THE SPEED

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XR-71 N-380RX — FLIGHT TEST 01 — CREW SOUND TRANSCRIPTION

[organization redacted] — [date redacted]

Classification of title: unclassified

The transcript begins at booster separation, at which point the crew-station recorder was switched to the flight-test channel. Instructions were given by the Commander and response was made by the operator to whom the instruction was addressed. Many incidental exchanges of comments occurred between the checklisted items, and have also been included. The crew are listed by function below.

The time in seconds from booster separation is shown next to most of the instructions, responses, and comments. Where no time is indicated, it should be taken for granted that the comment occurred almost at once after the preceding one, or even partly overlapping it.

A set of notes, referenced by number next to the recorded comments, is given following the sound transcription to clarify items which might otherwise be difficult to interpret.

Aircraft	XR-71, registration N-380RX, callsign "November Three Eight Zero Romeo Xray", abbreviated "November Romeo Xray"
Commander (pilot, inlets, navigation)	Senjougahara
Nuclear Operator (both powerplants)	Hanekawa
Joint Operation Controller ("Mustang Control")	Mustang

Crew Sound Transcription

Time	Speaker	Notes	
0	Senjougahara	(1)	Mustang, November Three Eight Zero Romeo Xray, booster separation complete.
	Mustang		November Romeo Xray, copied. Flight level three three zero, Mach one point three.
18	Senjougahara		Nuclear Operator, increase nuclear power until core temperatures of 1900 degrees are reached.
	Hanekawa	(2)	Nuclear power coming up, on a twenty-second period. Both cores.
	Hanekawa		I'd like a mark from you when the temperatures start up.
40	Senjougahara		You can watch your own meters.

Time	Speaker	Notes	
	Hanekawa		I can. I'd still like the mark.
	Senjougahara		Temperatures are increasing very slightly. Both.
54	Hanekawa		L1 and L2 coming up, both. Nothing on L3 yet.
60	Hanekawa		55 percent on L3, one. Two is following.
	Senjougahara		We're getting good power now, Nuclear Operator. Which couple?
74	Hanekawa	(3)	17 on one. 41 on two. 18 reads 700 and doesn't move.
	Hanekawa		Bad couple. Discarding 18.
86	Hanekawa		1800 on 17. Leveling off in power.
91	Hanekawa		Level on 17 at 1900. 41 at 1880, rising slightly. Possibly.
100	Senjougahara		Very good. Mustang, transition to nuclear powerplant complete.
	Mustang		Transition to nuclear powerplant complete, copied.
	Senjougahara		Nuclear Operator, is your temperature holding steady?
	Hanekawa		Holding steady within ten degrees. 1920 on 17.
125	Senjougahara	(4)	440 knots. Through flight level three seven zero. Nuclear Operator, increase power until core temperatures reach 2300 degrees.
	Hanekawa		Increasing power.
	Senjougahara		Stand by to lose some of your thermocouples. It may happen here.
	Hanekawa		I know.
150	Hanekawa		17 is oscillating. Switching control to couple 20 on one. It reads the same as 17 but it's more stable.
	Senjougahara		Right.
164	Hanekawa		2200 both.
	Senjougahara		Give me a mark when you're steady at 2300.
	Hanekawa		Starting to bring power back down to level.
180	Hanekawa		Dropped it a little too much on two.
	Senjougahara		Are you steady?
	Hanekawa		Not steady. Dropping.
192	Hanekawa		Coming back up.
195	Hanekawa	(5)	All right — the temperature is at 2300 at this moment, both cores. And it is level.
205	Senjougahara	(6)	Very good. Through four two zero, Mach one point seven. That's your flux maximum, by the way.
	Hanekawa		I see it. L3 is as high as it's going to be today.
225	Senjougahara		It comes down from here while the temperature stays where it is.
	Hanekawa		I know.
	Senjougahara		Of course you do.

