*35*
13:00:00	*LCI*	*"That's OK, we'll get it"*	*35*
13:00:13	*LCI*	*"Cirrus 52G which way are you turning now?"*	*35*
13:00:18	*52G*	*"I thought I was turning a right base for 35, 4252G"*	*35*
13:00:22	*LCI*	*"... that's fine 52G, uh, just make it uh, you say you're in a right turn, keep it tight, I need you to make it tight"*	*35*
13:00:29	*52G*	*"Keeping turn tight, 4252G"*	*35*
13:00:31	*LCI*	*LCI provided a traffic alert to "0GA" about traffic 1 mile away at 900 ft, which was N4252G. That pilot reported that she was "looking"*	*35*
13:00:37	*LCI*	*"N52G I need you to uh there you go, straight in to runway 35, cleared to land"*	*35*
13:00:43	*52G*	*"Straight in to runway 35 and I don't believe I'm lined up for that"*	*35*
13:00:49	*LCI*	*"Okay 52G roger turn to the right and climb and maintain 1600, right turn"*	*35*
13:00:57	*52G*	*"1600 right turn 4252G"*	*35*
13:01:00	*LCI*	*"Yes, ma'am, heading about 040, which 52G read back correctly*	*35*
13:01:16	*LCI*	*"OK 52G, let's do this. Can you do a right turn back to join the straight-in to 35? Could you do it like that?"*	*35*

CDT	COM	ATC Transmission/ Note	RY
13:01:25	*52G*	*"Yes, right turn back to 35, N4252G"*	*35*
13:01:29	*LCI*	*The controller instructed the pilot to make a right turn, "all the way around to runway 35," and again cleared the pilot to land. The pilot acknowledged.*	*35*
13:01:37	*52G*	*"35 cleared to land 4252G", replied by 52G with "thank you". At the same time, the Hobby Final controller was calling the tower to offer a space to put N4252G behind another aircraft, N4JJ, inbound on the runway 4 final. The LCI controller did not respond to that call.*	*35*
13:01:44	*LCI*	*N4JJ contacted the tower on a visual approach to runway 4. The LCI controller told the pilot to reduce to minimum speed, and advised that he would be number 2 for the airport following a Cirrus on 1 mile final for runway 35. The pilot of N4JJ acknowledged the information.*	*35*
13:02:02	*LCI*	*"Cirrus 52G, OK, you're looking good just continue a right turn for runway 35. Do you see runway 35 still?"*	*35*
13:02:10	*52G*	*"Yes, 35, 4252G have it in sight, continuing my roll around"*	*35*
13:02:14	*LCI*	*"Yes, ma'am, yeah you're good so you can start your descent to runway 35 there, and uh cleared to land on 35"*	*35*
13:02:21	*52G*	*"Cleared to land on 35, 52G, thank you very much"*	*35*
13:02:25	*LCI*	*"No problems winds are one zero zero at one zero, I'm sorry winds are one zero zero at one five gusts to two zero"*	*35*
13:02:30	*52G*	*"OK thank you, trying to lose altitude, 4252G"*	*35*
13:02:38	*LCI*	*"No problem, little bit of wind off the right"*	*35*
13:03:01	*LCI*	*"N52G if you don't want to land – if that's too high, we can put you back around the downwind, don't force it if you can't"*	*35*
13:03:08	*52G*	*"OK – we'll see, thank you, 4252G"*	*35*
13:03:28	*LCI*	*"OK, I think you're too high, Cirrus 52G, you might be too high"*	*35*
13:03:32	*52G*	*"OK – we'll go-around then, N4252G"*	*35*
13:03:44	*LCI*	*"Cirrus 52G, roger, just uh okay make you're just going to make a right traffic now for runway 35 we'll come back around and we got it this time"*	*35*
13:03:53	*52G*	*"Sounds perfect, right traffic for runway 35, 4252G"*	*35*
13:04:38	*LCI*	*the controller cleared N4252G to land, stating, "... make right downwind to runway 35, and you are cleared to land – there will be no other traffic for runway 4 so this one will be easy"*	*35*
13:04:48	*52G*	*"Making right traffic for downwind for runway 35, 4252G"*	*35*
13:04:53	*LCI*	*"... affirmative, and cleared to land on runway 35 via the right downwind and right base"*	*35*
13:05:02	*52G*	*"Thank you – right downwind, right base, runway 35, 4252G"*	*35*
13:06:00	*LCI*	*"... there's a 737 on short final runway 4 touching down right in front of you so just caution wake turbulence right there at that intersection"*	*35*
13:06:08	*52G*	*"OK, I got that in sight, N4252G"*	*35*
13:07:01		*A position relief briefing occurred on the LC position and a new controller (LC) took over.*	*35*
13:07:03	*LCI*	*The controller asked if the pilot of N4252G had runway 35 in sight.*	*35*
13:07:07	*52G*	*"Runway 35 in sight, 4252G"*	*35*
13:07:10	*LCI*	*"winds 090 at 13 gust 18, runway 35 again, cleared to land"*	*35*
13:07:18	*52G*	*"35 cleared to land trying to get [laugh] down again, 4252G"*	*35*
13:07:22	*LCI*	*"no problem"*	*35*
13:08:20	*52G*	*"4252G, going around again, third time will be a charm"*	*35*
13:08:25	*LCC*	*"OK, Cirrus 52G, just go ahead and make the left turn now to enter the downwind, midfield downwind for runway 4, if you can just keep it in a nice tight low pattern, I'm going to have traffic 4 miles behind you so I need you to just kind of keep it in tight if you could"*	*35*
13:08:41	*52G*	*"OK, this time I'll be runway 4, turning left, 4252G"*	*4*
13:08:45	*LCC*	*"Yeah and actually I might end up sequencing you behind that traffic, he's on 4 miles a minute, um it is gonna be a bit tight with the one behind it so, uh, when you get on the downwind, stay on the downwind and advise me when you have that 737 in sight. We'll either do 4 or we might swing you around to 35 uh uh ma'am, ma'am uh straighten up straighten up!"*	*4*

(HOU-ATCT-0064, 2018, p. 44-49)

Table 6-1 Summary of ATC transmissions, 12:57:02 - 13:08:45 CDT