
NASA

1
00:00:02,201 --> 00:00:03,436
[light mellow music]

2
00:00:03,469 --> 00:00:06,606
>> Announcer: NASA's Jet
Propulsion Laboratory presents

3
00:00:06,639 --> 00:00:08,007
the von Karman Lecture.

4
00:00:08,040 --> 00:00:11,077
A series of talks by
scientists and engineers

5
00:00:11,110 --> 00:00:13,246
who are exploring our planet,

6
00:00:13,279 --> 00:00:16,883
our solar system, and
all that lies beyond.

7
00:00:26,959 --> 00:00:28,428
>> Good evening,
ladies and gentlemen.

8
00:00:28,461 --> 00:00:29,962
How is everyone doing tonight?

9
00:00:29,995 --> 00:00:32,899
[attendees applauding]

10
00:00:32,932 --> 00:00:35,935
Well, as always, thank
you very, very much

11
00:00:35,968 --> 00:00:37,937
for coming out to
join us tonight.

12
00:00:37,970 --> 00:00:42,241
Tonight, as NASA celebrates
its 60th anniversary this year,

13
00:00:42,274 --> 00:00:44,110
we will be discussing
how robots have played

14
00:00:44,143 --> 00:00:46,913
an integral part in
space exploration.

15
00:00:46,946 --> 00:00:50,083
From America's very first
satellite, Explorer 1,

16
00:00:50,116 --> 00:00:53,052
to two tiny CubeSats currently
on their way to Mars,

17
00:00:53,085 --> 00:00:55,688
all built right here at JPL.

18
00:00:55,721 --> 00:00:58,324
The first of two panels will
focus on major milestones

19
00:00:58,357 --> 00:01:00,793
in robotic exploration.

20
00:01:00,826 --> 00:01:02,795
What it took to reach
those accomplishments,

21
00:01:02,828 --> 00:01:05,031
how far we've come
and how spacecraft

22
00:01:05,064 --> 00:01:07,166

have changed over the years.

23
00:01:07,199 --> 00:01:08,267
The second panel will focus

24
00:01:08,300 --> 00:01:10,002
on robotic spacecraft
developments

25
00:01:10,035 --> 00:01:12,572
we might expect to see in
the next couple decades

26
00:01:12,605 --> 00:01:14,640
and what different
demands we will be placing

27
00:01:14,673 --> 00:01:18,044
on those spacecraft as we
look to explore new worlds.

28
00:01:18,077 --> 00:01:19,178
So, ladies and gentlemen,

29
00:01:19,211 --> 00:01:20,680
to host our panel tonight,

30
00:01:20,713 --> 00:01:23,649
please help me welcome JPL
Public Outreach specialist,

31
00:01:23,682 --> 00:01:25,518
Mr. Preston Dyches.

32
00:01:25,551 --> 00:01:28,788
[attendees applauding]

33
00:01:34,026 --> 00:01:35,361
>> Well, hello, everybody.

34
00:01:35,394 --> 00:01:37,330
Thank you for being here.

35
00:01:37,363 --> 00:01:39,765
We're here to
celebrate a birthday.

36
00:01:39,798 --> 00:01:42,301
The National Aeronautics
and Space Administration

37
00:01:42,334 --> 00:01:44,570
is turning 60 this year.

38
00:01:44,603 --> 00:01:48,174
NASA began operations
on October 1st, 1958.

39
00:01:49,642 --> 00:01:53,079
Now, there are a lot of
incredible accomplishments

40
00:01:53,112 --> 00:01:55,348
we could celebrate
in NASA's history,

41
00:01:55,381 --> 00:01:58,651
but our program
tonight is to celebrate

42
00:01:58,684 --> 00:02:00,753
the role of the robots.

43
00:02:00,786 --> 00:02:03,756
That is the robotic or
automated spacecraft

44
00:02:03,789 --> 00:02:05,892

that we send on
uncrewed missions,

45
00:02:05,925 --> 00:02:07,927
that is without people on board,

46
00:02:07,960 --> 00:02:09,629
to study our home planet

47
00:02:09,662 --> 00:02:12,598
and to explore our
solar system and beyond.

48
00:02:12,631 --> 00:02:16,936
Now, automated spacecraft
extend our senses.

49
00:02:16,969 --> 00:02:19,772
Robots go where humans can't go

50
00:02:19,805 --> 00:02:23,409
or can't go because it's
too risky or can't go yet.

51
00:02:23,442 --> 00:02:25,912
And robots don't
have to come back,

52
00:02:25,945 --> 00:02:30,116
although, occasionally,
a few of them do.

53
00:02:30,149 --> 00:02:32,251
In the first part of our
show, we will hit a few

54
00:02:32,284 --> 00:02:34,554
of the milestones in
robotic exploration

55
00:02:34,587 --> 00:02:36,923
and reflect on
how far we've come

56
00:02:36,956 --> 00:02:39,058
and join us for the
second part as well

57
00:02:39,091 --> 00:02:40,660
where we'll take a look forward.

