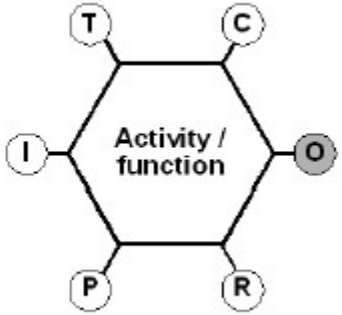
MINES PARIS
ParisTech

2nd FRAM WORKSHOP
20-22 February, 2008
Ecole des Mines de Paris
Sophia Antipolis, France



Normal people in normal organizations :FRAM analysis of a mid-air collision

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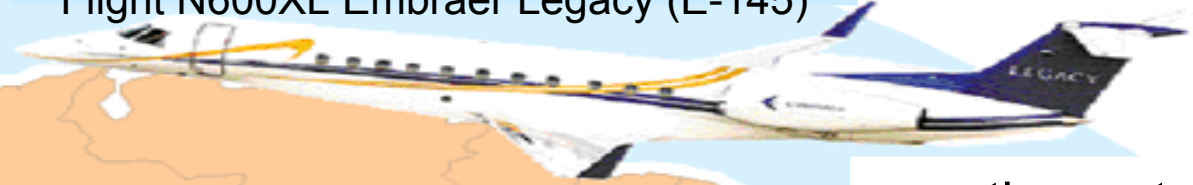
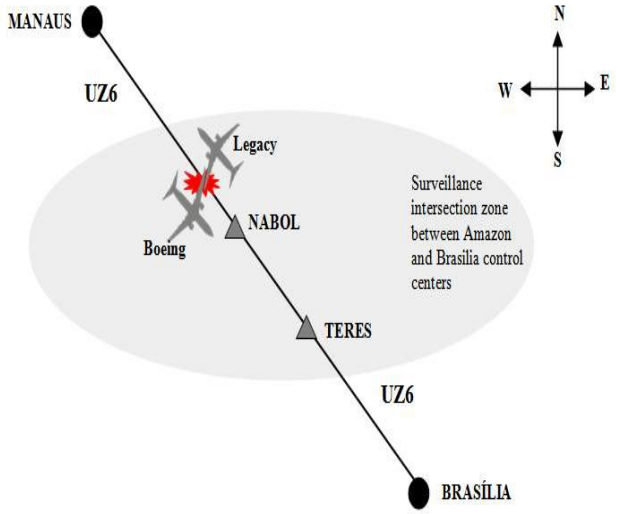
The collision

Flight GLO1907
Boeing 737-800

Flight N600XL Embraer Legacy (E-145)



154 people in the Boeing



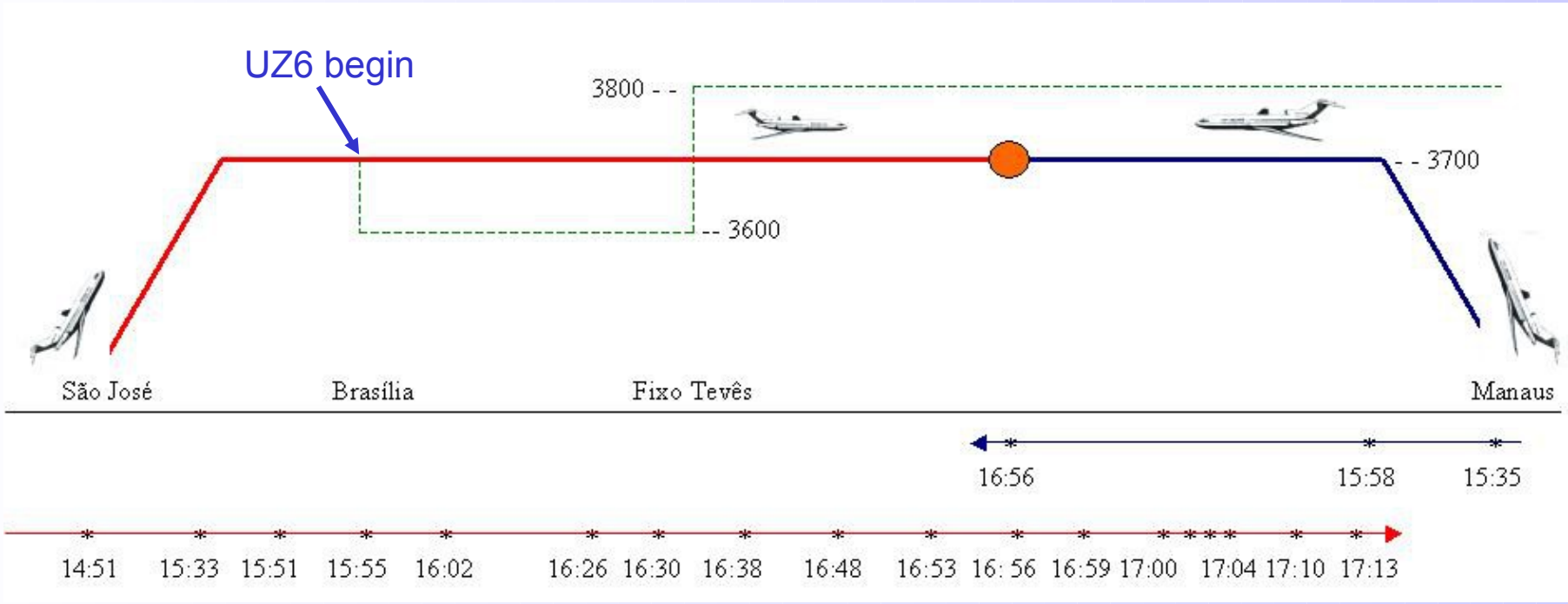
UZ6 dual lane airway

Fl. 360,380,400 – south/north
Fl. 350,370,390 – north/south

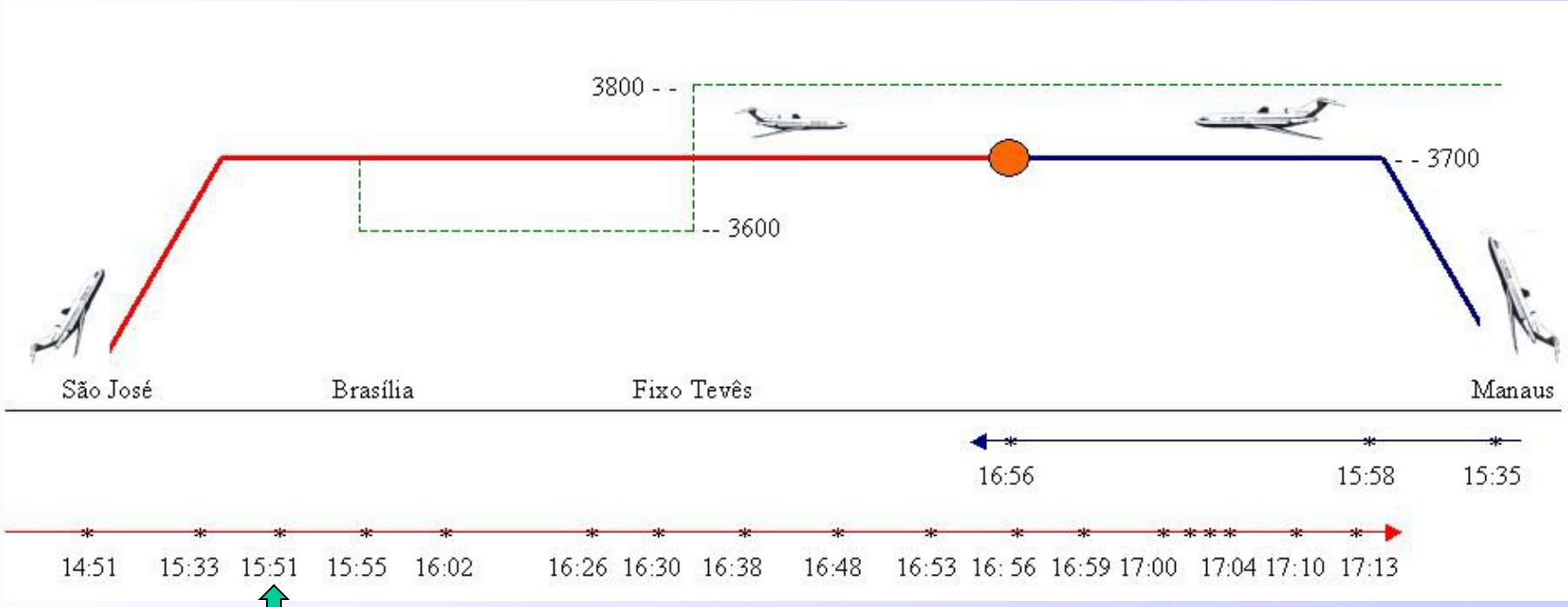
PART 1

What happened:
The timeline

Timeline

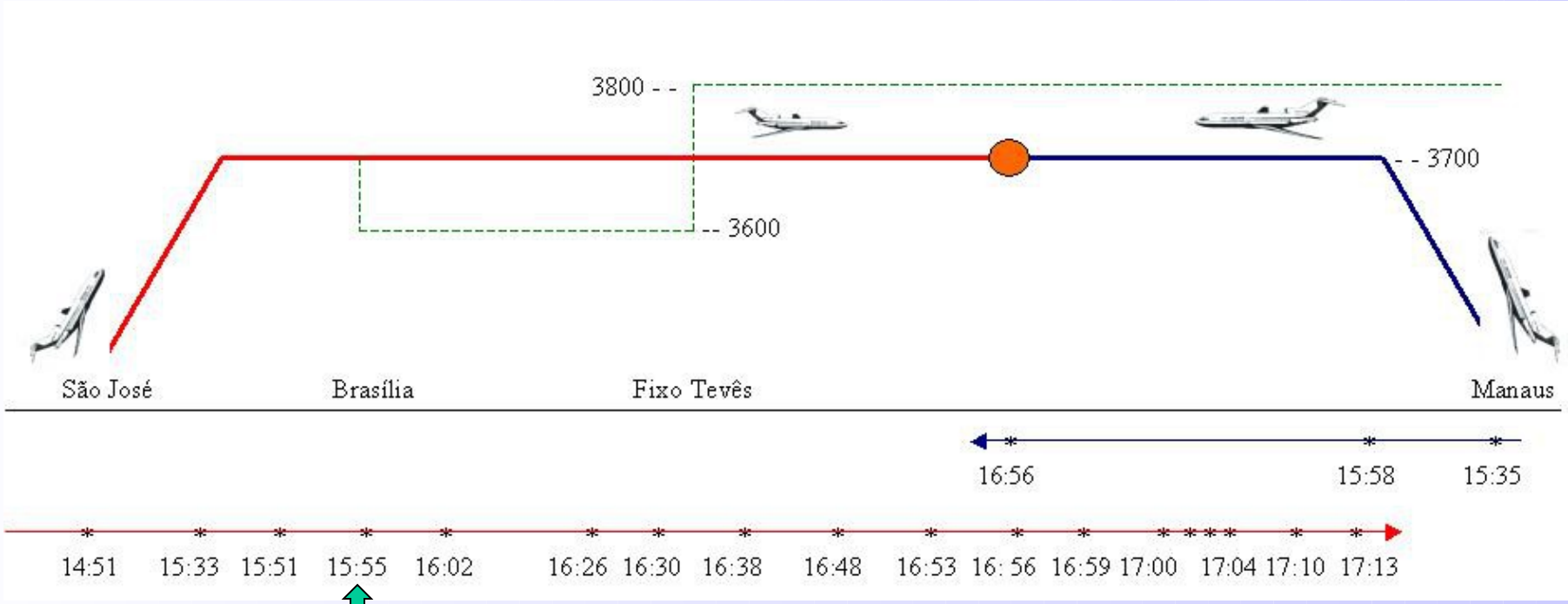


Timeline



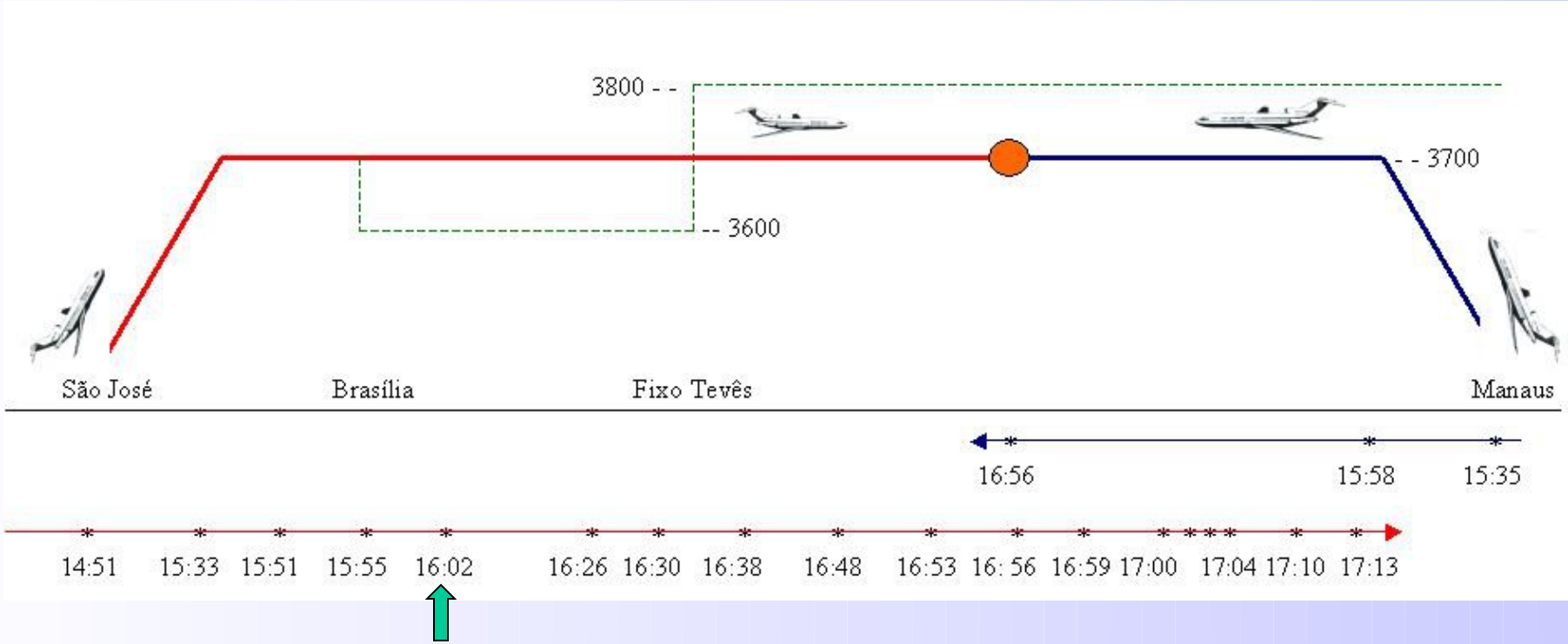
15:51 – Last bilateral contact between N600XL and Brasília ACC. Clearance for 37000 ft. Clearance limits not specified.