Time	Speaker	Notes	
240	Senjougahara		Four six zero. Mach one point eight. 450 knots, on the schedule. Mustang, confirm you are receiving airframe and powerplant telemetry.
	Mustang		We can watch your meters and we have the data. All of it.
267	Senjougahara		You handle the powerplants. I have the climb and the nav update.
	Hanekawa		Powerplants are mine.
300	Senjougahara	(7)	Five one zero, Mach two. Spikes are moving.
	Hanekawa		Is it supposed to be that loud?
	Senjougahara		Every time. It never gets quieter.
321	Hanekawa		Temperature dropped 40 with the flow change and came back. Following the air.
	Senjougahara		Following the air, copied.
360	Senjougahara		Five six zero, Mach two point three.
365	Hanekawa		We just lost thermocouple 27 on two, looks like.
	Senjougahara		Control?
	Hanekawa		Still on 41. 27 wasn't in the loop. I liked it, though.
420	Senjougahara		Mustang, flight level six one zero, inlets and doors are good. Mach two point six. Over [location redacted].
	Mustang		Flight level six one zero, copied.
440	Senjougahara		Look up.
	Hanekawa		I'm looking at couples.
	Senjougahara		Your couples will wait two seconds. Look up.
455	Hanekawa		It's going dark. It's blue and it's going dark.
	Senjougahara		Above 50,000 the sky is ours. Everyone below it gets the other one.
	Hanekawa		Temperatures and airflow normal.
	Senjougahara		Very good.
480	Senjougahara		Six six zero, Mach two point nine. Nuclear Operator, report temperatures.
	Hanekawa		2300 both. Flux is at 50 percent of what it was at four two zero and going down.
540	Senjougahara	(8)	Seven one zero. Mach three point two.
	Hanekawa		Is that the number?
	Senjougahara		It was the number. For two hundred years this was as fast as she went.
565	Hanekawa		She doesn't seem to notice.
	Senjougahara		She never wanted to stop here. Something else did.
	Hanekawa		The turbojets.

Time	Speaker	Notes	
	Senjougahara		Too much hot air, compressed. It melted the blades. She was always faster than her engines.
594	Hanekawa		And now she's slower than hers.
600	Senjougahara		Seven five zero, Mach three point four.
	Hanekawa		Outside —
	Senjougahara		Yes.
	Hanekawa		It isn't moving. The sea isn't moving. The sun on it is coming with us.
624	Senjougahara		It's doing 2000 knots. That's why.
	Hanekawa		It's as if we came close to stopping time for everyone except us.
	Senjougahara		Speed isn't a thing. It's a relation between things. At 2000 knots the relation goes strange.
650	Hanekawa		I never thought of it that way.
	Senjougahara		You never went this fast.
660	Senjougahara		Mustang, level, flight level seven eight zero, Mach three point five. Proceeding according to the test flight plan, as filed. Heading one five zero.
	Mustang	(9)	Cleared as filed. You don't need to report; we have you on telemetry. We'll be easy on comms so as not to distract you. Next contact prior to deceleration.
	Senjougahara		Copied.
702	Hanekawa		That was kind of them.
	Senjougahara		They're not being kind. They're listening.
	Hanekawa		To what?
	Senjougahara		To this.
721	Hanekawa		Nuclear Operator has a correlation on all meter readings at this level.
	Senjougahara		Very good.
735	Senjougahara		Mach three point five. 2300. Nothing is happening. This is the fastest nothing has ever happened.
	Hanekawa		May I say something not on the card?
757	Senjougahara		You've been saying things not on the card since separation.
	Hanekawa		Then one more. Is this what it's for? Eight minutes of nothing at 2000 knots.
779	Senjougahara		This is what it's for. This is the clean part.
	Hanekawa		Clean.
	Senjougahara		Speed is clean — everything in motion, added up at once. Slowness is unclean — everything tired, at rest, taken apart to see why. A new

Time	Speaker	Notes
		good and a new evil, once the old ones were finished with.
816	Hanekawa	I'm taking things apart. Thirty couples, one at a time.
	Senjougahara	Then you're the unclean part. Someone has to be.
833	Hanekawa	41 is drifting. Two reads 2290 on 41 and 2310 on 33. Which do you want me on?
854	Senjougahara	Whichever you trust.
	Hanekawa	33.
	Senjougahara	33, copied.
865	Hanekawa	And the evil. Who is it, down there?
	Senjougahara	Sunday crowds. Cities where the sun goes down and stays down on them. Lagoons.
885	Hanekawa	That's hard on lagoons.
	Senjougahara	The slow should be persecuted, whipped and tortured. I'd settle for below 50,000 feet.
	Hanekawa	You don't mean that.
907	Senjougahara	I mean the first half.
	Hanekawa	I don't think it's a good and an evil. I think it's a way of knowing things.
	Senjougahara	Go on.
	Hanekawa	It puts distant things next to each other. The field, an hour ago, and this. The cell, and this. Two things that were never in the same place, and you have them both at once, and you compare them, and you find what they share. It does the work of analogy for you. Mechanically. Anyone who goes fast enough gets wit for free.
963	Senjougahara	That's not a correction. That's the same thing.
	Hanekawa	I didn't know that.
	Senjougahara	You just know what you know.
	Hanekawa	I just know what I know.
984	Hanekawa	And what are we, then?
	Senjougahara	We are the speed. Speed is the divine straight line.
995	Hanekawa	Couple 44 on two just went.
	Senjougahara	Control?
	Hanekawa	On 33. That's three.
	Senjougahara	Two. 18 was dead before we started.
1018	Hanekawa	18 counts.