58
00:02:40,693 --> 00:02:42,161
So to get started,

59
00:02:42,194 --> 00:02:44,964
let's bring on a couple
of engineers here

60
00:02:44,997 --> 00:02:47,300
who have had their
hands in a slew

61
00:02:47,333 --> 00:02:49,268
of different robotic
missions over the years.

62
00:02:49,301 --> 00:02:52,405
Please welcome Julie
Webster and Rob Manning.

63
00:02:52,438 --> 00:02:55,642
[attendees applauding]

64
00:02:57,243 --> 00:02:58,044
Hey!

65
00:03:02,214 --> 00:03:03,015
>> Rob: All right.

66
00:03:03,048 --> 00:03:04,217
>> Welcome, guys.

67
00:03:04,250 --> 00:03:05,985
Well, so, let me
introduce you here.

68
00:03:06,018 --> 00:03:10,056
Julie Webster began her
career with NASA in 1987

69
00:03:10,089 --> 00:03:12,458
and has worked on
missions to Mars,

70
00:03:12,491 --> 00:03:14,961
Venus, Jupiter, and Saturn.

71
00:03:14,994 --> 00:03:16,762
She was the spacecraft
operations manager

72
00:03:16,795 --> 00:03:18,231
on the Cassini mission to Saturn

73
00:03:18,264 --> 00:03:21,067
and now serves as chief
engineer on the Juno mission

74
00:03:21,100 --> 00:03:23,035
which is orbiting Jupiter.

75
00:03:23,068 --> 00:03:25,771
Rob Manning currently
serves as chief engineer

76
00:03:25,804 --> 00:03:27,540
here at NASA JPL

77
00:03:27,573 --> 00:03:31,744
and he's worked on most JPL
Mars missions since the 1990s.

78
00:03:31,777 --> 00:03:33,412
And he was a key
member of the team

79
00:03:33,445 --> 00:03:35,748
that landed the
first rover on Mars.

80
00:03:35,781 --> 00:03:37,016
So, thank you both
for being here.

81
00:03:37,049 --> 00:03:38,251
>> It's a pleasure.
>> Thank you so much.

82
00:03:38,284 --> 00:03:39,919
>> So can you, just
to get us started,

83
00:03:39,952 --> 00:03:41,988
can you put into perspective

84
00:03:42,021 --> 00:03:46,425
what it's actually like to
control a robotic spacecraft

85
00:03:46,458 --> 00:03:49,328
that's millions of miles away

86
00:03:49,361 --> 00:03:51,998
and you'll never see
it or touch it again

87
00:03:52,031 --> 00:03:53,566

after it leaves the Earth

88
00:03:53,599 --> 00:03:55,134
and you're remotely
operating this thing.

89
00:03:55,167 --> 00:03:58,571
What is the task of operating
that thing actually like?

90
00:03:58,604 --> 00:03:59,538
>> Go ahead.

91
00:03:59,571 --> 00:04:00,573
>> Well, there's two things.

92
00:04:00,606 --> 00:04:02,041
The first thing you gotta do

93
00:04:02,074 --> 00:04:04,744
is you've gotta anticipate
everything in advance.

94
00:04:04,777 --> 00:04:07,079
So you try to remember
to catch all of the stuff

95
00:04:07,112 --> 00:04:08,448
so you can know.

96
00:04:09,648 --> 00:04:11,984
It's like a good lawyer,
you never ask a question

97
00:04:12,017 --> 00:04:14,987
that you don't
know the answer to.

98
00:04:15,020 --> 00:04:16,756

Until you get surprised.

99
00:04:16,789 --> 00:04:18,891
And the second thing is,

100
00:04:18,924 --> 00:04:20,993
and Rob and I talked about
this before the show,

101
00:04:21,026 --> 00:04:22,862
we were talking about

102
00:04:22,895 --> 00:04:26,399
that it's like your
grandmother's writing a letter.

103
00:04:26,432 --> 00:04:29,602
Everybody these days wants a
text and if 30 seconds later,

104
00:04:29,635 --> 00:04:31,404
somebody has an
answered your text,

105
00:04:33,472 --> 00:04:32,238
Where are you?

106
00:04:33,505 --> 00:04:36,743
And that works for the
first few thousands

107
00:04:38,177 --> 00:04:40,980
or tens of thousands of
miles away from the Earth

108
00:04:41,013 --> 00:04:44,684
but after that, you
have to wait for it,

109

00:04:44,717 --> 00:04:48,187
and by the time you gets to
Mars, it's 15, 20 minutes,

110
00:04:48,220 --> 00:04:52,024
by the time you get to Jupiter,
it's 45 minutes to get there

111
00:04:52,057 --> 00:04:54,994
and then 90 minutes
roundtrip light time,

112
00:04:55,027 --> 00:04:57,463
and then it's three
hours at Saturn

113
00:04:57,496 --> 00:05:00,566
so there's no instant
communication.

114
00:05:01,533 --> 00:05:03,102
>> Grandma, I love it.

115
00:05:03,135 --> 00:05:04,503
>> Grandma.

116
00:05:04,536 --> 00:05:05,738
Might bite.