Timeline



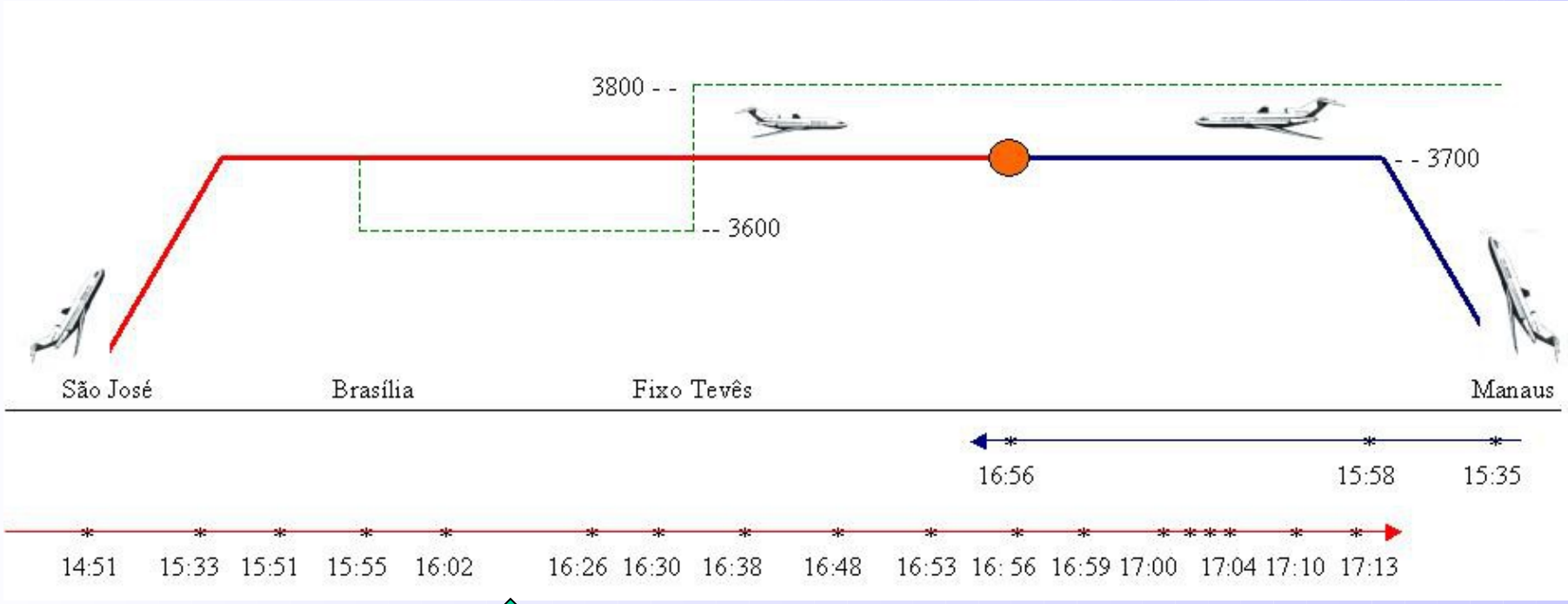
15:55 – N600XL reached dual-lane UZ6 airway. No communication to change flight level. Flight plan indicated level 360 (36000 ft). Level 370 maintained.

Timeline



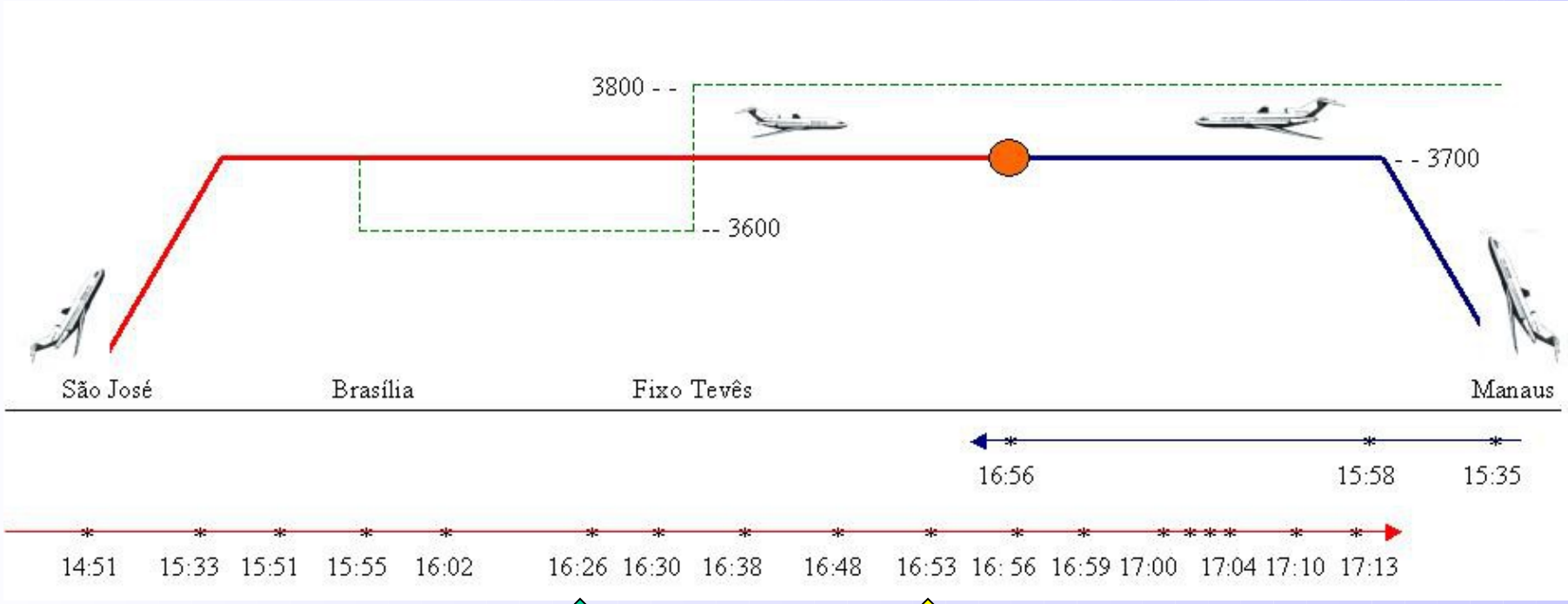
16:02 – N600XL transponder ceases to reply to Brasilia ACC surveillance radar. TCAS in standby mode. No action from Brasilia ACC.

Timeline



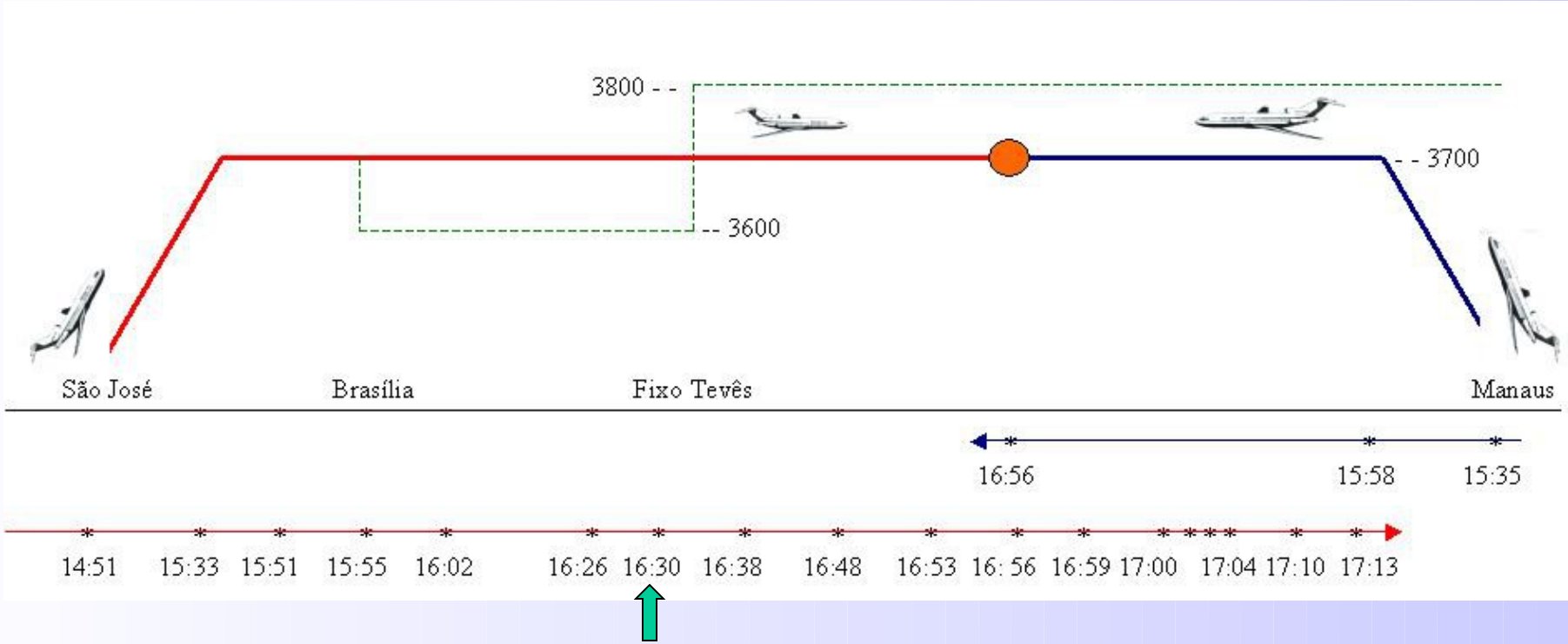
16:17 – Shift changeover in Brasila ACC workstation 8. Flight N600XL is passed to the new controller as being in *normal* situation, flight level 360.

Timeline



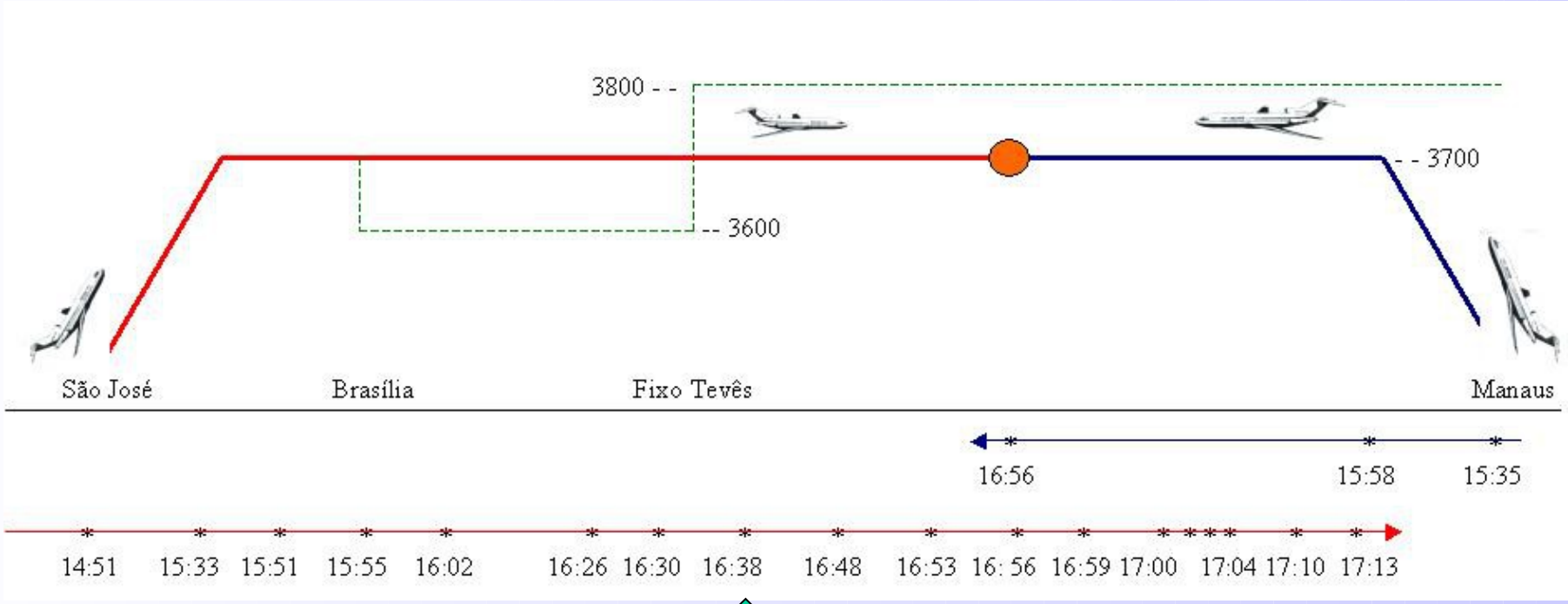
16:26 – From this moment Brasilia ACC makes 7 attempts to contact N600XL, the last one at 16: 53h.

Timeline



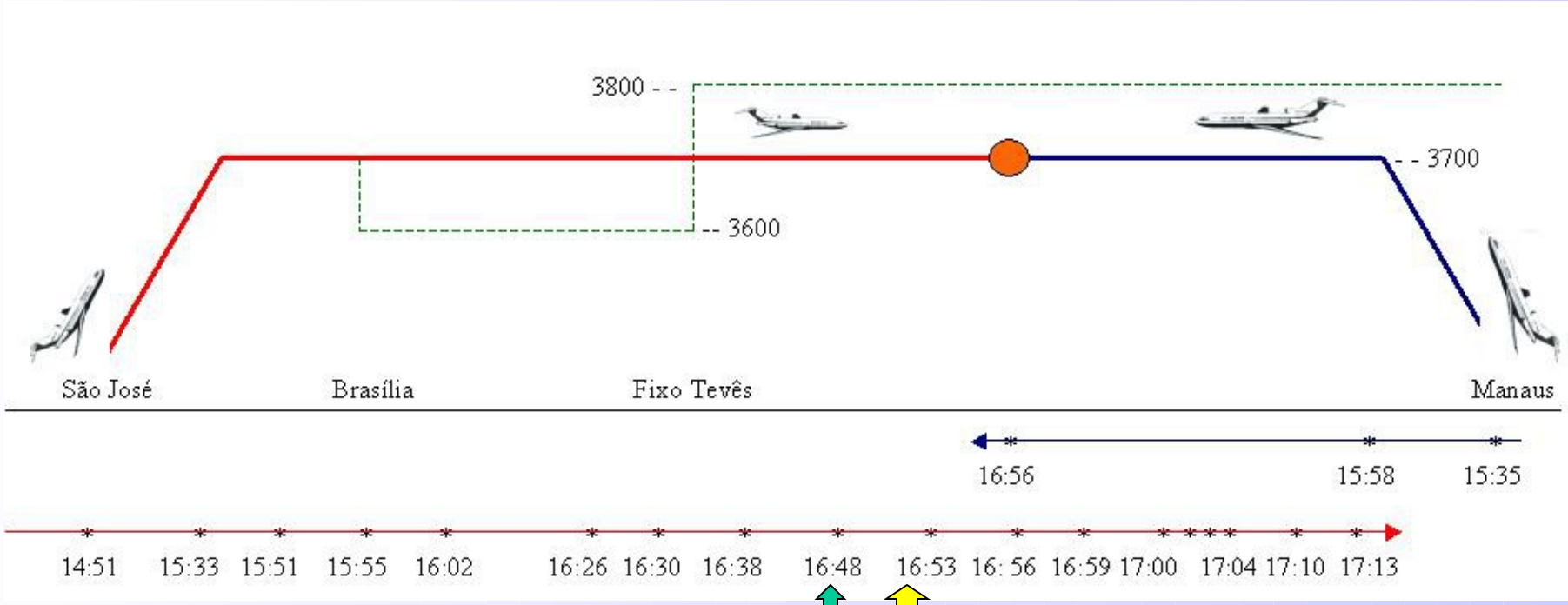
16:30 - Brasilia ACC lost N600XL target: for 2 minutes the primary (height-finding) radar did not register its presence and the secondary radar (which relies on the transponder) was already out.