Time	Speaker	Notes	
1100	Senjougahara		One minute to the turn point. Nuclear Operator, in the bank we're going to let her go. I'll want 2700.
	Hanekawa		Twenty-seven hundred.
1160	Senjougahara	(10)	Over the turn point. Initiating the bank, 30 degrees left, maintaining Mach and altitude. Nuclear Operator, monitor your temperatures.
	Hanekawa		Monitoring.
	Hanekawa		Such a strange remark from you, Commander.
	Senjougahara		Which.
1187	Hanekawa		"Monitor your temperatures." As if I had stopped.
	Senjougahara		It's on the card.
	Hanekawa		I know. I read the card.
1220	Senjougahara	(11)	We're in the bank. Mach three point five five, 400 knots, 1.15 G. We are going to let her go as fast as she wants. Nuclear Operator, increase nuclear power until core temperatures of 2700 are reached.
1251	Hanekawa		Nuclear power coming up.
1255	Hanekawa		2500 both.
	Hanekawa		For the record, I have eight hundred degrees in hand above that.
	Senjougahara		And she has none. Twenty-seven hundred.
	Hanekawa		Twenty-seven hundred.
1276	Hanekawa		2650. Leveling.
1280	Hanekawa		Leveling off at 2700 degrees. One on 20, two on 33.
	Senjougahara		Nuclear Operator, hold your temperatures as best you can.
	Hanekawa		All right.
1298	Senjougahara		Mach three point six. 410 knots. We're getting good power now, Nuclear Operator. Do you feel it?
	Hanekawa	(12)	Feel? My face is hot. My nose itches. My ears are doing the thing.
1325	Senjougahara		That's the flux. Nobody without your genome could sit there. An ordinary person would already be on the floor.
	Hanekawa		I did hundreds of hours on these in the cell. I never blushed in the cell.
1352	Senjougahara		The cell had a wall.
	Hanekawa		The cell had a wall. Why do they need us to fly it?
	Senjougahara		They don't trust machines that much. Your couples are analog.
1378	Hanekawa		They're two hundred years old. So is she.
	Senjougahara		The design is. The skin isn't. One day they'll trust a machine enough to give it her. Not today.
1400	Senjougahara		Mach three point eight. 420 knots. Heading zero seven eight.

Time	Speaker	Notes	
1412	Hanekawa		Temperatures 2700 both, holding within ten. Flux is low. I'm holding 2700 on almost nothing.
	Senjougahara	(13)	The sky is doing the work now. The air comes in at 1000 degrees before you touch it.
1441	Hanekawa		Then what am I for?
	Senjougahara		The other seventeen hundred.
	Hanekawa		And the powerplants are for —
	Senjougahara	(14)	Somewhere with air and no oxygen. That's all the card says.
1467	Hanekawa		It isn't on the card at all.
	Senjougahara		Then that's all it doesn't say.
1520	Senjougahara	(15)	Skin thermocouples through 1000. Leading edges 1100.
	Hanekawa		Is that the number?
	Senjougahara		It's the number. She'll willingly go to speeds that harm her. The engines used to stop her. Now nothing does except me.
1551	Hanekawa		And the ratio.
	Senjougahara		And the ratio. You can add 1700 degrees to whatever the sky hands you, and the sky hands you more with every tenth of a Mach. At four she's done. At four and a half she's a glider with a very hot duct.
1586	Hanekawa		So she can't. Even if I gave her the 800.
	Senjougahara		With your 800 she goes to four point four and the leading edges go to 1400 and come off. She can. She'd just be dead.
	Hanekawa		"Willingly."
	Senjougahara		Willingly.
1621	Hanekawa	(16)	Commander, the SAS.
	Senjougahara		Busy. That's normal in the bank.
	Hanekawa		Can it be disengaged for manual flight?
	Senjougahara		No. On my familiarization they asked if I'd like to try Mach three without it. I held her ten seconds. Then the simulator died.
	Hanekawa		Died.
1659	Senjougahara		Crashed. They recorded my face. That was the test.
	Hanekawa		That's unkind.
	Senjougahara		That's the job. Most pilots can't hold her for one second. The speed takes you.
	Hanekawa		The speed.
1700	Senjougahara		Mach three point nine three. Flight level eight zero zero. Heading three five three. 430 knots.