117
00:05:05,771 --> 00:05:06,672
>> My grandma did
the same thing,

118
00:05:06,705 --> 00:05:08,975
the letters get fewer and fewer,

119
00:05:10,109 --> 00:05:11,410
spaced further
and further apart.

120
00:05:11,443 --> 00:05:12,912
And so it is kind of strange,

121
00:05:12,945 --> 00:05:15,748
and actually, it is weird to
see stuff that you've touched

122
00:05:15,781 --> 00:05:18,284
here on Earth and then gradually

123
00:05:18,317 --> 00:05:21,654
have it feel like it's getting
further and further away,

124
00:05:21,687 --> 00:05:23,689
and the weirdest
thing is to see stuff

125
00:05:23,722 --> 00:05:26,392
that your vehicle
does so far away,

126
00:05:26,425 --> 00:05:30,262
it does what we ask it
to, it's kind of strange.

127
00:05:30,295 --> 00:05:31,864
It feels like it's,

128
00:05:31,897 --> 00:05:34,934
it's a weird split between,

129
00:05:34,967 --> 00:05:36,569
I feel my brain is
split between feeling

130
00:05:36,602 --> 00:05:39,905
we've created a robot
that does our bidding

131
00:05:39,938 --> 00:05:43,309
versus, as Preston said,
it becomes an extension

132
00:05:43,342 --> 00:05:46,178
of our bodies out
there and our minds.

133
00:05:46,211 --> 00:05:48,481
But these things
are not, you know,

134
00:05:48,514 --> 00:05:50,383
we design them ourselves

135
00:05:50,416 --> 00:05:53,753
but it's remarkable how much
they take a life of their own.

136
00:05:53,786 --> 00:05:55,688
>> Well, they develop their
own personalities, don't they?

137
00:05:55,721 --> 00:05:56,889
>> They do.

138
00:05:56,922 --> 00:05:58,724
>> But it's mostly the quirks.

139
00:05:58,757 --> 00:06:00,593
It's the things that
you don't anticipate,

140
00:06:00,626 --> 00:06:02,762
that that's how they
develop their personalities.

141
00:06:02,795 --> 00:06:07,066

It's like, you can build
identical spacecraft

142
00:06:07,099 --> 00:06:09,201
and yet, once you
send them out there,

143
00:06:09,234 --> 00:06:12,138
this one will have a
wire that didn't go right

144
00:06:12,171 --> 00:06:14,607
or this one will have
that that got hot.

145
00:06:14,640 --> 00:06:19,378
And so, their personalities
are really kinda their quirks.

146
00:06:19,411 --> 00:06:20,813
>> Quirks.

147
00:06:20,846 --> 00:06:23,949
>> Yeah, somewhere between
R2-D2 and HAL 9000.

148
00:06:23,982 --> 00:06:25,384
[laughing]

149
00:06:25,417 --> 00:06:28,821
And so, I'm sorry, Rob,
I'm afraid I can't do that.

150
00:06:28,854 --> 00:06:29,789
That actually happened.

151
00:06:29,822 --> 00:06:31,357
We had to have a robot,

152

00:06:31,390 --> 00:06:34,393
Curiosity did to us once,
it's not a very good day.

153
00:06:34,426 --> 00:06:37,296
>> Well, you guys could
both speak to the task

154
00:06:37,329 --> 00:06:40,766
or the process, I guess, of
planning each day's operations

155
00:06:40,799 --> 00:06:42,101
for a spacecraft, right?

156
00:06:42,134 --> 00:06:43,602
I mean, 'cause in some respects,

157
00:06:43,635 --> 00:06:45,738
it's not really a
technological task, is it?

158
00:06:45,771 --> 00:06:46,572
It's a really human process.

159
00:06:46,605 --> 00:06:48,073
>> It's a human thing.

160
00:06:48,106 --> 00:06:50,376
And the further your
spacecraft goes out,

161
00:06:50,409 --> 00:06:53,546
the longer you have to
plan for it in advance

162
00:06:53,579 --> 00:06:57,450
and I never worked a tactical
mission where you got the data

163
00:06:57,483 --> 00:06:59,351
and turned it around
and work next day

164
00:06:59,384 --> 00:07:03,689
but like the sequences
that we built on Cassini

165
00:07:03,722 --> 00:07:07,460
were designed years in
advance were finalized

166
00:07:07,493 --> 00:07:10,529
and sent up for 10
weeks at a time.

167
00:07:10,562 --> 00:07:13,566
So you had to think
ahead and know

168
00:07:13,599 --> 00:07:15,801
where your spacecraft
was going to be

169
00:07:15,834 --> 00:07:20,039
or supposed to be at every
second along the way.

170
00:07:20,072 --> 00:07:21,273
>> So those pictures,

171
00:07:21,306 --> 00:07:24,510
the Cassini project
to me has created

172
00:07:24,543 --> 00:07:27,613
some of the most spectacular
space photography

173

00:07:27,646 --> 00:07:30,316
and sometimes, I don't know
how you figured this out

174
00:07:30,349 --> 00:07:33,118
in advance but he
created these visualize

175
00:07:33,151 --> 00:07:37,423
where Deimos will be, or
with respect to the rings.