Timeline



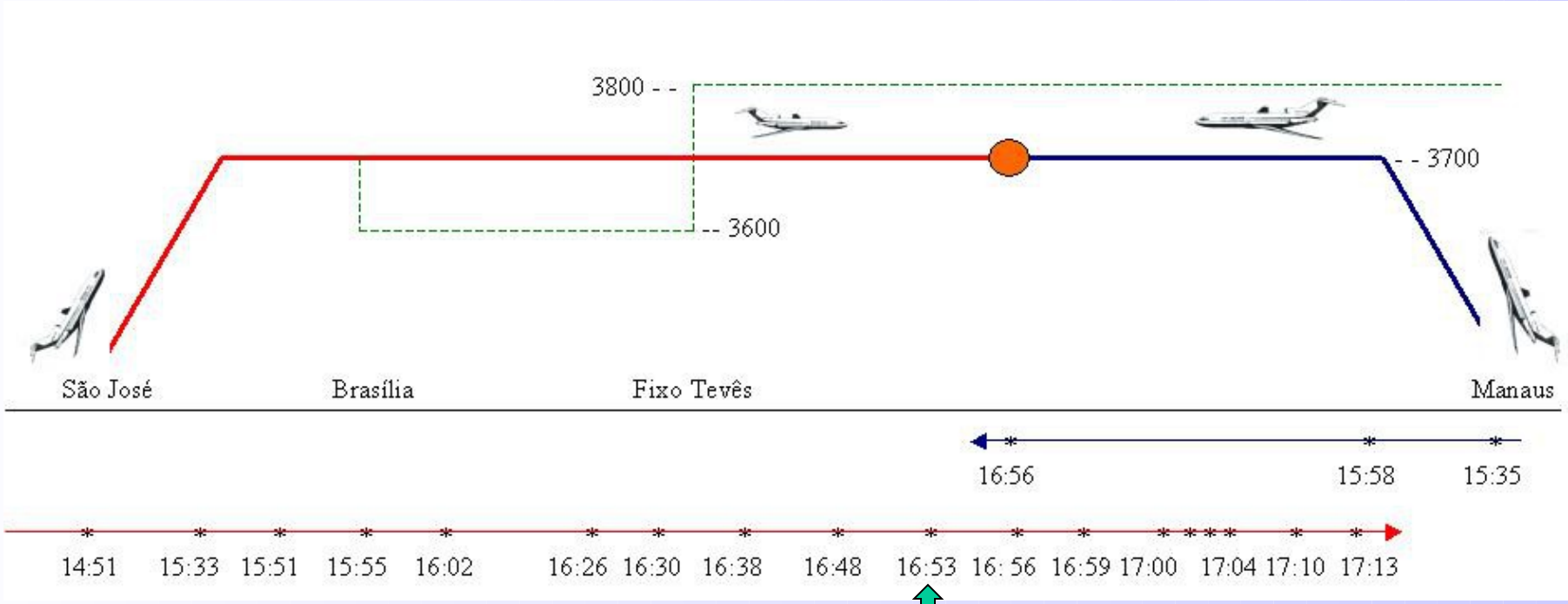
16:38 – Total loss of radar contact.

Timeline



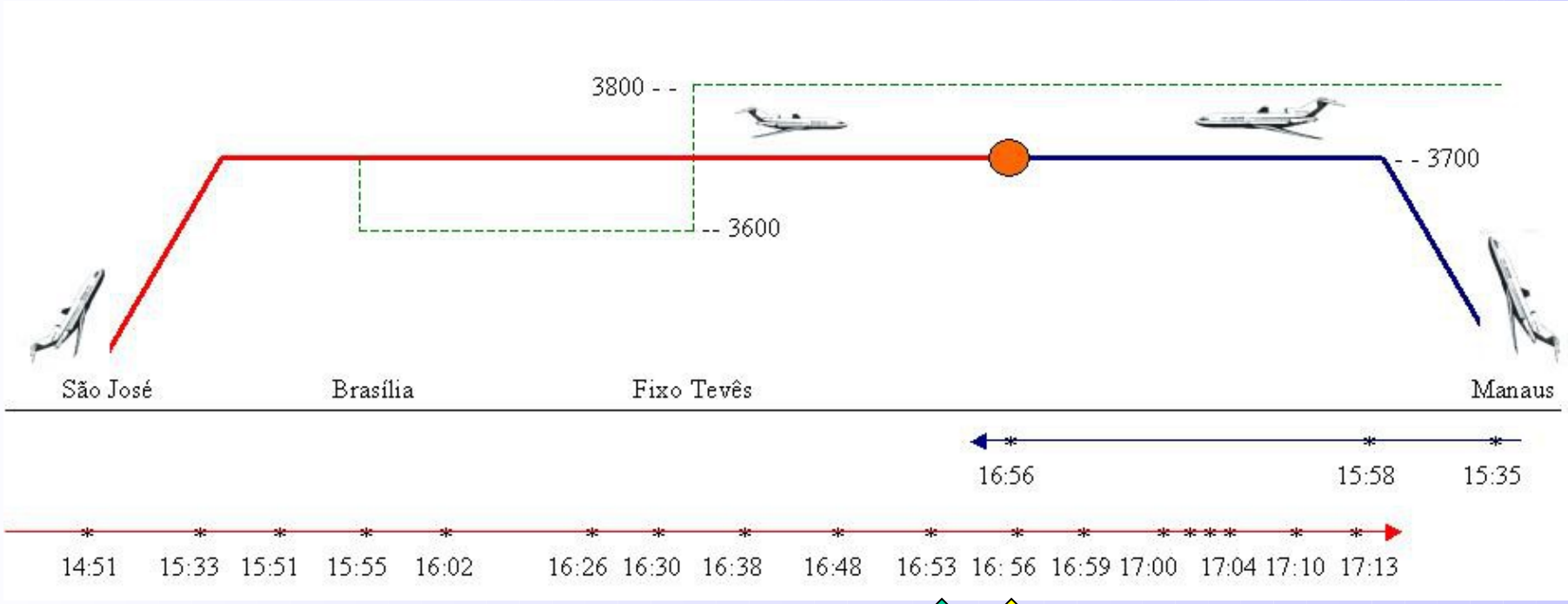
16:48 – N600XL made 12 attempts to contact Brasilia ACC, the last one at 16:52.

Timeline



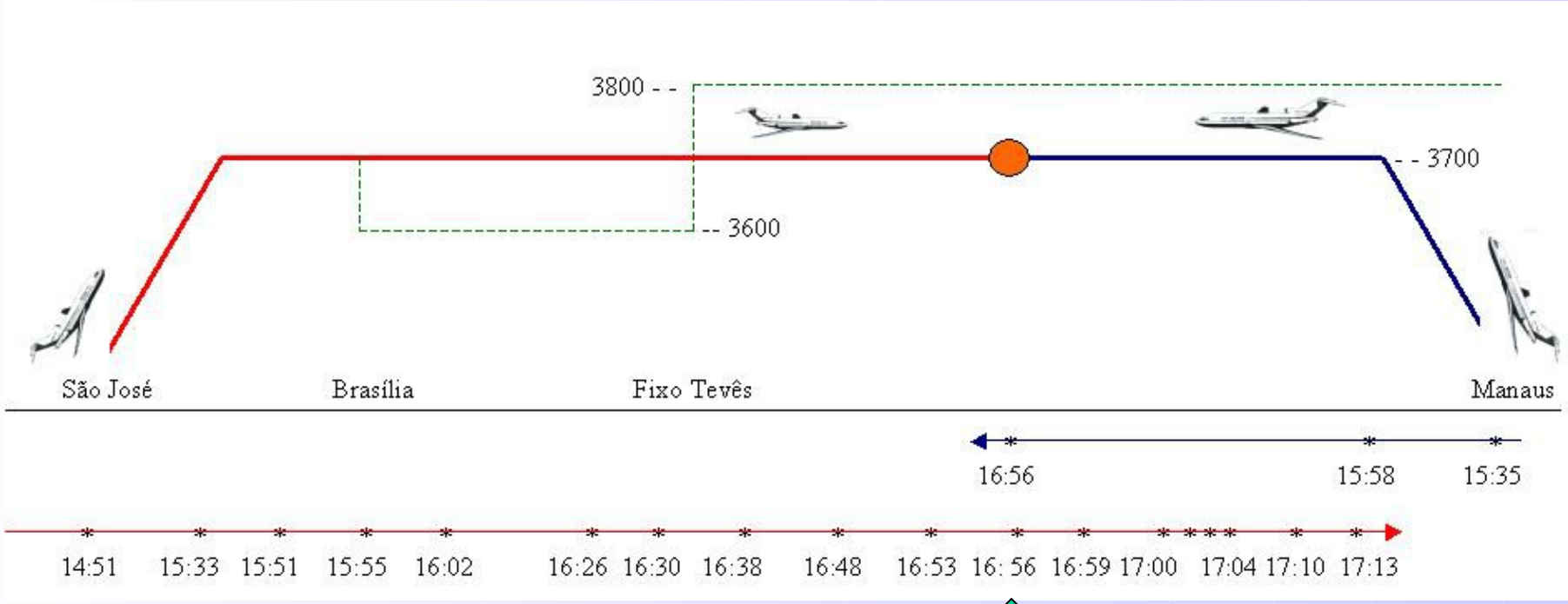
16:53 – Brasília ACC sent a blind call to the N600XL to change its communication frequency. N600XL crew did not get all the numbers. Brasilia ACC did not copy the Legacy reply.

Timeline



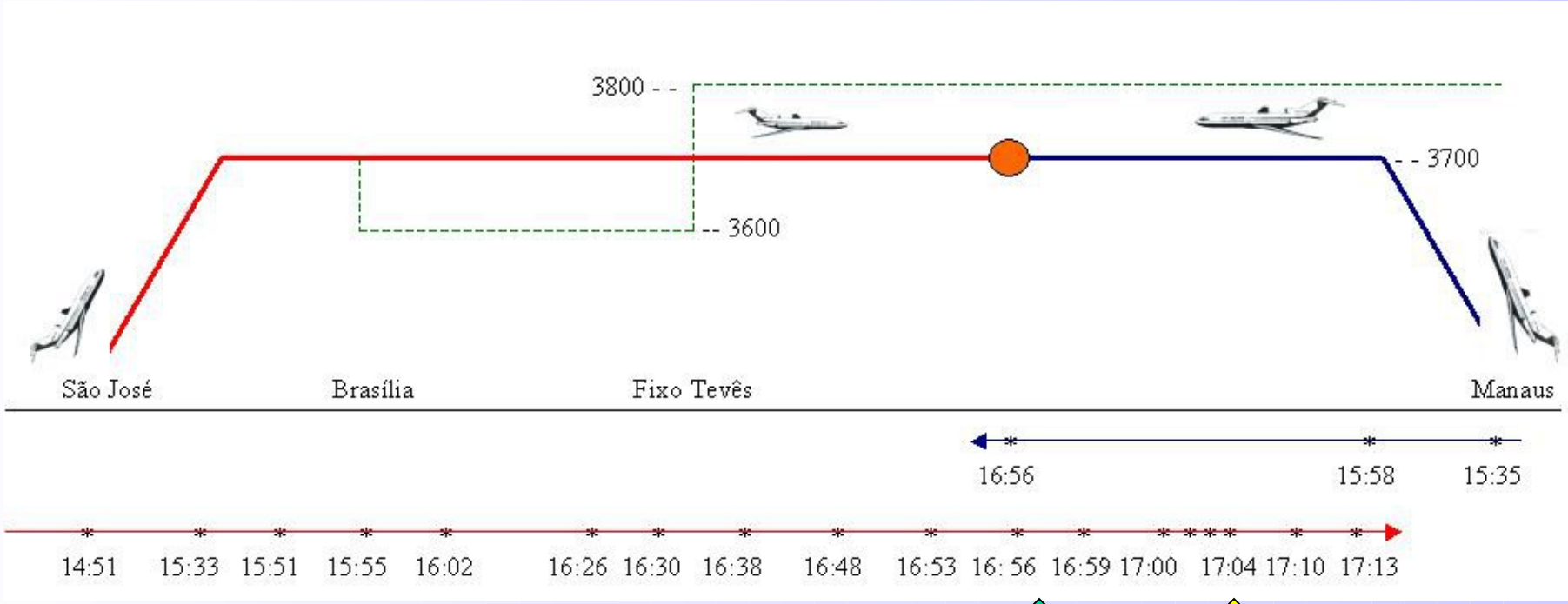
16:54 – N600XL made 7 more attempts to contact Brasilia ACC, the last one at 16:56, seconds before the collision.