Time	Speaker	Notes	
	Hanekawa		2700 both, holding. Couple 9 on one just went. Control still on 20.
	Senjougahara		Very good.
1760	Hanekawa		It's black up there.
	Senjougahara		It's noon.
	Hanekawa		It's black at noon.
	Senjougahara		The light was there before anything else was. Everything you see, you see because something arrived at the one speed nothing gets to break. So you don't see the world. You see the light's report of it. Late.
1800	Hanekawa		Then what's objective about it?
	Senjougahara		Nothing. It arrives, you accept it. That's the whole contract. Speed is the light of light.
	Hanekawa		You've said that before.
1824	Senjougahara		I read it somewhere.
	Senjougahara		Nuclear Operator. How much time do you need from scram to blowers?
	Hanekawa	(17)	Ten minutes. I don't want to bring her in hotter than that. I've lost four couples. I can't see everything in there.
1857	Senjougahara		No doubt. Ground's going to hate this anyway.
1880	Senjougahara	(18)	Rolling out. Field bearing on the nose, heading three zero two. 520 miles. Mach three point nine eight.
	Hanekawa		2700 both.
1915	Senjougahara	(19)	Mach four point zero. 437 knots. 13 under the placard. Flight level eight zero zero.
	Hanekawa		2700, 2700. Flux at the bottom of the linear range.
1940	Senjougahara		That's all of it. That's everything she has.
	Hanekawa		Thrust equals drag.
	Senjougahara		Thrust equals drag. She'd go faster and she can't.
	Hanekawa		You said nothing stops her except you.
	Senjougahara		Nothing does.
1969	Hanekawa		2700 does. I have 800 in hand and she'd take all of it. Willingly. What's stopping her is me.
	Senjougahara		Hold it there.
	Hanekawa		Holding.
1992	Senjougahara		Placard is 1200 feet under us. One degree of nose is 20 seconds.
	Hanekawa		And up?

Time	Speaker	Notes	
	Senjougahara		Up, she slows. Up is free. Faster she can't, higher she can't, and lower is the placard. Down is the only one that's quick.
2026	Hanekawa	(20)	So this is her coffin corner.
	Senjougahara		Nothing's stalling. Otherwise yes.
	Hanekawa		How do you hold one degree at Mach four?
2046	Senjougahara		I don't. She does. I hold her.
2075	Hanekawa	(21)	Commander.
	Senjougahara		Yes.
	Hanekawa		At the beginning it was about getting from one place to another. Space. Now it isn't.
	Senjougahara		Now it's time. Speed is how you handle time. You take a piece of it that wasn't yours.
2107	Hanekawa		How we fight time.
	Senjougahara		How we beat it. Time kills everyone. Speed is the only thing anyone found that does anything to it.
	Hanekawa		And it has a price.
2132	Senjougahara		Everything you are, on the controls, or you die. That's the price. There's no smaller coin.
	Hanekawa		The remedy for death costs the risk of death.
2152	Senjougahara		Yes. Isn't that funny.
	Hanekawa		You're not laughing.
	Senjougahara		No.
2164	Senjougahara		Knowing you can go faster than what your body and your mind were made for — it's peace. A particular kind. I sit here with her in my hands and I think: I wonder how fast I can go without dying.
	Hanekawa		Senjougahara-chan.
	Senjougahara		Nuclear Operator.
2197	Hanekawa		Correction. Commander. You're fighting something that's built into everything. It doesn't lose.
	Senjougahara		I know.
	Hanekawa		We're wired to enjoy exactly the things that finish us. A warrior poet said that.
	Senjougahara		Which one.
2225	Hanekawa		I don't know everything. I just know what I know.
2233	Senjougahara		Hanekawa. Planning the normal descent at 350 knots, stand by.
2240	Senjougahara		Mustang, November Romeo Xray, prior to deceleration.

Time	Speaker	Notes	
	Mustang		November Romeo Xray, go ahead.
	Senjougahara		Deceleration in 60 seconds. Scram at Mach three point two, flight level seven eight zero, approximately 110 miles. We'll want the airspace from there to the field and the blower teams at the end of the rollout.
2279	Mustang		Copied. Airspace is yours from 120 miles. Blower teams are staged.
	Senjougahara		Copied.
2300	Senjougahara		Nuclear Operator, decrease temperature to 1900 degrees.
	Hanekawa		Temperature coming down.
2315	Hanekawa		100 degrees down.
	Hanekawa		Two hundred down.
	Senjougahara	(22)	Opening the forward bypass doors.
	Hanekawa		What is that?
2332	Senjougahara		Air. Going overboard. It makes drag, and drag is all we have.
2340	Hanekawa		I'm leveling at 1900 degrees. Both.
	Senjougahara		Very good.
2360	Senjougahara		Mach three point eight. She still doesn't want to slow down.
	Hanekawa		Decrease to 1500?
	Senjougahara		Decrease to 1500. Let it drift.
2382	Hanekawa	(23)	All right, I'll let it drift downward. It's slow. The rod's in as far as I'm going to put it until scram. Any faster and I'm out of phase with it.
2420	Senjougahara		Mach three point six. 400 knots.
	Hanekawa		1500 on the left. Right is at 1540 and drifting. And that's about the floor for now.
	Senjougahara		Floor?
2446	Hanekawa	(24)	The air comes in at 900 and something. I can't take a core below the air. Until you slow down there is nothing I can do below that.
2467	Senjougahara		Then I'll slow down.
	Hanekawa		Please.
2480	Senjougahara		Mach three point four. Decrease to 1300.
	Hanekawa		1300. It's following the air more than me now.
2510	Senjougahara		Mustang, November Romeo Xray scramming and transitioning to glide in 30 seconds.
	Mustang		Scram and transition to glide in 30 seconds, copied.
	Senjougahara		Nuclear Operator, on my mark.
	Hanekawa		Ready.