176
00:07:39,725 --> 00:07:40,893
>> Julie: Wrong planet.

177
00:07:40,926 --> 00:07:43,162
>> Wrong planet,
wrong planet, sorry.

178
00:07:43,195 --> 00:07:44,797
They all look alike to me.

179
00:07:44,830 --> 00:07:46,732
No, Titan's over there.

180
00:07:47,866 --> 00:07:51,136
You can can see things
between its rings,

181
00:07:51,169 --> 00:07:52,938
you see the shepherd
moons right there.

182
00:07:52,971 --> 00:07:55,774
But it all has to been
worked out way in advance.

183
00:07:55,807 --> 00:07:57,443
>> Way in advance.

184
00:07:57,476 --> 00:08:00,312
And the uncertainty
of the timing,

185
00:08:00,345 --> 00:08:02,681
you get better and then
sometimes you find yourself

186
00:08:02,714 --> 00:08:06,052
a few seconds to,
maybe even minutes off

187
00:08:07,219 --> 00:08:10,155
and you allow dead time
so that you can move it

188
00:08:10,188 --> 00:08:13,325
at the last second as you get
better and better knowledge.

189
00:08:13,358 --> 00:08:15,261
>> So, it's like clockwork.

190
00:08:15,294 --> 00:08:16,495
It's like a very precise time.

191
00:08:16,528 --> 00:08:17,763
>> It's a very--
>> Time, exactly.

192
00:08:17,796 --> 00:08:19,431
>> It's like
choreography, you know.

193
00:08:19,464 --> 00:08:20,900
>> Actually, the essence
of a robot, right?

194
00:08:20,933 --> 00:08:22,768

You tell it, here's a sequence
of things I want you to do

195
00:08:22,801 --> 00:08:24,136
and it hopefully.

196
00:08:24,169 --> 00:08:25,371
>> Does it.
>> Does it.

197
00:08:25,404 --> 00:08:27,473
>> What you don't wanna
do is to do something

198
00:08:27,506 --> 00:08:29,208
you didn't ask it to do.

199
00:08:29,241 --> 00:08:30,709
>> Julie: Which is how they
develop their personalities.

200
00:08:30,742 --> 00:08:31,577
>> Yeah.

201
00:08:32,978 --> 00:08:36,649
>> Let's take a look
back now at some of the,

202
00:08:37,816 --> 00:08:40,553
and some of the greatest
hits that are playing

203
00:08:40,586 --> 00:08:42,255
on some phones here.

204
00:08:43,689 --> 00:08:46,125
Let's take a look back at
some of the early milestones

205

00:08:46,158 --> 00:08:48,561
of robotic exploration.

206
00:08:48,594 --> 00:08:52,531
Starting in December 1962
as the Mariner 2 spacecraft

207
00:08:52,564 --> 00:08:55,968
was approaching Venus
for NASA's first flyby

208
00:08:56,001 --> 00:08:57,636
of another planet.

209
00:08:57,669 --> 00:08:58,837
Here's a video.

210
00:08:58,870 --> 00:09:00,105
>> Narrator: In
December, Mariner 2

211
00:09:00,138 --> 00:09:02,508
was closing in fast on Venus

212
00:09:02,541 --> 00:09:04,710
but it was in a
precarious state.

213
00:09:04,743 --> 00:09:07,279
Portions of the spacecraft
were overheating,

214
00:09:07,312 --> 00:09:09,148
several critical
telemetry sensors

215
00:09:09,181 --> 00:09:11,450
had stopped working altogether.

216

00:09:11,483 --> 00:09:13,819
It was taking all the
energy the solar panels

217
00:09:13,852 --> 00:09:18,090
could produce to keep the
spacecraft functioning.

218
00:09:18,123 --> 00:09:21,527
On December 14th, Mariner
2 made its closest approach

219
00:09:21,560 --> 00:09:25,731
to Venus, flying by at a
distance of 20,000 miles.

220
00:09:27,065 --> 00:09:30,135
In Pasadena, a steady
stream of science data

221
00:09:30,168 --> 00:09:32,504
came pouring back
as audible sounds

222
00:09:32,537 --> 00:09:34,774
throughout mission control.

223
00:09:38,844 --> 00:09:41,680
Scientists were elated,
although most of the results

224
00:09:41,713 --> 00:09:45,884
were more confirmations
than new discoveries.

225
00:09:45,917 --> 00:09:50,923
There was no onboard camera
so there were no pictures.

226
00:09:52,090 --> 00:09:53,459

There was also no sign
of a magnetic field

227
00:09:53,492 --> 00:09:56,528
or a radiation
belt like Earth's.

228
00:09:56,561 --> 00:09:59,398
For a planet considered
Earth's twin for its size

229
00:09:59,431 --> 00:10:02,368
and near proximity,
Venus revealed itself

230
00:10:02,401 --> 00:10:06,538
to be a hellish world
filled with carbon dioxide,

231
00:10:06,571 --> 00:10:11,410
and where surface temperatures
are hot enough to melt lead.