Timeline



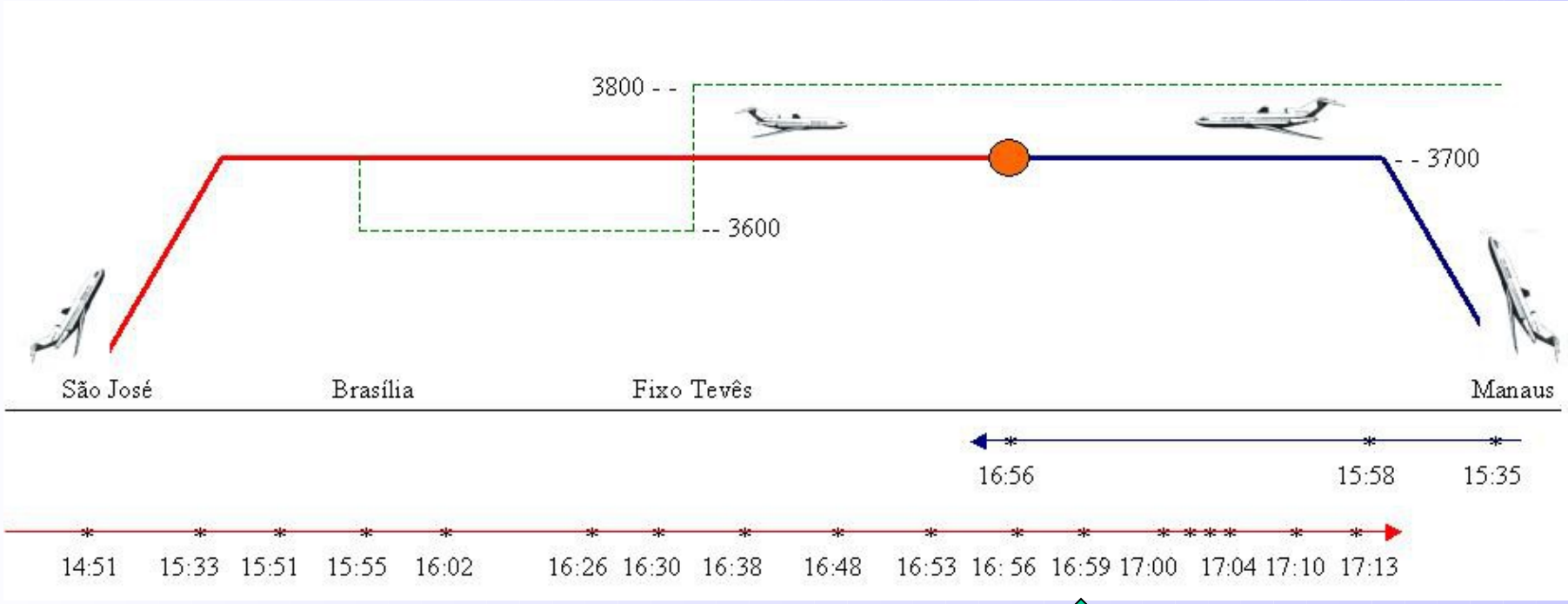
16:56 – Collision

Timeline



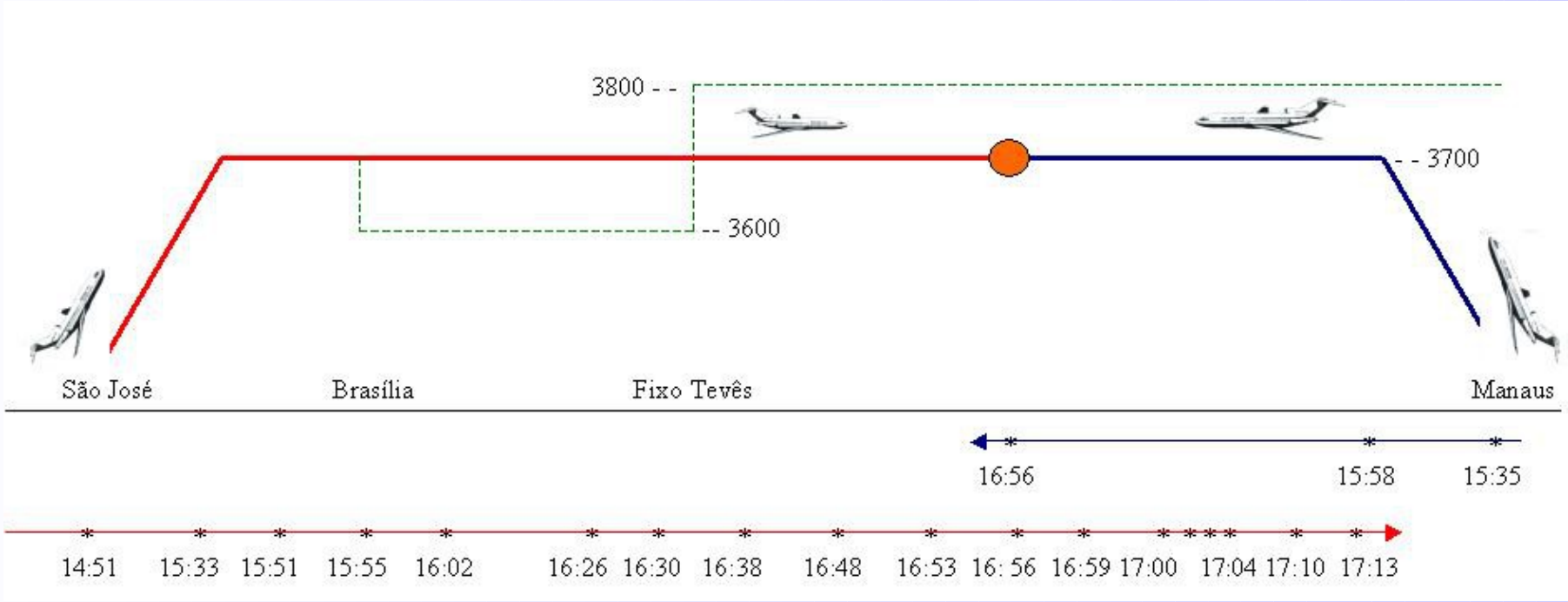
16:57 – N600XL tried to call Brasila ACC 9 more times, the last one at 17:04.

Timeline



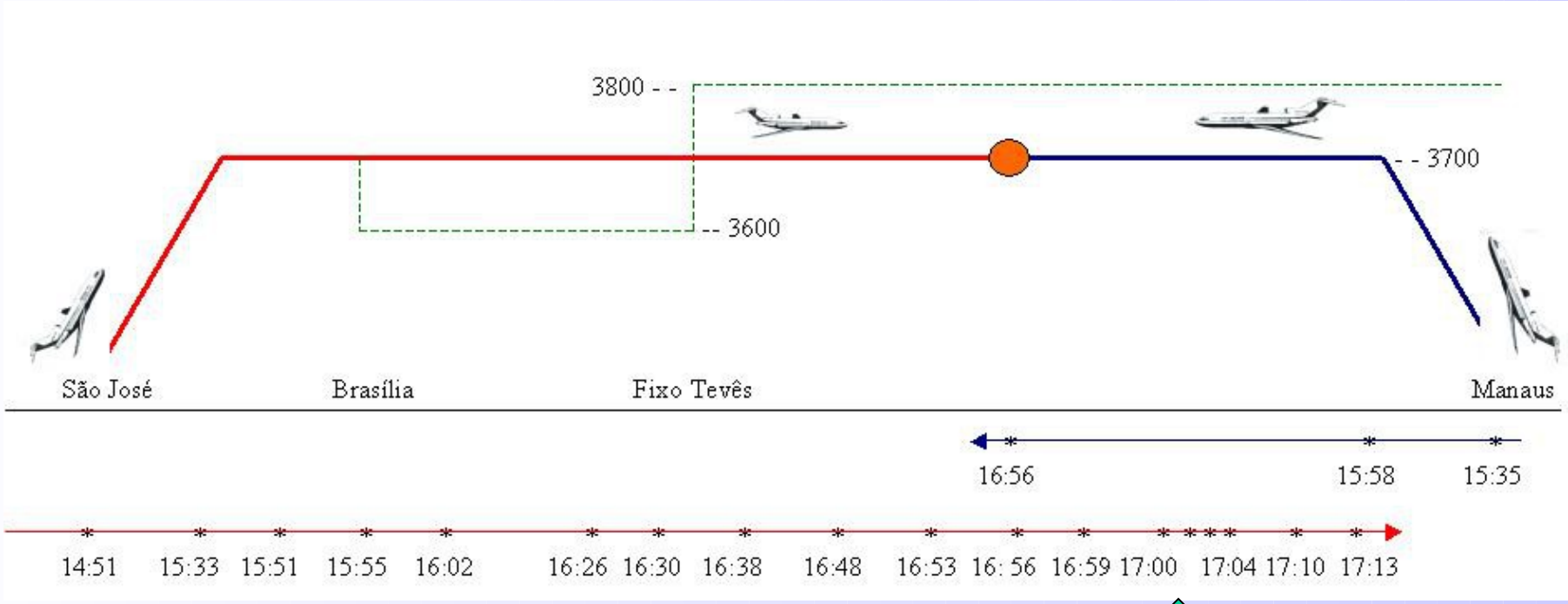
16:59 – After the collision, the N600Xl crew noticed that the TCAS was OFF, and turned it on.

Timeline



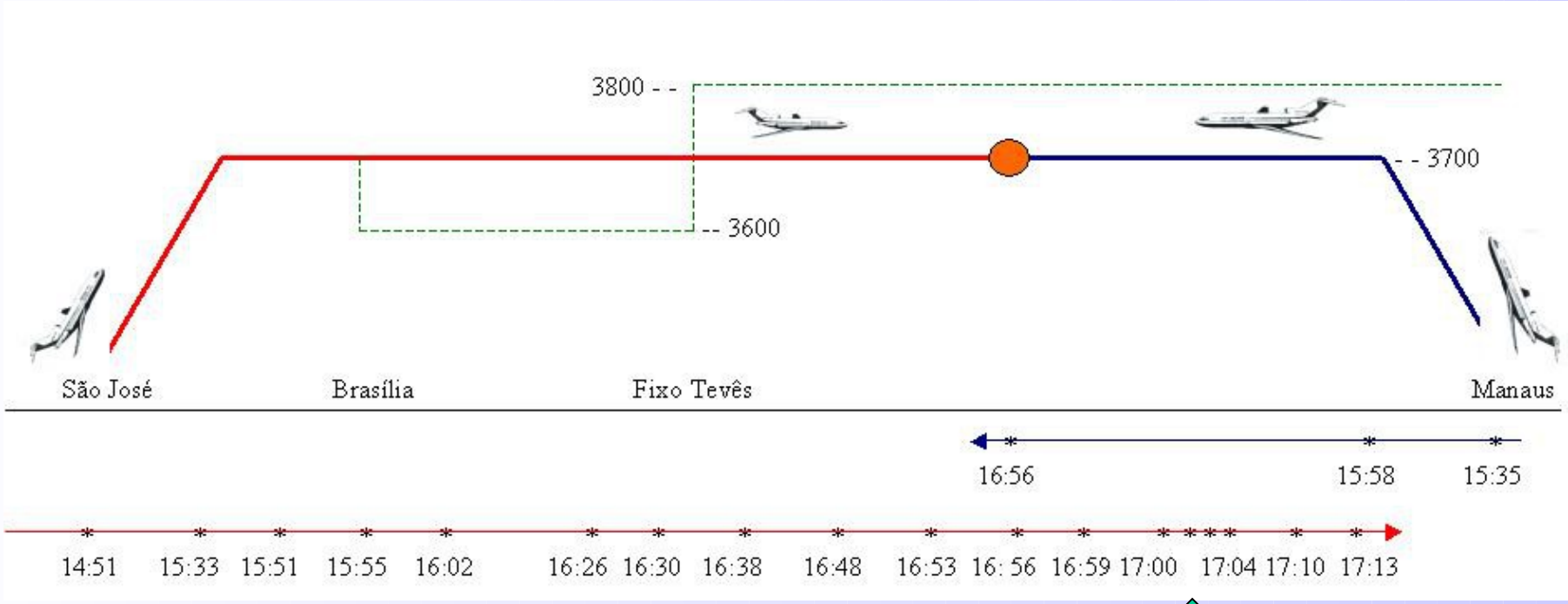
17:00 – Amazon ACC tried to make contact with N600XL, without success.

Timeline



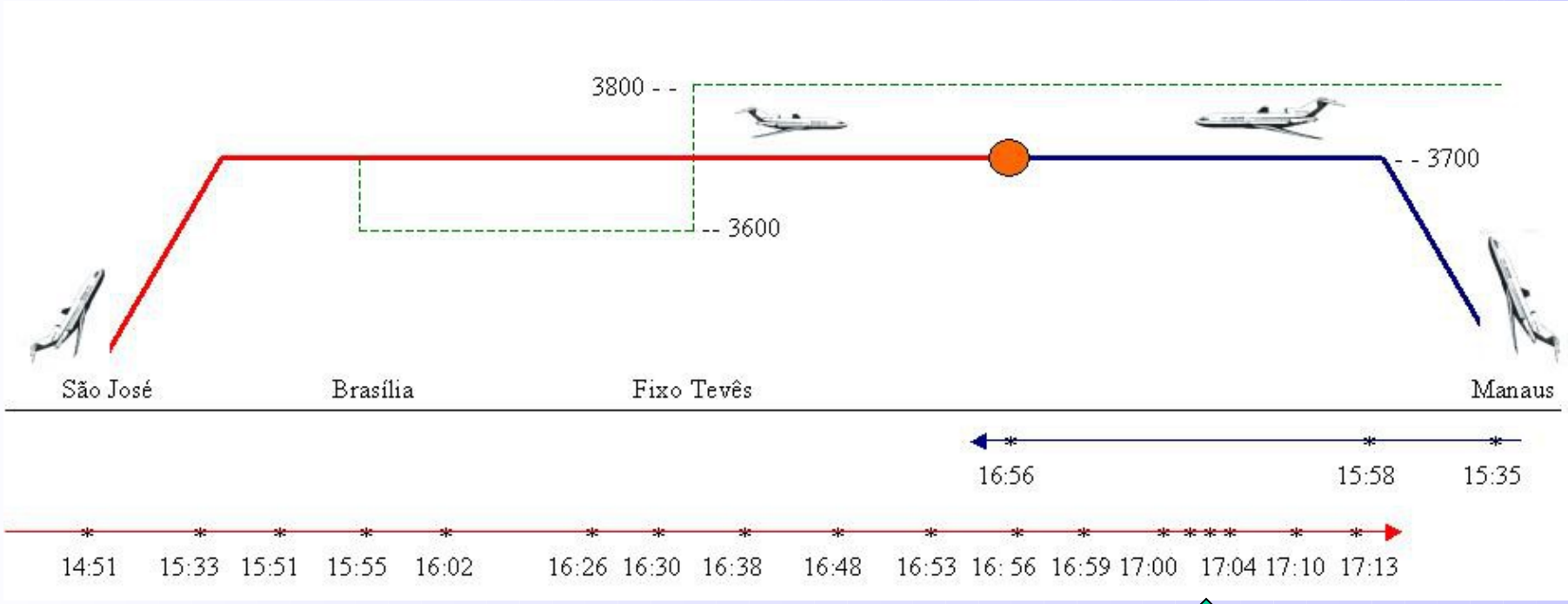
17:01 - N600XL tried to contact Amazon ACC using another aircraft to make na emergency landing in the Air Force airport Brig. Veloso.

Timeline



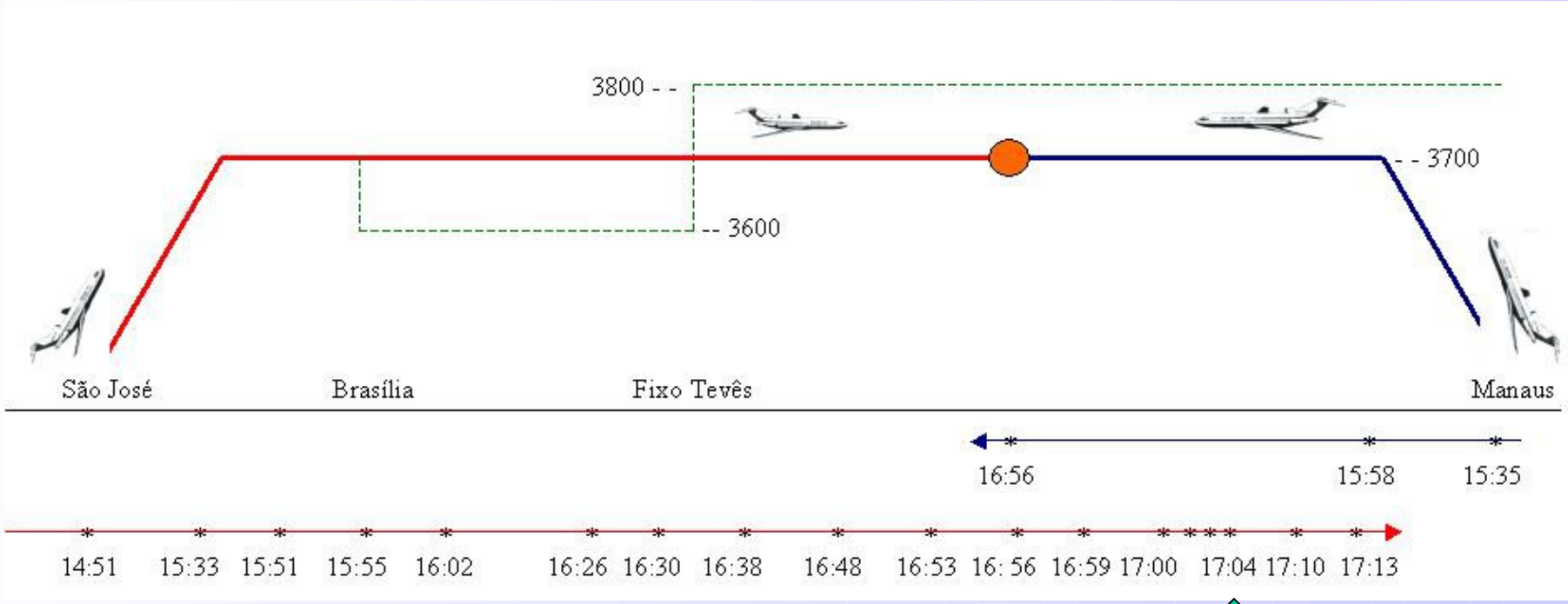
17:02 – Amazon ACC started to receive transponder replies from the N600XL, after the code change to 7700 - emergency.