Time	Speaker	Notes	
2535	Senjougahara		Three. Two.
2540	Senjougahara		Scram.
	Hanekawa		Scram.
	Hanekawa		Reactors are scrammed. Both rods in.
2546	Senjougahara		Reactors are scrammed. Mach three point two, 365 knots, transitioning to glide, 350. Confirm the cores are cooling.
	Hanekawa		Flux falling — L3 off scale low, L2 going. Cores are cooling.
2571	Hanekawa		1300, 1100, 950. She'll hold at the air. 750 and something. Then only as you slow.
	Senjougahara		Copied.
2589	Senjougahara		Now she's an airplane.
2600	Senjougahara		Six eight zero. Mach two point seven five.
	Hanekawa	(25)	Cores at 540, holding with the air. Decay heat under a megawatt each, estimated. I don't have a meter for it.
	Senjougahara		Copied.
2627	Senjougahara	(26)	Spikes moving forward. Doors full open.
	Hanekawa		What are these noises? I never heard them any other time.
	Senjougahara		Air dumping. The doors, then the spikes coming forward as she slows. She only makes these coming down.
2652	Hanekawa		It sounds like she hates it.
	Senjougahara		She does.
2660	Senjougahara		Five seven zero. Mach two point one. Sink 12,000.
	Hanekawa		There's no go-around procedure.
	Senjougahara		There's no air restart.
2680	Hanekawa		I could bring them back critical in —
	Senjougahara	(27)	And then? You need air through them. Half a Mach at the inlet, at least. Below two five zero she can't make it and I can't dive her to it.
	Hanekawa		Nobody tried.
2712	Senjougahara		Nobody tried in real life.
2720	Senjougahara		Four five zero. Mach one point four five.
	Hanekawa		So we're frigate birds. We can stay up forever and we can't take off on our own.
2741	Senjougahara		Frigate birds. So don't miss.
	Hanekawa		You don't miss.
	Senjougahara		I don't miss. If I do, we eject and she goes in the sea.
2761	Hanekawa		That would be a waste.

Time	Speaker	Notes	
	Senjougahara		It would be a waste.
2780	Senjougahara	(28)	Subsonic. Three three zero, 340 knots. Sink 13,000.
	Hanekawa		She's quieter.
	Senjougahara		She's a brick. A quiet one.
2840	Senjougahara		Two zero zero. Mach point seven four.
	Hanekawa		Cores at 40 and the air. Residual generation is low enough that an interruption in airflow could be tolerated.
	Senjougahara		Sweet.
	Hanekawa		"Sweet."
2867	Senjougahara		It's on the card.
	Hanekawa		It is not on the card.
2900	Senjougahara		Mustang, November Romeo Xray, 10,000, 13 miles, 340 knots. Committed to land.
	Mustang		November Romeo Xray, radar contact. Airspace is yours. Blower teams at the end of three zero. Cleared to land.
2926	Senjougahara		Cleared to land.
2940	Senjougahara		Bleeding to 250.
2980	Senjougahara	(29)	Three thousand. Gear down. Leading-edge bleed on.
	Hanekawa		The nose is high.
	Senjougahara		Twelve degrees. She lands with her nose in the air and her pilot looking at the sky. You get used to it.
3009	Hanekawa		I can see the runway.
	Senjougahara		Good. Tell me if it moves.
3020	Senjougahara		Long final. Runway in sight. 250.
3040	Senjougahara		Short final. 200. With 200 knots on final there's not much opportunity for last-minute corrections, so I'm not going to make any.
	Hanekawa		Temps and airflow within specs.
	Senjougahara		Very good.
	Hanekawa		Commander.
	Senjougahara		Not now.
3070	Senjougahara	(30)	Touchdown.
3072	Senjougahara		Chute.
	Hanekawa		Chute's out. I felt it.
	Senjougahara		Nuclear Operator, report temperatures.
	Hanekawa		Temperatures coming up slightly. 60, 70. It's the air slowing down, not the cores.