232
00:10:11,443 --> 00:10:15,047
20 days after passing
Venus, Mariner 2 transmitted

233
00:10:15,080 --> 00:10:18,985
half an hour of telemetry
and then went silent.

234
00:10:20,986 --> 00:10:23,589
>> So Mariner 2 made it to Venus

235
00:10:25,223 --> 00:10:27,993
and it gave it NASA
its first in space

236
00:10:28,026 --> 00:10:31,397
but it was dicey and the

spacecraft didn't last

237
00:10:31,430 --> 00:10:32,531
long after.

238
00:10:32,565 --> 00:10:34,667
So I wonder if you guys could
talk about what it takes

239
00:10:34,700 --> 00:10:38,103
to keep a spacecraft
going for months or years,

240
00:10:38,136 --> 00:10:39,905
for long enough to
complete its mission

241
00:10:39,938 --> 00:10:42,007
and what's changed over time

242
00:10:42,040 --> 00:10:44,810
that's made spacecraft
more reliable?

243
00:10:44,843 --> 00:10:48,213
>> Well, yeah, a lot
of it is understanding

244
00:10:48,246 --> 00:10:49,748
the space environment,

245
00:10:49,781 --> 00:10:52,584
having an idea how
things work, that whole.

246
00:10:52,617 --> 00:10:55,621
You heard the reference
to the thermal

247

00:10:55,654 --> 00:10:58,057
that things were too
hot, things were too cold

248
00:10:58,090 --> 00:11:01,126
and that's been the bane
of a lot of spacecraft

249
00:11:01,159 --> 00:11:05,397
is the thermal environment,
the radiation environment,

250
00:11:05,430 --> 00:11:09,435
the understanding space
so as we've gotten better

251
00:11:09,468 --> 00:11:12,071
with understanding space
and how hot it can be

252
00:11:12,104 --> 00:11:14,540
if you're facing the sun
and how cold it can be

253
00:11:14,573 --> 00:11:15,741
if you're not,

254
00:11:16,675 --> 00:11:18,210
that's a lot of it.

255
00:11:18,243 --> 00:11:21,213
>> Right, I mean we
you think about stuff

256
00:11:21,246 --> 00:11:24,183
that we, the humans
make on this planet,

257
00:11:24,216 --> 00:11:26,885
it's mostly stuff for

around room temperature,

258
00:11:26,918 --> 00:11:30,622
maybe a little cold or a
little warmer in an atmosphere.

259
00:11:30,655 --> 00:11:34,960
If you're facing a heat source,
the heat will radiate away

260
00:11:34,993 --> 00:11:38,197
but also there's atmosphere
cooling it down but in space,

261
00:11:38,230 --> 00:11:41,567
with no air, the sun
just bakes one side

262
00:11:43,535 --> 00:11:45,337
thousands of degree temperatures

263
00:11:45,370 --> 00:11:47,606
if you don't have some
way to get the heat off

264
00:11:47,639 --> 00:11:49,641
and then the back side,
that looks at deep space.

265
00:11:49,674 --> 00:11:53,145
It's looking at the residual
microwave background radiation

266
00:11:53,178 --> 00:11:56,548
from the Big Bang at little
below three degrees Kelvin.

267
00:11:56,581 --> 00:11:58,283
Three degrees below
absolute zero.

268
00:11:58,316 --> 00:11:59,852
So it's like a
super weird place.

269
00:11:59,885 --> 00:12:02,788
I mean this is just, this
is not how we live here

270
00:12:02,821 --> 00:12:06,425
in this planet and try
taking your television,

271
00:12:06,458 --> 00:12:09,128
put in outer space,
it just wouldn't last.

272
00:12:09,161 --> 00:12:11,463
And then not to mention,
the other things

273
00:12:11,496 --> 00:12:14,399
that we've discovered
after Mariner 2

274
00:12:14,432 --> 00:12:15,901
about the radiation effects.

275
00:12:15,934 --> 00:12:17,402
Oh, my goodness.

276
00:12:17,435 --> 00:12:19,438
>> The radiation effects and
just tracking the spacecraft.

277
00:12:19,471 --> 00:12:22,941
Just trying to stay in
communication with it

278

00:12:22,974 --> 00:12:23,942
as you walk.

279
00:12:23,975 --> 00:12:25,544
You've ever been separated
by walkie talkies

280
00:12:25,577 --> 00:12:28,313
and the further you got
or you got behind a tree

281
00:12:28,346 --> 00:12:31,150
and all of a sudden,
you're not texting

282
00:12:31,183 --> 00:12:33,285
or calling back and forth.

283
00:12:33,318 --> 00:12:36,588
So learning how to talk
and to to capture it

284
00:12:36,621 --> 00:12:39,258
as the Doppler shifted
the radio signal

285
00:12:39,291 --> 00:12:41,527
and things like that,
all of that was new.

286
00:12:41,560 --> 00:12:43,162
>> Preston: So we've learned
more as we've gone on.

287
00:12:43,195 --> 00:12:44,630
>> Rob: Yeah.

288
00:12:44,663 --> 00:12:47,633
>> And the people that
work Earth missions today

289
00:12:47,666 --> 00:12:50,803
still don't understand how
different deep space is.