Timeline



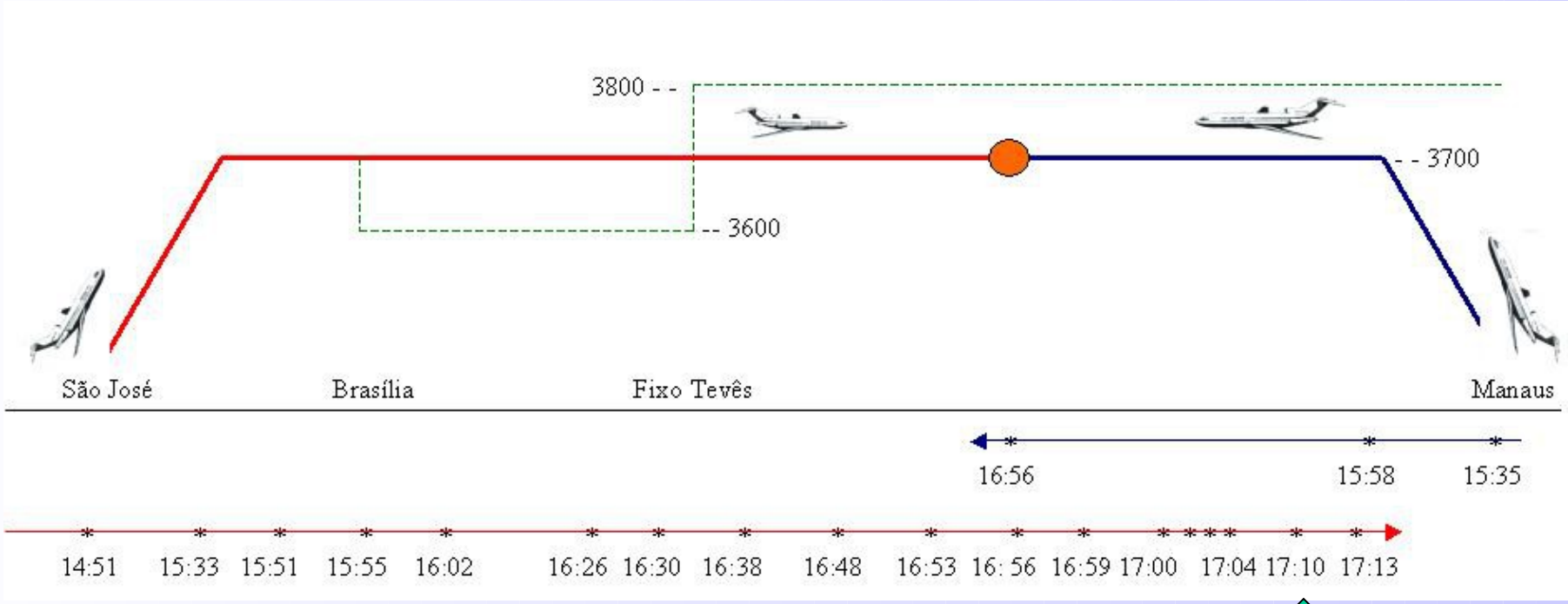
17:03 – The N600XL started procedures for emergency landing.

Timeline



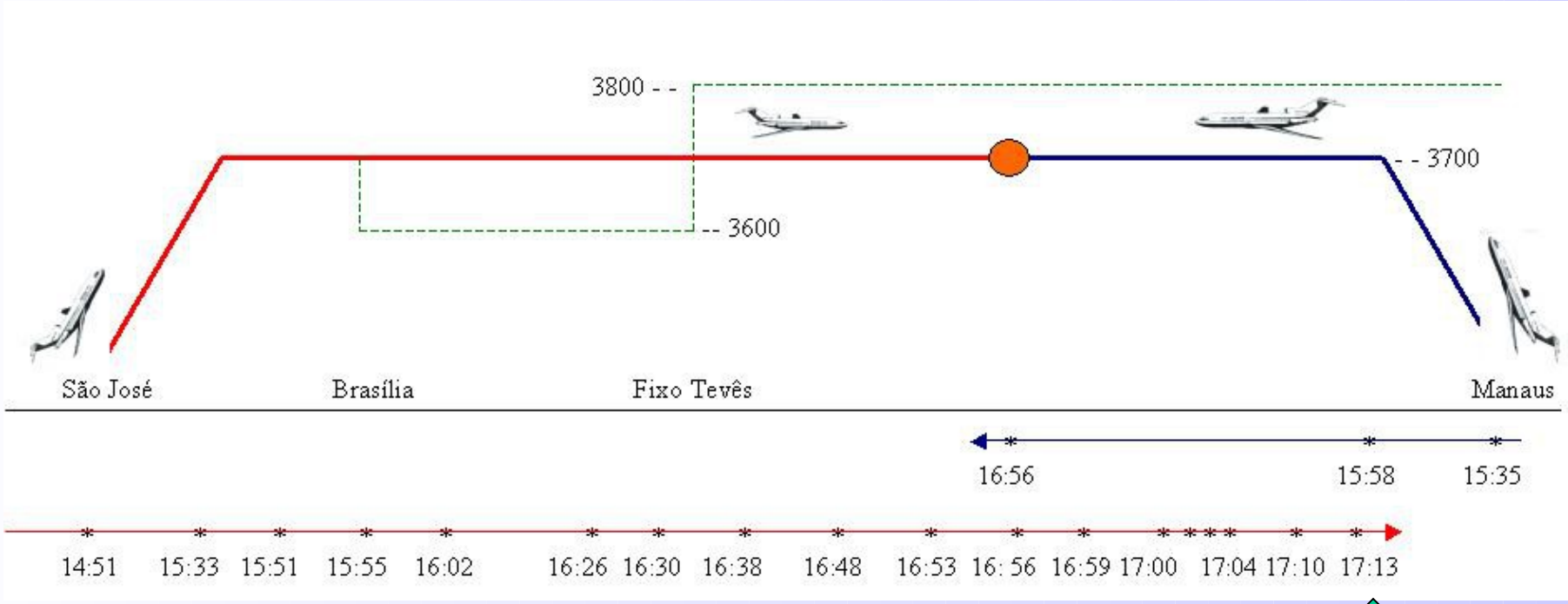
17:04 – Last of the 9 call attempts to the Amazon ACC.

Timeline



17:10 - The Amazon ACC made more 4 call attempts, without response.

Timeline



17:13 – The other aircraft informed Amazon ACC of N600XL's emergency situation.

The facts: safety barrier meltdown

- Flight plan not followed
- Incomplete clearance dialogues
- TCAS OFF
- Controllers' inaction
- Radar and communication problems

Preliminary investigation findings

- There is no loss of radar surveillance between the Amazon ACC and flight 1907
- There is no registered evidence in the communication records about any N600XL request to the air traffic control centers to change its flight level, after it had reached the 370 flight level
- There is no registered evidence about any instruction for the N600XL to change its flight level coming from the ACC
- There is no registered evidence of any TCAS generated traffic alert alarm or instruction for evasive action to avoid collision to the crews of either aircraft
- There is no registered evidence of any manifestation in either crew related to any possible visual perception of an approaching aircraft
- There is no attempt for action or evasive maneuver, according to the data existing in flight recorders

It therefore seems that …

The entire system (including the human element, pilots and controllers, technology and organization) was not aware that two aircraft were flying at the same level and in opposite directions

PART 2

How and why did it happen?

Flight plan not followed

- Submitted by Embraer to the ACC - a *normal* way to prepare and submit flight plans for small jets
- P ... Z6 dual la
- La ... *“N ... **ce to E** ... ”*
- **C** ... **cl** ... *ce, it happens all the time. You have to fly according to the authorization …The actual flight plan is the clearance that you receive from the control center” – N600XL pilot*

Belief-bias effect: people make judgments based on prior beliefs and general knowledge, rather than on the rules of logic or the information available

Incomplete clearance

- **Congressional Hearing Report concludes *"(...) that communicating a partial authorization for the flight of an aircraft is a procedure without any normative support"***

Time	Operator	Communications
14:33:33	Brasilia ACC Controller	Talk São Jose
14:33:35	São Jose TWR controller	Hi Brasilia. The November six zero zero x-ray lima to Eduardo Gomes São Jose Eduardo Gomes ... requesting level three seven zero.
14:33:50	Brasilia ACC Controller	... Level three seven zero transponder four five seven four Poços de Caldas.
14:33:55	São Jose TWR controller	Three seven zero direction Poços. What is the frequency he calls you there?
14:33:59	Brasilia ACC Controller	One two six fifteen ... one three three five
14:34:04	São Jose TWR controller	One three three five three seven zero direction Poços. OK
14:34:09	Brasilia ACC Controller	Bye bye
14: 34:10	São Jose TWR controller	Bye bye

Source: CPI final report (Camara dos Deputados ,2007).

The TCAS functioning

Time	Operator	Communication
16:56:38	Co-pilot on Legacy radio	Brasília, November six zero zero Xray Lima.
16:56:50	Co-pilot on Legacy radio	Brasília, November six zero zero Xray Lima.
16:56:54	Cockpit microphone	**Impact sound - collision**
16:56:56	Pilot, Co-pilot	Uh oh
16:56:56	Cockpit microphone	Automatic pilot (...)
16:59:08	Co-pilot	This.
16:59:12	Pilot or Co-pilot	Deep breath sound
16:59:13	Co-pilot	Man, are you with TCAS on?
16:59:15	Pilot	**The TCAS is off**
16:59:25	Co-pilot	All right, pay attention only at the traffic. We will succeed, we will succeed we will succeed. I know that.
Just after the collision, the co pilot started a visual flight (... *pay attention only at the traffic* ...) which make sense only in the absence of the TCAS/transponder. After that, when the pilot set the emergency code 7700 the transponder worked well.		
17:02:06	Pilot	I will set to seven thousand and seven hundred. It is an emergency!
17:02:08	Co-pilot	Yes, set it up.

Investigation findings

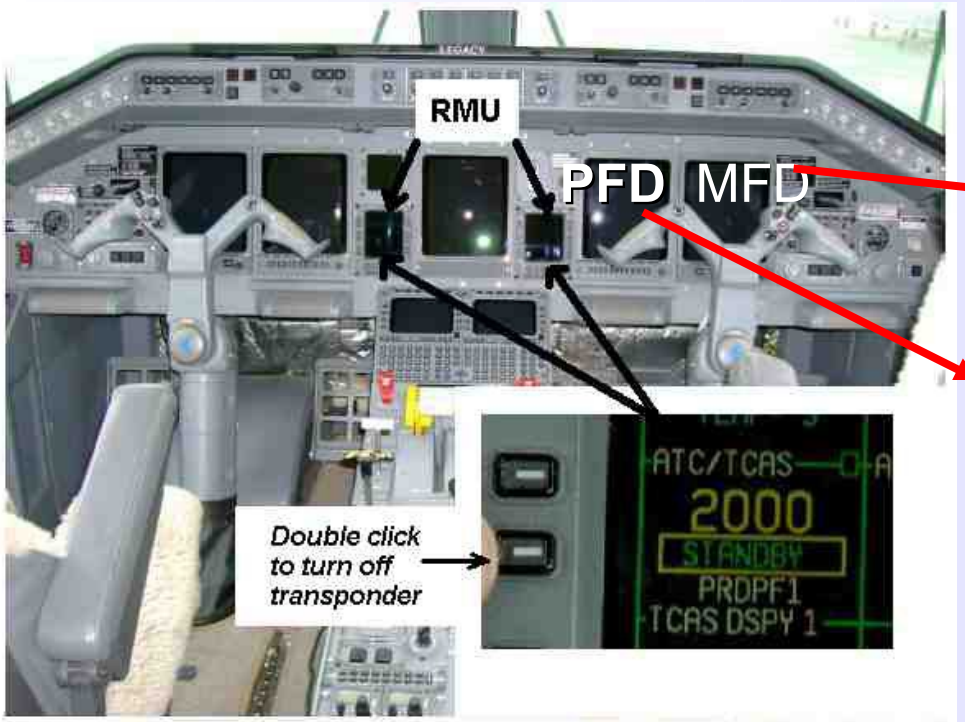
- *"In accordance with their description documents and certifications, the transponder and TCAS systems did not present design or integration errors. Or be it, they functioned as they had to function. (...) We are now focussing our investigation on the operational factor, or be it, on the relationship of the operation of... of the human being with that system"*

- "*The transponder stopped functioning. We did all the tests to try to exclude the possibility of a technical failure in the transponder. We did not find technical malfunctions. The equipment functioned according to its characteristics. Therefore, we focus on the operational factor. What I can say at this moment is that I have no indication that the pilots turned off the transponder intentionally. I do not have… looking at the CVR, I have nothing that indicates any action related to this equipment.*

- **HOW CAN IT BE TURNED OFF?**

- **WHY DID THE PILOTS NOT PERCEIVE IT WAS OFF?**

Legacy panel
TCAS OFF - actuation and indications



" (...) the ATC/TCAS standby mode is indicated on the RMU and Cockpit Displays (PFD/MFD), however these indications may not be apparent to pilots, especially during periods of high workload" (Irish Aviation Authority, 2005, pp 2).

The controllers' inaction

N600XL was flying in the dual lane airway UZ6 at the wrong flight level – zulu time + 3 hours

- 18:55 – first automatic change in radar scope
- 19:02 – transponder ceased to reply to ATC
- 19:17 – shift changeover in Brasilia ACC
- 19:26 – first communication attempt from Brasilia ACC
- 19:48 – first communication attempt from N600XL
- 19:57 – the collision

GLO 1907
Estimating
NABOL at 19:59

N600XL
Estimating
NABOL at 19:54

19:17
Shift
changeover

19:15
45 minutes
before collision
ATC had GLO
flight strip.