Time	Speaker	Notes	
3096	Senjougahara		Report airflow through the cores.
	Hanekawa		Airflow through the cores decreasing with speed. Still positive.
3110	Senjougahara		Rollout complete. Chute jettisoned. Exiting the runway. Blower teams in sight. Mustang, November Romeo Xray clear of the active.
	Mustang		Clear of the active, copied.
3140	Senjougahara		Fast taxi, 90 knots.
3230	Senjougahara		Blower station. Stopping. Brakes are hot. Everything is hot.
	Mustang		Blower teams have you. Hold position.
3290	Hanekawa	(31)	Blowers on. Airflow through both cores. Cores at inlet plus a few degrees and going nowhere.
	Senjougahara		Very good.
	Senjougahara		Do we have time for a couple of comments here?
	Hanekawa		Yes.
3319	Senjougahara		It looks like our maximum was Mach four point zero, 437 knots at flight level eight zero zero. Core temperatures 2700, 2710 max. Leading edges 1100. 51 minutes from separation to touchdown.
3348	Hanekawa		Four couples lost. 27, 44, 9, and 18 was dead before we started.
	Senjougahara		Very good. Very, very good.
	Senjougahara		So was it fun?
3371	Hanekawa		Fun would not be the first word I'd use. Intense, maybe. Cerebral.
	Senjougahara		Hanekawa. The beer is on me.
	Hanekawa		Correction: Nuclear Operator. And jellyfish jerky.
3393	Senjougahara		Good meat makes the worries go away.
	Hanekawa		Someone said that.
	Senjougahara		A con man.
3408	Mustang		November Romeo Xray, Mustang. Let's knock off the unnecessary chatter. We're not through yet.
	Senjougahara		Copied.
	Hanekawa		Copied.

[End of transcription.]

Notes for Transcription

(1) The aircraft is registered N-380RX and was called by its full callsign, "November Three Eight Zero Romeo Xray", on first contact after separation and by the abbreviated "November Romeo Xray" thereafter. The transcript starts at booster separation, at which point the aircraft was at Mach 1.3, flight level 330, 437 KEAS, approximately 25 nautical miles from the field on a heading of 150°. Both reactors had been brought critical during the booster burn (about 90 seconds before separation) and were idling at a core temperature of 1500 °F, so that the powerplants were producing thrust at the moment of separation. A ramjet produces no useful thrust below an inlet Mach number of about 0.5; the boosters exist to get past that.

(2) "Period" is the reactor period, the time for the neutron level to increase by a factor of e. L1, L2 and L3 are the three ion-chamber channels displayed to the Nuclear Operator for each reactor, covering successive ranges of neutron level. The Nuclear Operator has no direct indication of thermal power in megawatts; power is inferred on the ground from airflow and temperature rise.

(3) The reactors are No. 1 (left) and No. 2 (right), numbered as engines are; the Commander says "left" and "right", the Nuclear Operator "one" and "two". Thermocouples are numbered per reactor. Several dozen are installed in each core; the Nuclear Operator selects one as the control couple for each reactor and changes it when it becomes noisy or fails. Couple 18 on No. 1 was found stuck at 700 °F before the flight and was carried as a known failure. Losses during the flight: 27 (No. 2, 365 s), 44 (No. 2, 995 s), 9 (No. 1, 1700 s).

(4) The airspeed indicator at both crew stations reads knots equivalent airspeed (KEAS) — airspeed corrected to sea-level density, the quantity the airframe is limited on — and every airspeed spoken in the transcript is that figure; the crew say "knots" and never qualify it, as the original airframe's crews did not. The placard is 450 KEAS. The climb was flown on a 450 KEAS schedule, in which altitude leads Mach number: Mach 1.6 at flight level 410, Mach 2.5 at 600, Mach 3.2 at 710.

(5) Peak fission power of the flight was reached here: about 238 MW per reactor, 476 MW for the pair, at 195 s — the moment the cores arrived at 2,300 °F at Mach 1.7 / flight level 420, the densest air flown at that core temperature. The pair together were then producing more than a single Tory II-C demonstrated in 1964 (461 MW) and 93 % of its rating. From this point the power needed to hold temperature fell continuously: about 220 MW per reactor at 240 s, 100 at 540 s, 70 in cruise, and 76 at Mach 4.0 with the cores 400 °F hotter (note 6).