290
00:12:50,836 --> 00:12:53,872
>> Yeah, and just figuring
out where your spacecraft is

291
00:12:53,905 --> 00:12:55,141
in outer space.

292
00:12:57,075 --> 00:12:58,577
The science of,

293
00:12:58,610 --> 00:13:00,612
Cassini can actually look
out its window and see--

294
00:13:00,645 --> 00:13:01,613
>> Preston: Could, past tense.

295
00:13:01,646 --> 00:13:02,815
>> Could, could, paste tense.

296
00:13:02,848 --> 00:13:03,849
>> Could, oh.

297
00:13:05,684 --> 00:13:06,552
I miss Cassini.

298
00:13:06,585 --> 00:13:07,386
>> Hard for me too.

299
00:13:07,419 --> 00:13:08,654
>> Yeah, I know.

300
00:13:08,687 --> 00:13:10,489

So it could look out its
window and see the moons

301
00:13:10,522 --> 00:13:12,591
and kind of we can sort of
figure out from the pictures

302
00:13:12,624 --> 00:13:14,526
but most of our spacecraft,
if you look out,

303
00:13:14,559 --> 00:13:15,994
it just see a bunch
of stars and the sun.

304
00:13:16,027 --> 00:13:17,462
You don't know where it is.

305
00:13:17,495 --> 00:13:20,032
And so we have to figure
out where our spacecraft are

306
00:13:20,065 --> 00:13:24,336
from this planet by coming
up with these wild tricks

307
00:13:24,369 --> 00:13:28,073
using radio signals
to bounce a beam back,

308
00:13:28,106 --> 00:13:29,508
a little kinda boop.

309
00:13:29,541 --> 00:13:31,343
Send a boop and have
a have that boop

310
00:13:31,376 --> 00:13:34,046
reflected off of the
radio like a mirror,

311
00:13:34,079 --> 00:13:36,615
bounce back and if you time it,

312
00:13:36,648 --> 00:13:37,950
you can figure it out how far.

313
00:13:37,983 --> 00:13:41,286
>> In inertial
radiation, inertial gyros

314
00:13:41,319 --> 00:13:42,554
and things like that,

315
00:13:42,587 --> 00:13:46,225
you have to first learn
what the programmer did,

316
00:13:47,692 --> 00:13:51,597
did they put it in J 2000
or 1958 terms or XYZ.

317
00:13:52,764 --> 00:13:53,966
>> Preston: Programming
language did they use.

318
00:13:53,999 --> 00:13:55,434
>> What programming
language did they use.

319
00:13:55,467 --> 00:13:57,069
>> Early spacecraft
had no computers.

320
00:13:57,102 --> 00:13:58,036
>> Had no computers.

321
00:13:58,069 --> 00:13:59,838
Well, they had analog computers.

322
00:13:59,871 --> 00:14:02,908
>> And barely at that, it was
mostly closed in controllers.

323
00:14:02,941 --> 00:14:04,243
>> Closed in controllers.

324
00:14:04,276 --> 00:14:07,079
>> Kind of an exotic
toaster ovens.

325
00:14:07,112 --> 00:14:08,881
[attendees laughing]

326
00:14:08,914 --> 00:14:10,682
>> But it was.
>> Not to knock it.

327
00:14:10,715 --> 00:14:13,418
Even Voyager had
very rudimentary

328
00:14:13,451 --> 00:14:14,119
logic for controlling.

329
00:14:14,152 --> 00:14:15,320
In fact, most of our spacecraft

330
00:14:15,353 --> 00:14:17,556
didn't know where they
were in outer space

331
00:14:17,589 --> 00:14:19,958
or even knew its
orientation, let alone,

332
00:14:19,991 --> 00:14:22,261
where it's positioned

but it did know

333
00:14:22,294 --> 00:14:24,229
that there was a
bright star over there

334
00:14:24,262 --> 00:14:26,365
and if it moves too
far away from it,

335
00:14:26,398 --> 00:14:27,866
the sensor would complain.

336
00:14:27,899 --> 00:14:29,134
>> Julie: Would complain.

337
00:14:29,167 --> 00:14:31,536
>> And that's all I
needed to do and so,

338
00:14:31,569 --> 00:14:33,038
so it's very simple.

339
00:14:33,071 --> 00:14:34,539
Let me also point out that
these vehicles back then

340
00:14:34,572 --> 00:14:38,243
and up until Cassini which
is one among the first,

341
00:14:38,276 --> 00:14:40,112
well, they're all built by hand.

342
00:14:40,145 --> 00:14:41,546
These vehicles were
designed and built.

343
00:14:41,579 --> 00:14:42,848

We didn't use computers.

344
00:14:42,881 --> 00:14:45,117
Lots of big blueprints, pencils.

345
00:14:45,150 --> 00:14:46,051
>> Julie: Lots of blueprints.

346
00:14:46,084 --> 00:14:47,319
We still get the blueprints.