The N600XL
flight strip
was already in
the scope

Vicinity of Brasilia VOR

19:57
Collision

Red line – ATC radar was not receiving Legacy's transponder

Radar scope updates every 10 sec. – 300 times from the loss of transponder signal to the collision

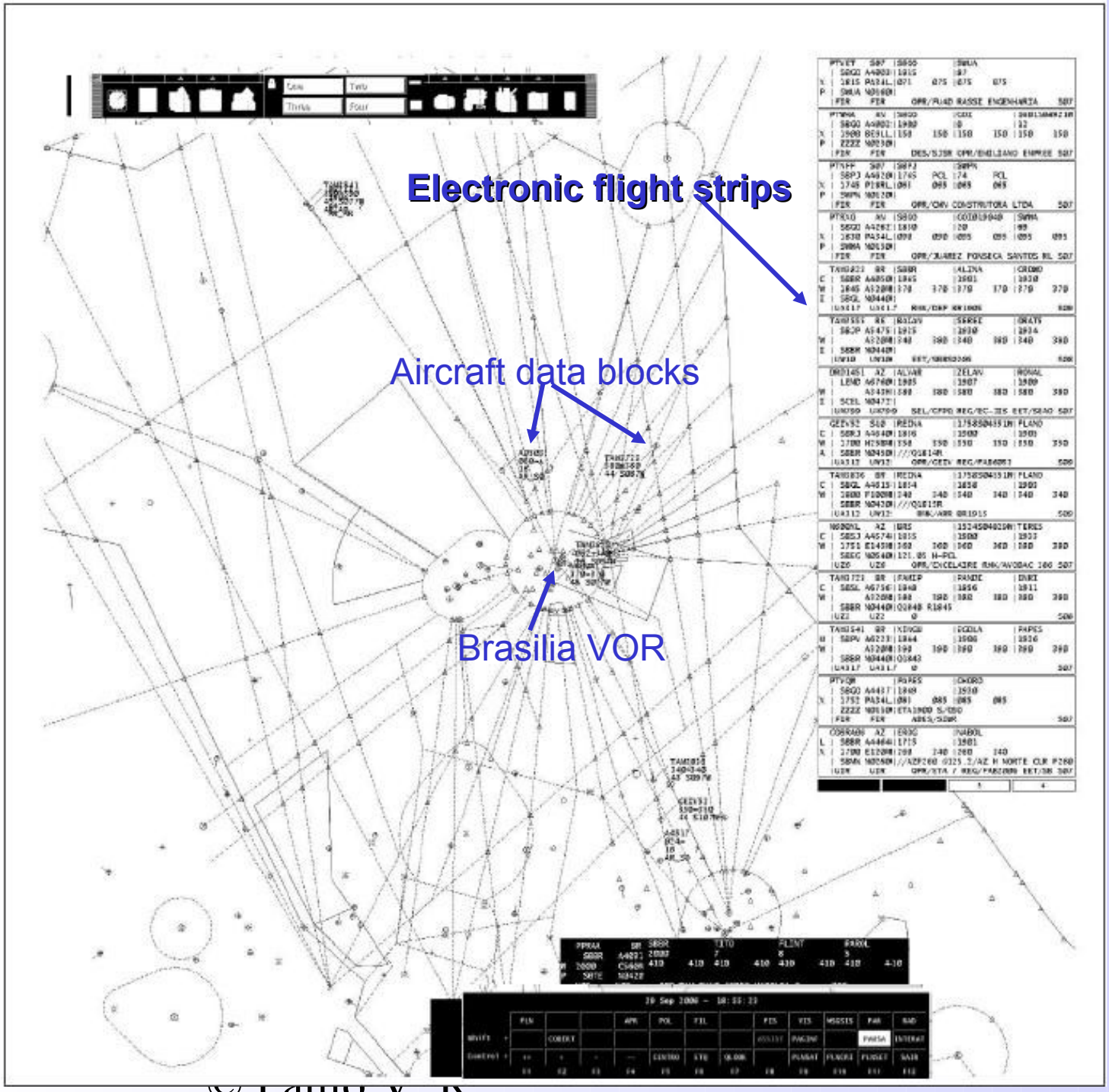
19:02 - Loss of transponder signal

(Aeronautical Chart in Effect at Time of Accident)

The controllers' inaction

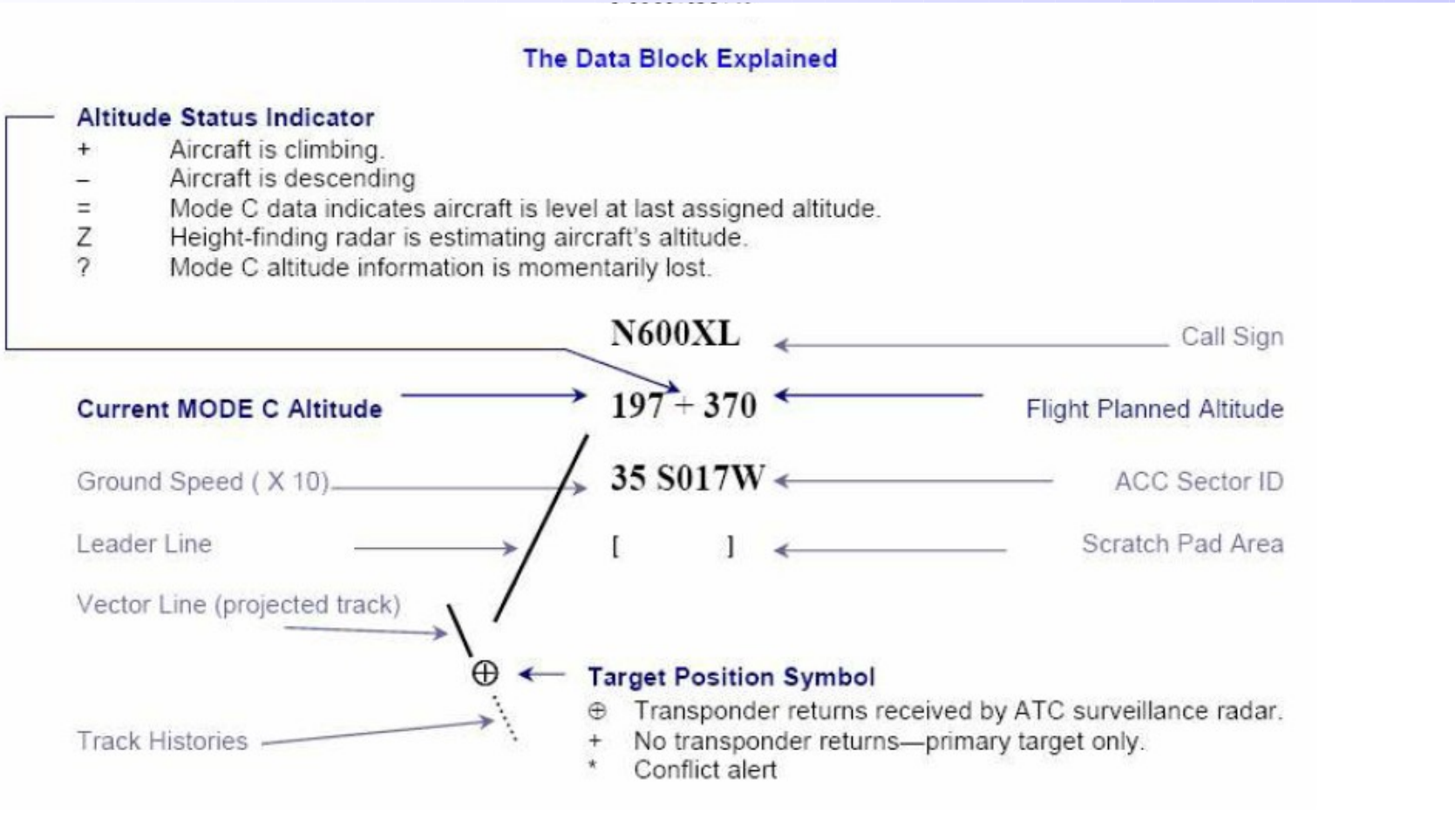
- What they were actually seeing
- To perceive and to act
- Communication problems
- What they said

Radar screen



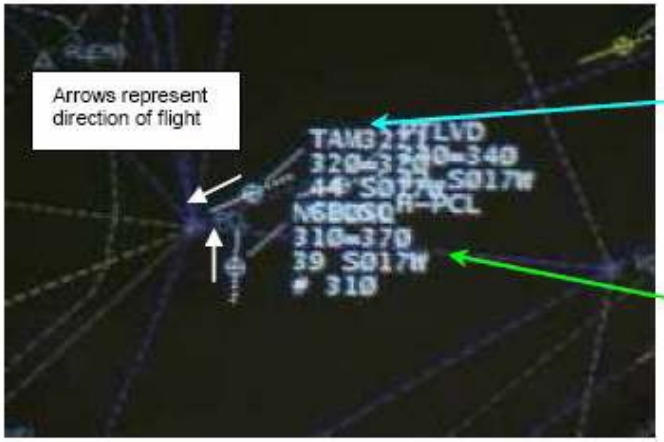
Brasilia ACC radar screen - detail

The data block



Conflict detection

ATC Restricts N600XL's Climb to FL310 to Avoid Conflict With Southwest Bound Jet at FL320



TAM Flight
Proceeding southwest at FL320. Data block shows aircraft level at this altitude.

N600XL
Controller restricted N600XL's climb to FL310 for conflicting traffic. Data block shows aircraft level at FL310 as assigned. Scratchpad area reflects altitude restriction.

Clear of conflicting traffic:
ATC subsequently issues clearance to N600XL to climb and maintain FL370.

What the controllers actually saw - 1

Data Block Shows N600XL Cruising at Assigned Altitude of FL370 Prior to Reaching Brasilia

Target position symbol shows N600XL's transponder signal received by ATC.

Vicinity of Brasilia VOR

N600XL data block showed Mode C altitude of FL370 for over thirty minutes prior to the aircraft reaching Brasilia.

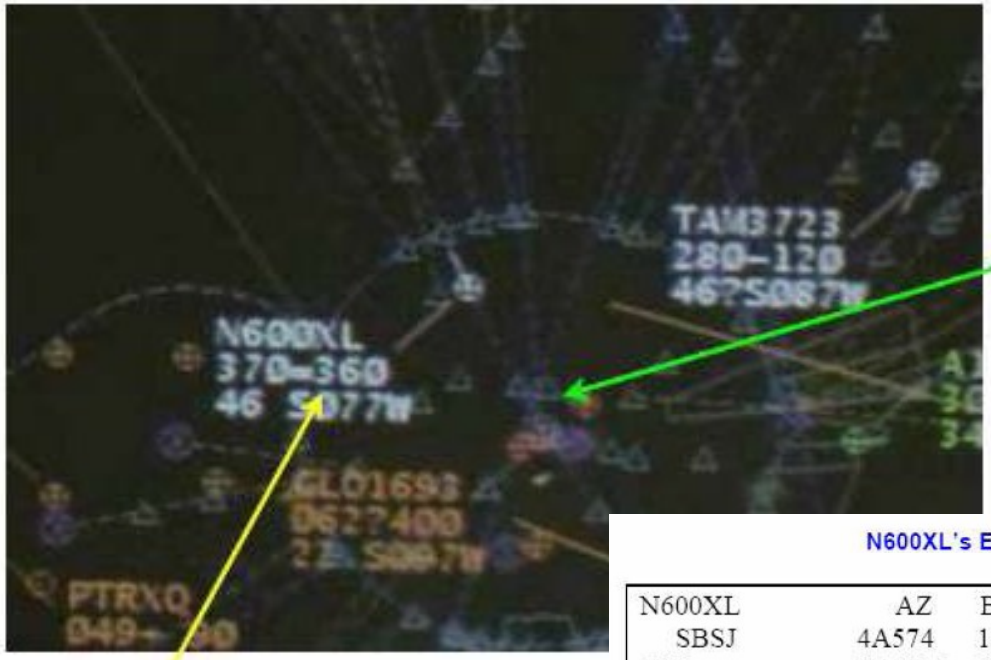
What the controllers actually saw - 1

18:55Z: Prior to Brasilia, N600XL's Data Block Alerts Controller of a Planned Altitude Change

- Data block alerts controller that FL360 is ATC approved altitude after N600XL crosses Brasilia VOR.
- Mode C altitude shows **N600XL at its last assigned altitude of FL370**.
- Since the accident, it has been recommended that ATC software be modified to prevent the retention of flight plan altitude information in the data block because it frequently conflicts with the ATC altitude clearance, as it did here.

What the controllers actually saw - 2

N600XL's Data Block After Passing Brasilia VOR



Brasilia VOR

360 - planned flight level

N600XL's Electronic Data Strip (with Portions Highlighted)

N600XL	AZ	BRS		1524S04829W	TERES	NABOL	
SBSJ	4A574	1855		1900	1933	1954	
1751	E145M	360	360	360	380	380	380
SBEG	NO540						
				125.05 H-PCL			
UZ6	UZ6			OPR/EXCELAIRE RMK/AVODAC 286 S07			

Gol Flight 1907's Electronic Data Strip (with Portions Highlighted)

GLO1907	AZ	NABOL	TERES
SBEG	A6542	1959	2020
	B738M	370	370
SBBR	NO450		
UZ6	UZ6	RMK/ARR BR2010	

What the controllers actually saw - 3

19:02Z: ATC Radar Scope Reveals Loss of the Legacy's Transponder

No transponder signal: Controller is required to initiate contact with N600XL, but fails to do so.

"Z" signifies that Height-Finding Radar (not more precise Mode C) is supplying altitude data.

What the controllers actually saw - 4

Sample of Estimated Altitudes Supplied by Height-Finding Radar After Loss of Transponder Signal at 19:02Z

190748

radar estimating 33,400 ft.

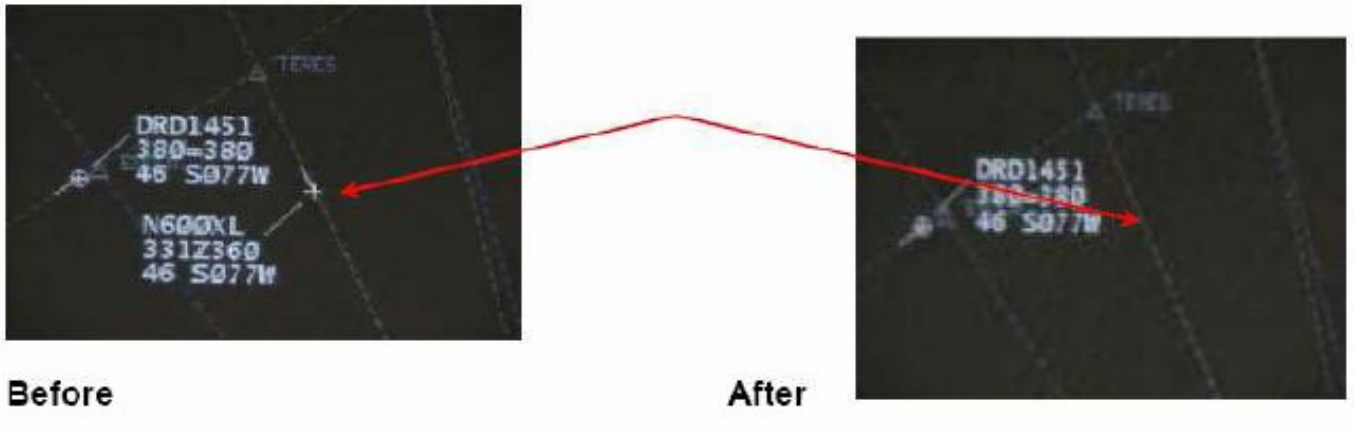
FDR confirmed 37,000ft.