(6) Fission power required to hold a given core temperature is proportional to mass flow through the core, and mass flow falls with altitude faster than it rises with Mach number. The flux maximum of the flight therefore occurred at Mach 1.7 / flight level 420 (note 5), and the reading fell continuously thereafter while core temperature was held constant; at Mach 4 / flight level 800

the estimate is about 76 MW per reactor.

(7) The inlet spikes and bypass doors are scheduled by an analog computer from inlet pressure ratios, as in the original airframe. Spike translation begins at about Mach 1.8 and is accompanied by a change in duct noise. The temperature dip at 321 s is the core following the airflow change, and is normal.

(8) Mach 3.2 was the original airframe's operational limit. The limit was set by compressor inlet temperature — the stagnation temperature of the air entering the turbojets — and not by the airframe. The same quantity limits the XR-71; see note 13.

(9) Mustang Control's decision to withhold routine calls during cruise was planned, on the grounds that telemetry made them unnecessary and that the crew's attention at flight level 780 was better spent elsewhere. It has the effect of leaving the crew alone on the channel for twenty-six minutes.

(10) A 30° bank gives a load factor of 1.15 at any speed; the turn radius is about 105 nautical miles at Mach 3.5, about 135 at Mach 4. Flown accelerating between the two, the turn averaged about 120 nautical miles of radius and covered about 430 nautical miles of arc through 208° — rather than 180°, so that the roll-out heading pointed directly at the field. It took 12 minutes. A steeper bank would have added induced drag and cost speed; the bank angle was chosen so that the aircraft could accelerate through the turn.

(11) 2700 °F is the test-card limit for this flight. It is an airframe number: at 2700 °F level flight is possible at Mach 4.0 / flight level 800, where the 450 KEAS placard and the leading-edge temperature limit are reached together. The core itself is rated to 3500 °F continuous; the Nuclear Operator's "eight hundred in hand" refers to this margin.

(12) The crew are synthetic, engineered for tolerance of the neutron and gamma flux from two unshielded reactors some fifteen metres behind the crew station. Flushing, pruritus of the nose and involuntary movement of the ears are reported by both crew members as reliable indications of high flux and are not considered abnormal. An unmodified human in the crew station would have been incapacitated within minutes at cruise power. G tolerance is not enhanced.

(13) The stagnation temperature of the incoming air is $T_0 = T_{ambient} \times (1 + 0.2\ M^2)$: about 909 °F at Mach 3.5, 1211 °F at Mach 4.0, 1622 °F at Mach 4.6. Thrust per kilogram of air is proportional to $\sqrt{(T_{core} / T_0)} - 1$, and the kilograms of air per second fall with altitude; drag, for an aircraft that must lift its own weight, does not — it stays near the weight divided by the lift-to-drag ratio. So the core temperature needed to hold a given Mach number rises with altitude, and at a given altitude rises steeply with Mach: at flight level 800 level flight needs about 2,260 °F at Mach 3.5, 2,700 at Mach 4.0, 2,850 at Mach 4.2 and 3,000 at Mach 4.4 — of which only the first two are under the 450-knot placard. The Commander's figures from 1440 s to 1590 s (seventeen hundred, four point four, fourteen hundred) are from the card.

(14) The purpose of the test program is not stated on the test card. A nuclear ramjet requires an atmosphere as working fluid but no oxygen; the Commander's remark here is the only indication in the record.

(15) Skin thermocouples are read at the crew station. Leading-edge stagnation temperature at Mach 3.85 is about 1117 °F; at Mach 4.0, 1211 °F. The original airframe's titanium was limited to about 1000 °F; the XR-71's leading edges are in a refractory composite carrying a 1200 °F limit.

(16) Stability augmentation system. At this speed the aircraft is operating at the edge of the control loop, the regime where the rate at which the world changes approaches the rate at which the operator can track it. The augmentation closes the loop the pilot cannot, and manual reversion is not provided. ---

(17) Decay heat depends on the power history, not the peak: the flight ran 42 minutes at an average of roughly 190 MW (both reactors) but the last four minutes before scram at about 55 MW, and the short-lived fission products that dominate the first minutes after shutdown remember those four minutes. Integrated over the record, decay heat is estimated at 2.4 MW (both reactors) at scram plus 10 seconds, 1.7 MW at plus 1 minute, 1.0 MW at plus 5 minutes and 0.7 MW at plus 10 minutes; a constant-power estimate would give roughly twice these figures. Either way it would raise the temperature of a core with no airflow by only a few degrees per minute. The ten-minute requirement stated by the Nuclear Operator is therefore procedural: with several in-core thermocouples lost, local temperatures could not be verified, and the card requires a margin before airflow is interrupted for the transfer to ground blowers.

(18) Distance to the field at roll-out was 520 nautical miles. Cruise altitude had been allowed to rise from flight level 780 to 800 during the turn.