347
00:14:47,352 --> 00:14:50,822
>> And hand, just hand
soldered, electronics

348
00:14:50,855 --> 00:14:54,593
with, sometimes, with
just individual wires

349
00:14:54,626 --> 00:14:55,394
from a blueprint

350
00:14:55,427 --> 00:14:57,796
trying to make sure
that the design

351
00:14:57,829 --> 00:14:59,331
was built like the blueprint.

352
00:14:59,364 --> 00:15:01,233
And that's how it was
done for years and years.

353
00:15:01,266 --> 00:15:04,536
Can you imagine how easy
it was to make a mistake

354
00:15:04,569 --> 00:15:06,605
with thousands of,

355
00:15:06,638 --> 00:15:09,775
hundreds of thousands of
feet, sometimes, of wires.

356
00:15:09,808 --> 00:15:12,911
>> Or the bane of my existence
where you had to rework it

357
00:15:12,944 --> 00:15:15,314
when you had to pull off
a circuit and rework it

358
00:15:15,347 --> 00:15:17,382
and you hope you got
all the solder out

359
00:15:17,415 --> 00:15:20,485
and if you didn't get
all the solder out.

360
00:15:20,518 --> 00:15:21,420
>> Yeah, you need good wires.

361
00:15:21,453 --> 00:15:22,621
>> And then you worry.

362
00:15:22,654 --> 00:15:25,023
Anybody that's ever
worked on cars.

363
00:15:25,056 --> 00:15:27,092
>> So obviously,
we've come a long way

364
00:15:27,125 --> 00:15:28,927
and you guys no longer have
to get your hands dirty

365

00:15:28,960 --> 00:15:31,196
with solder on them, right?

366
00:15:32,297 --> 00:15:34,833
>> Julie: They didn't
let us do that.

367
00:15:34,866 --> 00:15:36,501
>> It got me once,
and that was it.

368
00:15:36,534 --> 00:15:38,370
>> So let's move forward in time

369
00:15:38,403 --> 00:15:40,539
to the next major milestone

370
00:15:40,572 --> 00:15:41,773
which is once we succeeded

371
00:15:41,806 --> 00:15:44,209
in just reaching
on other planets,

372
00:15:44,242 --> 00:15:46,378
the next major milestone
was to stay for a while

373
00:15:46,411 --> 00:15:47,980
and have a good look around.

374
00:15:48,013 --> 00:15:50,148
In other words, to
orbit another world.

375
00:15:50,181 --> 00:15:52,584
And so Julie, you
have sent four,

376

00:15:52,617 --> 00:15:55,087
you've worked on four orbiters
on four other planets.

377
00:15:55,120 --> 00:15:57,589
Can you talk about
what's different

378
00:15:57,622 --> 00:15:59,391
about getting a robot into orbit

379
00:15:59,424 --> 00:16:02,094
and operating there for
an extended period of time

380
00:16:02,127 --> 00:16:05,597
versus just a spacecraft that's
cruising from here to there

381
00:16:05,630 --> 00:16:06,999
or flying by a place.

382
00:16:07,032 --> 00:16:09,434
>> Well, the most important
thing is time to go.

383
00:16:09,467 --> 00:16:12,637
If you're orbiting,
you have critical times

384
00:16:12,670 --> 00:16:14,373
that where you
wanna take pictures

385
00:16:14,406 --> 00:16:15,774
or you wanna not take pictures

386
00:16:15,807 --> 00:16:18,677
or you wanna maneuver
the spacecraft or not.

387
00:16:18,710 --> 00:16:22,914
If you're just cruising,
your time to go is forever

388
00:16:22,947 --> 00:16:25,684
and so you have, something
we're gonna talk about

389
00:16:25,717 --> 00:16:27,185
in a minute, fault protection

390
00:16:27,218 --> 00:16:30,723
that you can be imperfect
for a long time.

391
00:16:32,524 --> 00:16:36,928
If you have to make an encounter
with a moon or a planet

392
00:16:36,961 --> 00:16:39,598
or take a picture at exact time,

393
00:16:39,631 --> 00:16:43,769
you have to be very mindful
and you have to stay in contact

394
00:16:43,802 --> 00:16:46,205
with that vehicle more often.

395
00:16:47,172 --> 00:16:48,473
Lots of times, we let them go

396
00:16:48,506 --> 00:16:50,842
and not kind of stay in
contact like once a week

397
00:16:50,875 --> 00:16:53,045
or something like that.

398
00:16:53,078 --> 00:16:55,647
Cassini was nine hours a
day and then sometimes,

399
00:16:55,680 --> 00:16:58,150
every other day and
then every third day.

400
00:16:58,183 --> 00:17:02,187
So it's just a matter of
the critical time to go

401
00:17:03,354 --> 00:17:05,590
and that's what I try to
teach, it's time to go.

402
00:17:05,623 --> 00:17:08,160
>> Okay, well let's take a
look now at the first time

403
00:17:08,193 --> 00:17:11,730
NASA put a spacecraft into
orbit around another planet

404
00:17:11,763 --> 00:17:13,665
with Mariner 9 in 1971.

405
00:17:16,568 --> 00:17:18,570
>> Narrator: The first
great engineering challenge

406
00:17:18,603 --> 00:17:22,040
in robotic exploration was
to fly by a destination

407
00:17:22,073 --> 00:17:24,042
for a brief glimpse.