10 sec. later

radar estimating 37,200

What the controllers actually saw - 5

19:31Z: Radar Contact Lost with N600XL.
The Target Position Symbol and Data Block for the Legacy Disappear From Brasilia Center's Radar Scope in One Radar Sweep.



1934
N600XL appear as an unidentified symbol

1938
N600XL disappear again

1940
N600XL appear again

1941
N600XL disappear from ACC

The communication attempts

- 16:26:51 to 16:34:08 - Brasilia ACC makes 6 attempts frequency 125.05
- 16:48:13 to 16:52:07 - Legacy makes 12 attempts using several frequencies (2 attempts freq. 123.30, 1 attempt freq. 133.05 and 8 attempts with other non-identified frequencies)
- 16:53:38 - Brasilia ACC contacts Legacy over the **135.09** frequency. Instructs Legacy to contact Amazon ACC using the 123.32 or 126.45 frequencies. Legacy did not get the numbers.
- 16:56 - The collision

Communication frequencies

Sector	Sector frequencies as presented in the aeronautic chart of the UZ6 airway	Frequencies activated in the workplace 8	Frequencies not activated in the workplace 8
7	123.30 – 128.00 – 133.05 – 135.90 – 121.50	**135.90**	**123.30** – 128.00 – **133.05**
8	122.25 – 125.20 – 135.00 – 121.50	122.25 – 125.20	135.00
9	125.05 – 133.10 – 121.50	122.25 – 133.10	-

In bold N600XL used frequencies

- ACC registered clearly flight 1907's communications over the 125.20 frequency
- Radio system was working properly at that moment, in a *normal* way
- Communications problems were related to frequencies used, not to flaws in radio system

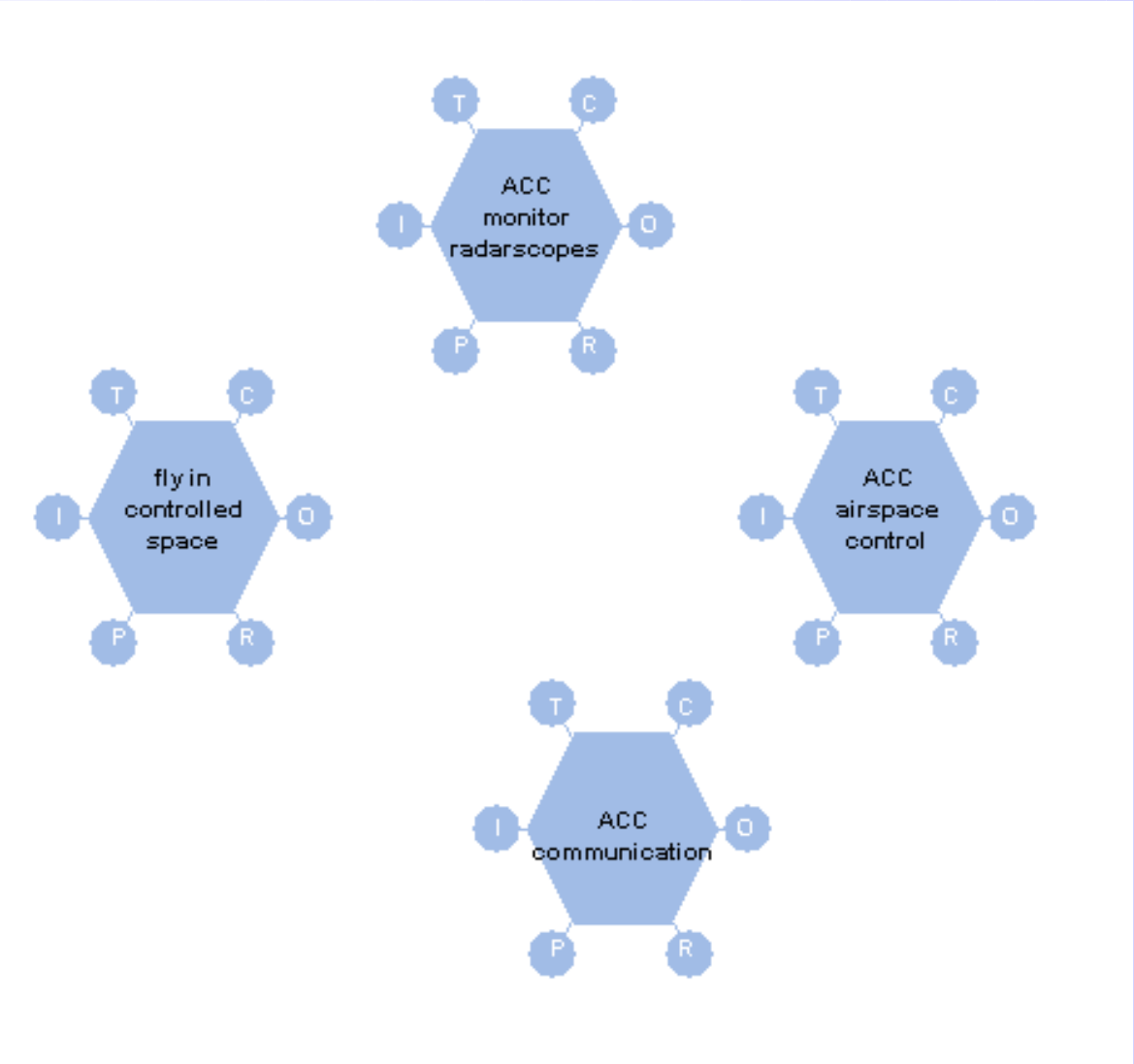
What they said (to perceive and to act)

- Main controller: Before N600XL entered sector 7, he communicated with its crew verifying that it was at level 370 (the correct level at that moment).
- In the period from 18:55 (aircraft entered sector 7) to 19:17 (shift changeover), he perceived the loss of the surveillance radar, but it did not alarm himself. He said he was satisfied with information coming from the primary radar. He informed his relief controller that the N600XL was in the level 360, because he knew about the inaccuracy of the primary radar information and assumed that Legacy was following the flight plan that was displayed in the electronic strips.
- Assistant controller: He perceived that the N600XL did not have complete information on the radar screen, and considered that to be a normal situation. Even being unsure about the aircraft's actual altitude, he coordinated with the Amazon ACC controller the level of 360, based on the electronic flight strip indication.
- Controller after shift changeover: He received the Legacy as being at level 360 and did not query the outgoing controller. He told he had misgivings about the abnormal transponder functioning, and tried 8 times to contact the Legacy.

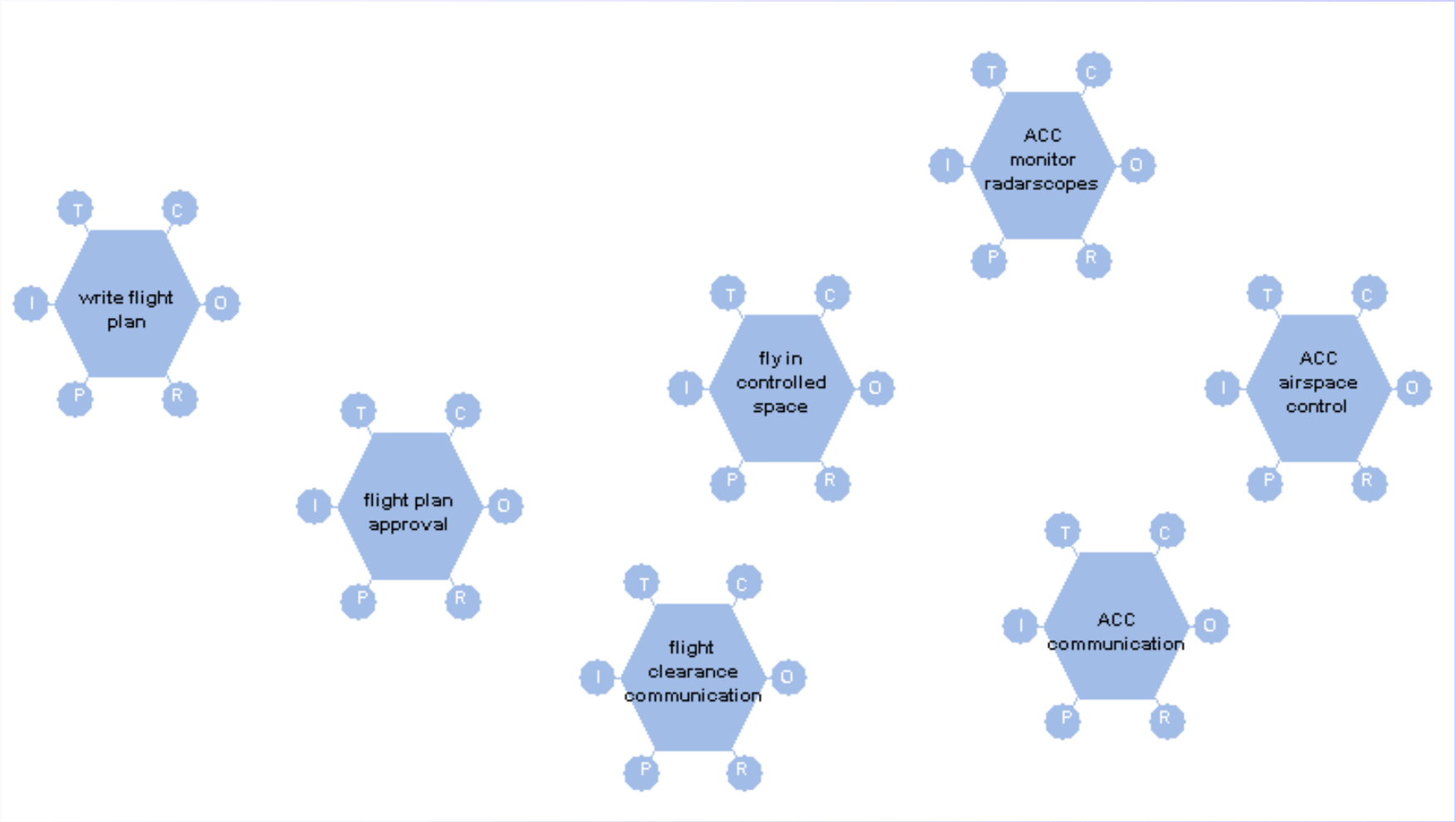
PART 3

The normal system functioning
FRAM in a mid-air collision

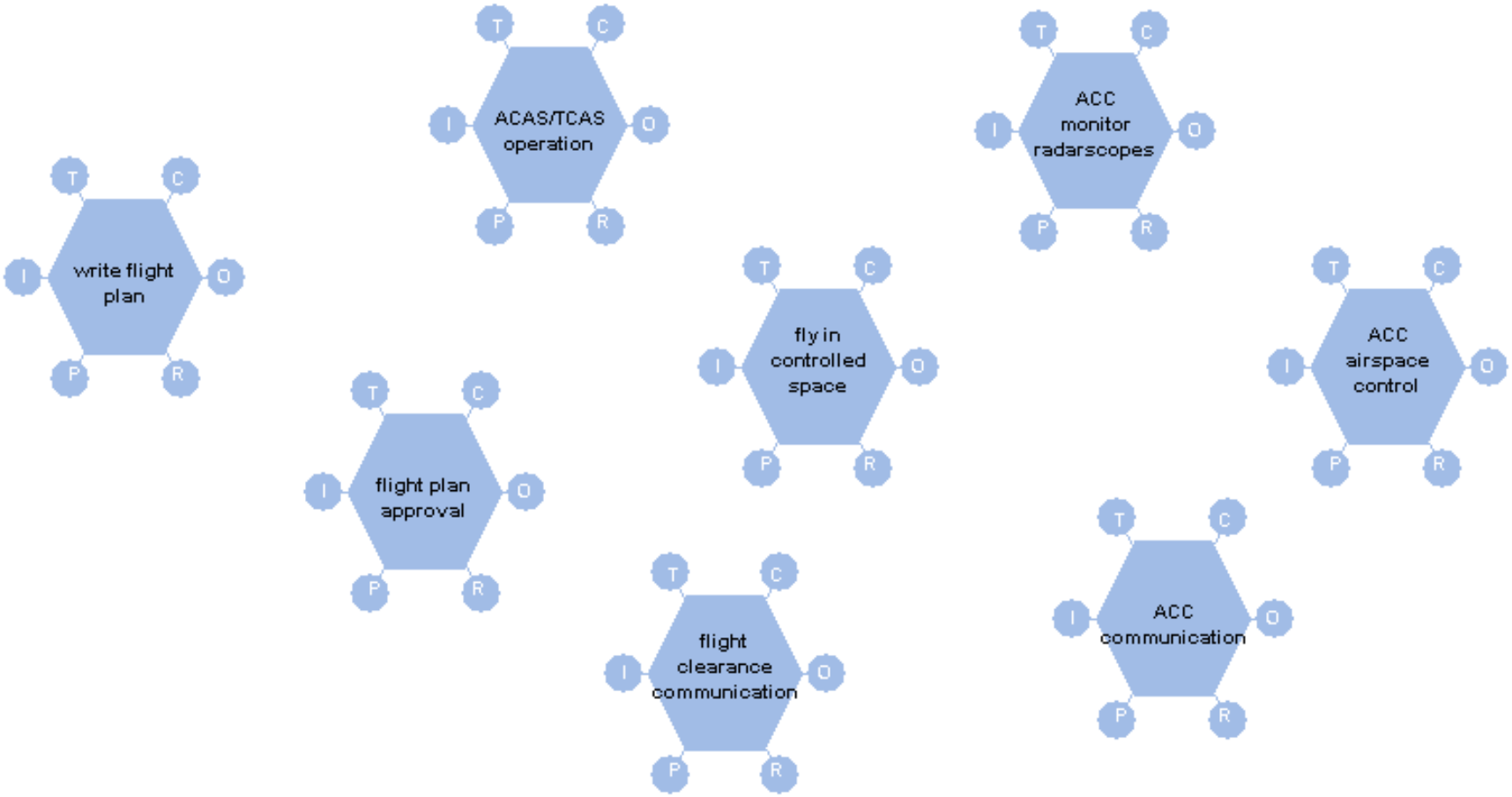
Main functions pilots and ACC controllers