(19) At Mach 4.0 / flight level 800 / 437 KEAS the powerplants at 2,700 °F produce thrust approximately equal to drag: about 15,000 lbf for the pair against 84,000 lb at a lift-to-drag ratio of 5.6. The incoming air is at 1,211 °F, the cores at 2,700 °F, and the 166 kg/s both inlets capture leaves roughly 400 m/s of velocity increment after losses, no more. 2,700 °F is therefore the least core temperature that holds Mach 4.0 at this altitude, and flight level 800 is the lowest altitude at which Mach 4.0 is under the 450-knot placard (at flight level 750 it would be 493 knots): the three numbers on the card set each other. Fission power to hold the condition is about 76 MW per core. The placard lies about 1,270 ft below; at 2,317 knots true airspeed one degree of nose-down pitch is some twenty seconds to it, with surplus thrust on the way down. The condition was held for about six and a half minutes.

(20) "Coffin corner" is the aviator's term for the altitude at which an aircraft's low-speed limit and its high-speed limit meet — the stall speed, rising with altitude in indicated terms, and the Mach limit, falling — so that there is no speed at which it can be flown. The XR-71's corner at Mach 4 is not aerodynamic in that sense; nothing stalls. It is the meeting of two other limits. The 450-knot

placard sets the lowest altitude at which Mach 4 may be flown: flight level 800, at 437 knots. The 2,700 °F card limit sets the highest altitude at which Mach 4 can be sustained: also flight level 800, where thrust equals drag with about 3 °F of core temperature in hand (note 19). The permitted band for the test point is therefore one flight level wide. Above it she cannot hold speed; below it she exceeds the placard; no altitude within the placard allows more speed. Only slowing down has margin.

(21) No speech was recorded from about 2050 s to 2075 s. Telemetry shows no change in any parameter during this interval.

(22) The XR-71 has no flaps, spoilers or speed brakes. The only means of adding drag in flight is to open a bypass door and spill inlet air overboard; this is a technique inherited from the original airframe's crews. With the doors open and the cores at 1900 °F the deceleration from Mach 4.0 to 3.2 took about four minutes and 140 nautical miles.

(23) The Nuclear Operator's comments here refer to the control rods, which are driven hydraulically from the demand levers and are slow. At low demand the reactor is far subcritical and the neutron level is held up by delayed neutrons; small changes in the rate at which the demand lever is moved are met by large rod excursions. She chose to let the temperature drift down rather than chase it, and to complete shutdown with the scram rod.

(24) The core cannot be cooled below the stagnation temperature of the incoming air by any rod position, since the air is what cools it. At Mach 4 that floor is about 1211 °F; at Mach 3.2, about 750 °F. Once the reactors are scrammed the core drops to this floor (plus about 10 °F of decay heat at the airflow then obtaining) with a time constant of about 17 seconds, and thereafter follows the airplane's speed down.

(25) See note 17. The Nuclear Operator's estimate is from the card.

(26) With engine air dumped overboard and the spikes translating forward as the aircraft slows, the original airframe made noises its crews described as heard at no other time. The XR-71 does the same.

(27) A restart in flight would require the cores critical and an inlet Mach number of at least 0.5 with the aircraft in an attitude the inlets can use. Below about flight level 250 neither the altitude nor the airspeed to achieve this in a dive is available. The aircraft is therefore committed to land from the scram onward. The emergency procedure for a missed approach is ejection; the aircraft is to be scuttled at sea.

(28) The original airframe's windmilling descent from flight level 800 and Mach 3.2 to 10,000 feet took slightly over six minutes and 102 nautical miles at 375 KEAS, an average of about 11,600 feet per minute. The XR-71's cold ducts are comparable. Subsonic, at 340 knots and about 5:1 with no thrust at all, the sink rate is still 12,000–13,000 feet per minute at flight level 330 and about 8,000

at 10,000 feet; the original airframe's 6,000 feet per minute subsonic was with two engines at idle.

(29) The leading-edge boundary-layer control is bleed air blown over the leading edge and is fitted for approach stability. At 84,000 pounds — the aircraft lands at its take-off weight, having burned no fuel — approach speed is 200 KEAS and touchdown about 175, at an angle of attack near twelve degrees. The original airframe, at 60,000 pounds, used 175 and 155.

(30) Touchdown at 3070 s, 51 minutes 10 seconds after separation, 8 minutes 50 seconds after scram. Drag chute deployed at 3072 s and jettisoned at the end of the roll.

(31) Blowers on at 3290 s, 12 minutes 30 seconds after scram, against the ten-minute requirement of note 17. Ground blowers will run for several days.