Flight plan elaboration functions companies, pilots and controllers

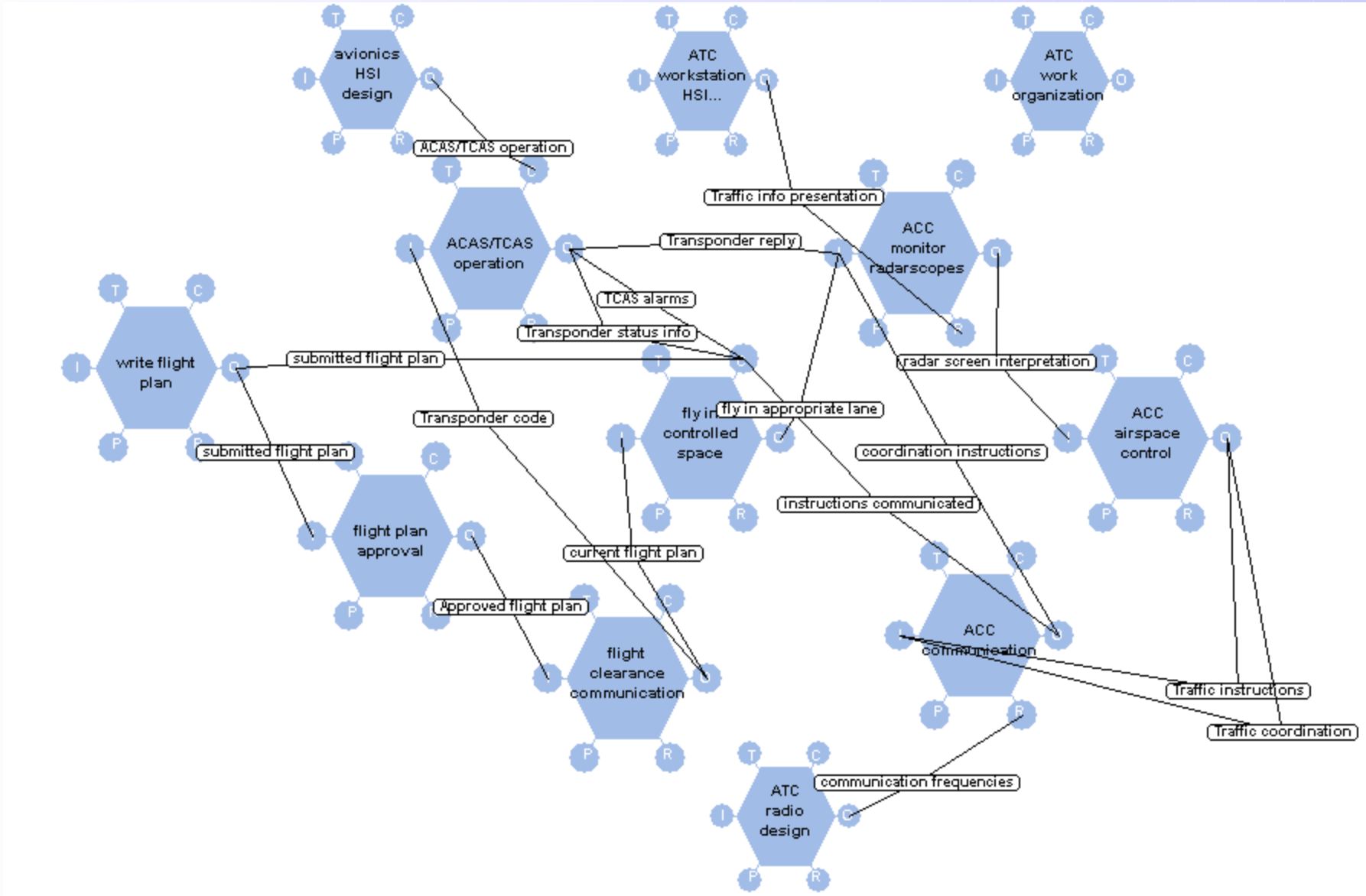


Collision detection functions ACAS/TCAS/transponder

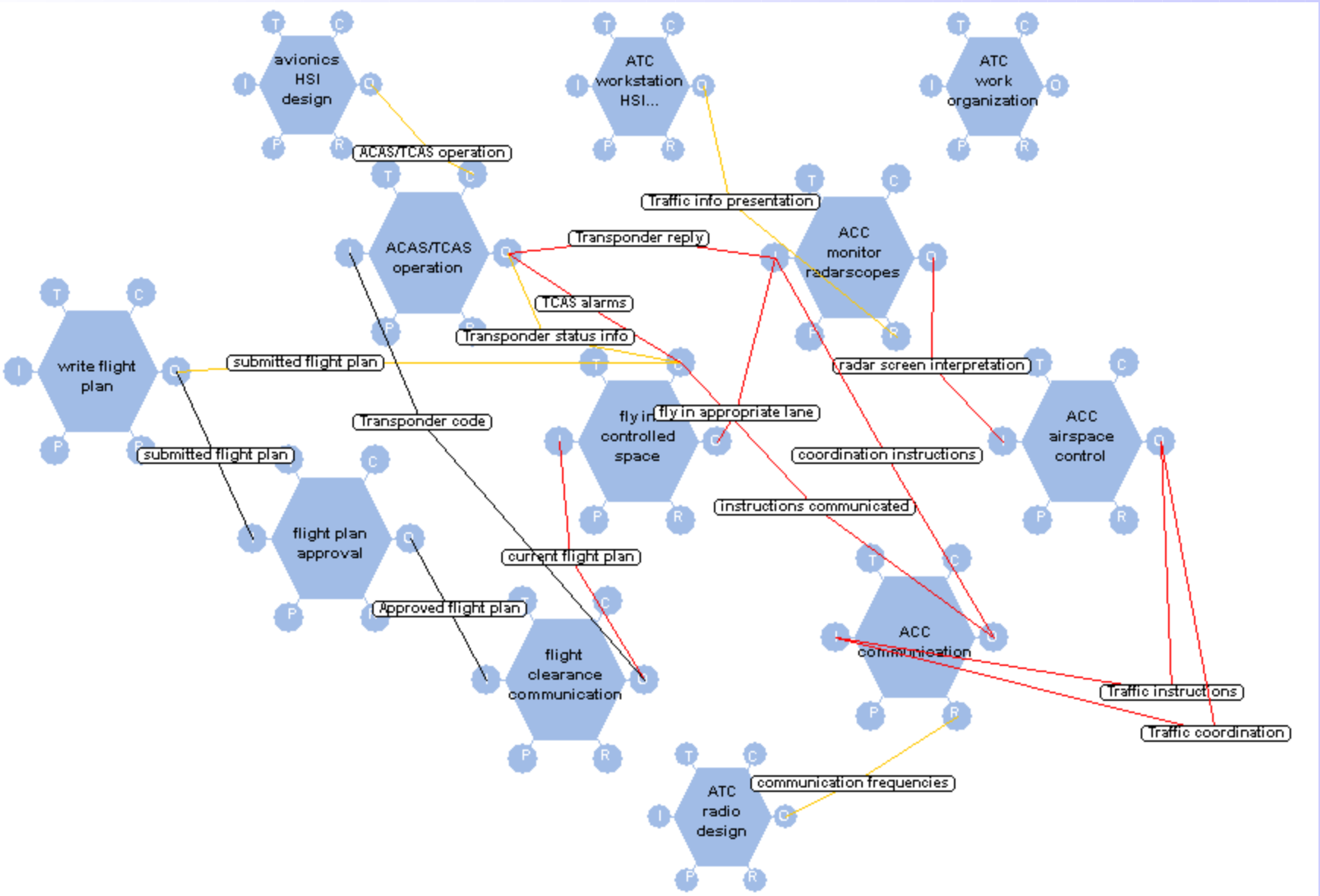


Design functions equipment, organization

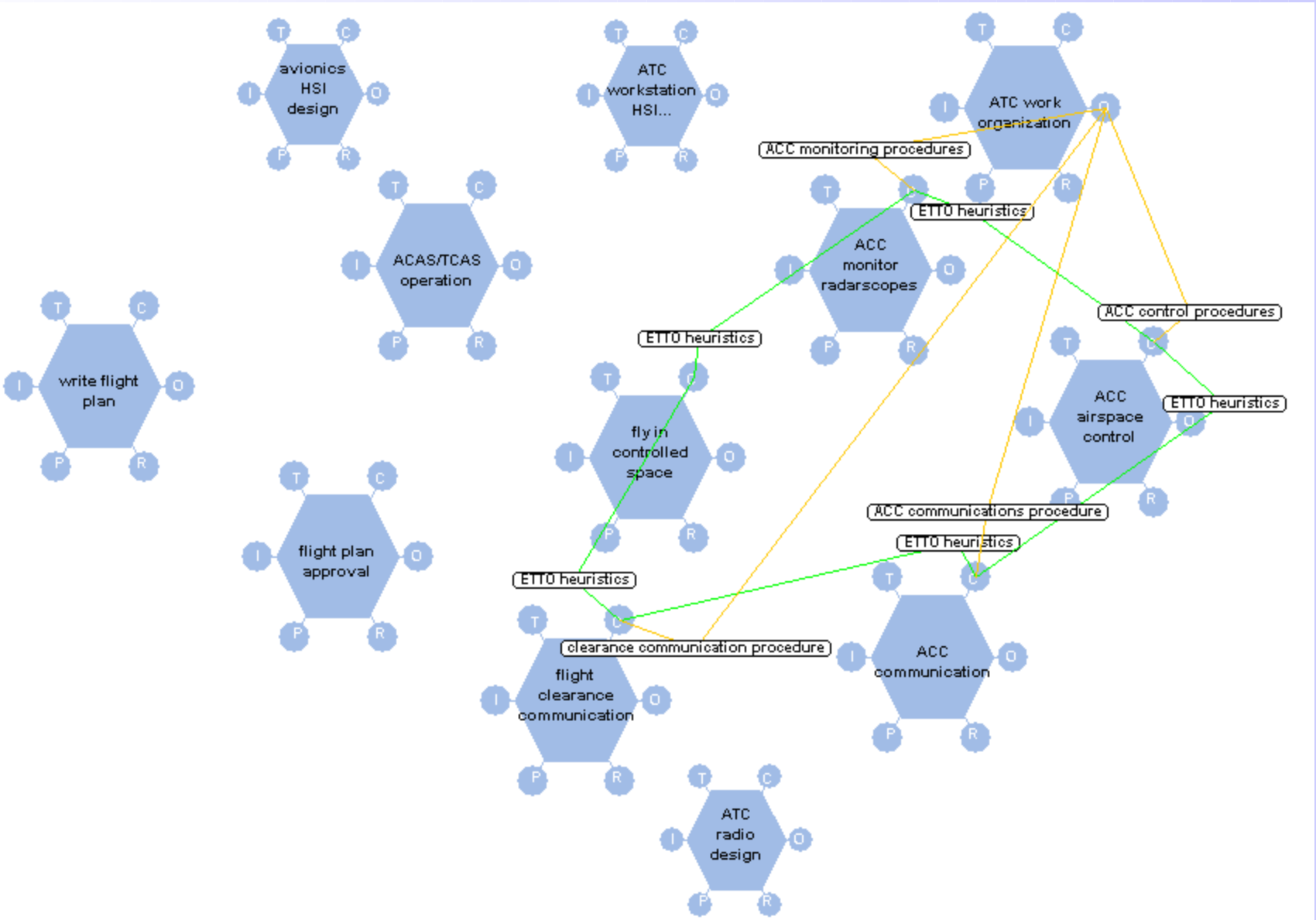
The working system



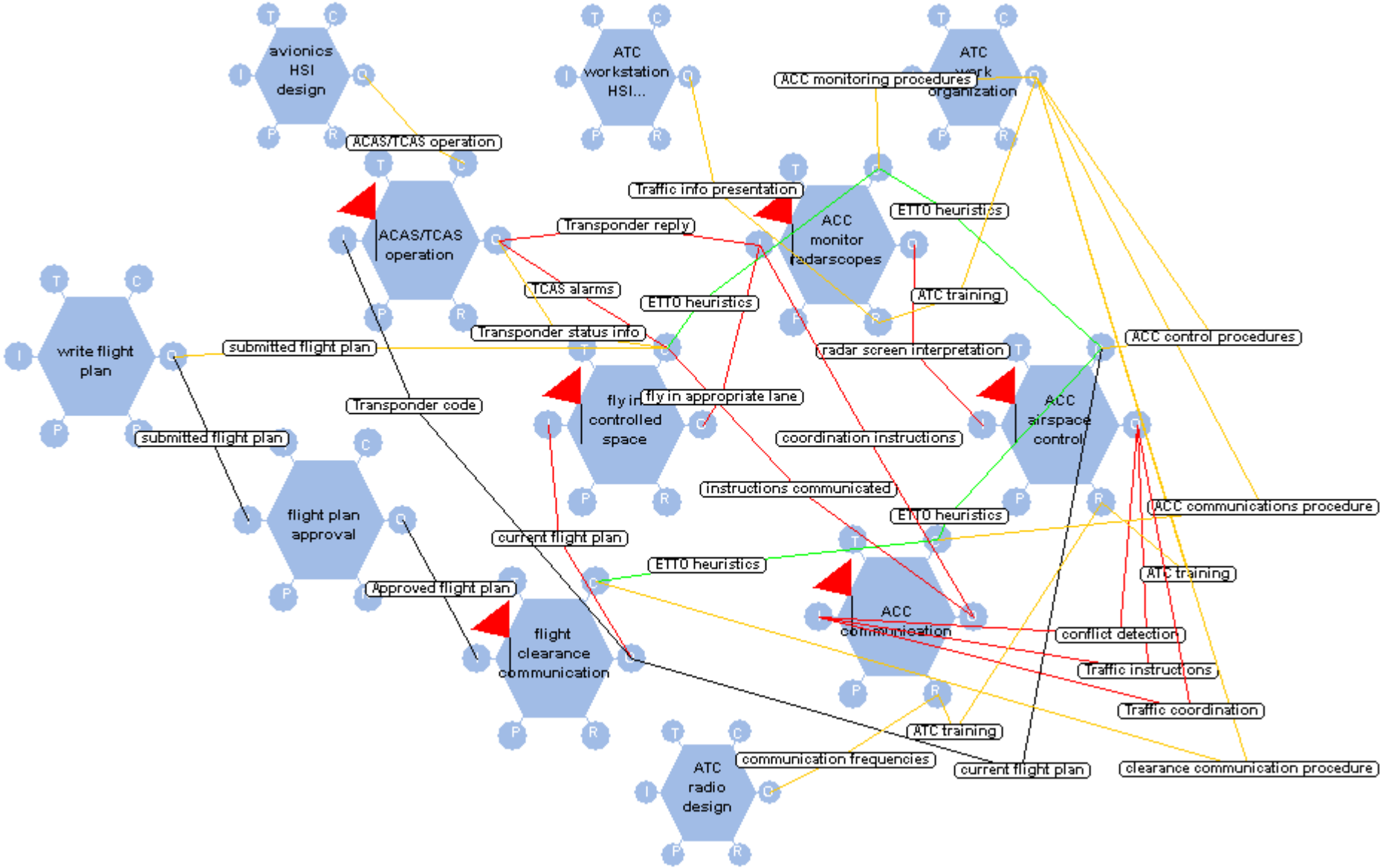
What happened?



How did it happen?



Why did it happen?
Resonance



If there is no seed,
if the bramble of cause, agency, and procedure
does not issue from a fault nucleus,
but is rather unstably perched between scales,
between human and non-human,
and between protocol and judgment,
then the world is a more disordered and dangerous place

Galison, 2000