408

00:17:24,075 --> 00:17:25,844
The next feat was
to build a machine

409
00:17:25,877 --> 00:17:29,214
capable of going into
orbit around a planet.

410
00:17:29,247 --> 00:17:33,385
In 1971, a very next
opportunity to go to Mars,

411
00:17:33,418 --> 00:17:35,921
JPL had taken the
idea of an orbiter

412
00:17:35,954 --> 00:17:38,790
from the drawing board
to the launch pad.

413
00:17:38,823 --> 00:17:42,260
>> The basic spacecraft was
pretty much pure Mariner

414
00:17:42,293 --> 00:17:45,697
but it had this humongous
propulsion module on it

415
00:17:45,730 --> 00:17:48,100
to slow the spacecraft
down when you got to Mars

416
00:17:48,133 --> 00:17:51,269
to the point where it could
be captured by Mars gravity.

417
00:17:51,302 --> 00:17:54,439
That presented some
interesting challenges.

418

00:17:54,472 --> 00:17:59,111
You had to store propellants
in space for nine months

419
00:17:59,144 --> 00:18:01,446
and then use them and
crush your fingers

420
00:18:01,479 --> 00:18:04,850
and hope that everything worked
the way it was supposed to.

421
00:18:04,883 --> 00:18:07,419
>> Announcer: Mariner 9
became the first spacecraft

422
00:18:07,452 --> 00:18:09,855
ever to orbit another planet.

423
00:18:13,191 --> 00:18:16,595
>> It was a kind of
epiphany in the sense

424
00:18:16,628 --> 00:18:19,197
of what an orbiter can
do versus of flyby.

425
00:18:19,230 --> 00:18:21,666
The previous flybys, and
it was just coincidentally,

426
00:18:21,699 --> 00:18:26,371
they'd flown by the
uninteresting side of Mars.

427
00:18:26,404 --> 00:18:28,773
>> And when the dust cleared,

428
00:18:28,806 --> 00:18:31,176
we found a planet that

was completely unlike

429
00:18:31,209 --> 00:18:33,345
the one that Mariner 4 had seen

430
00:18:33,378 --> 00:18:36,381
and that Mariner 6
and 7 completely.

431
00:18:37,849 --> 00:18:41,720
And so this planet which we
had labeled is like the moon

432
00:18:41,753 --> 00:18:44,556
sudden looked like the Earth
except bigger volcanoes,

433
00:18:44,589 --> 00:18:46,858
bigger flood channels,
the canyon that runs

434
00:18:46,891 --> 00:18:49,161
the distance of the
United States across

435
00:18:49,194 --> 00:18:53,365
and is 60 miles wide in
places and six miles deep.

436
00:18:55,200 --> 00:18:56,468
The Grand Canyon of Arizona

437
00:18:56,501 --> 00:19:00,172
would fit in one little
tributary off the side.

438
00:19:00,205 --> 00:19:03,675
So we got really zapped because
not only was it Earth-like

439
00:19:03,708 --> 00:19:05,977
but everything is
larger than the Earth.

440
00:19:06,010 --> 00:19:08,547
So that left us
bewildered geologically

441
00:19:08,580 --> 00:19:11,516
but people are interested
in life on Mars.

442
00:19:11,549 --> 00:19:13,118
We're ecstatic because clearly,

443
00:19:13,151 --> 00:19:18,157
there had been an aqueous
phase in this planet's history.

444
00:19:19,591 --> 00:19:21,726
>> So if you stay for a while
and take a good look around,

445
00:19:21,759 --> 00:19:24,996
you're likely to see
even more amazing things.

446
00:19:25,029 --> 00:19:27,465
So let's move forward a
little bit further in time.

447
00:19:27,498 --> 00:19:32,037
Now in 1976, NASA was ready
to try landing on Mars

448
00:19:32,070 --> 00:19:33,505
for the very first time.

449
00:19:33,538 --> 00:19:35,874

This was the Viking mission
and it had two orbiters,

450
00:19:35,907 --> 00:19:37,642
each of them was
carrying a lander.

451
00:19:37,675 --> 00:19:42,681
So Rob, what is it about
having a robotic spacecraft

452
00:19:44,082 --> 00:19:47,319
actually land itself on Mars
that makes it such a challenge?

453
00:19:47,352 --> 00:19:50,455
>> Well, we like to
whine about that a lot.

454
00:19:50,488 --> 00:19:52,391
And I'm the top whiner.

455
00:19:53,258 --> 00:19:54,426
Landing on Mars is really hard.

456
00:19:54,459 --> 00:19:56,995
In fact, if some of
you've seen this video,

457
00:19:57,028 --> 00:20:00,098
7 Minutes of Terror, the
seven minutes started

458
00:20:00,131 --> 00:20:02,867
back in the Viking days
in this Viking lander

459
00:20:02,900 --> 00:20:04,302
and what's striking,

460
00:20:04,335 --> 00:20:06,538
so they're the ones,
the Viking team

461
00:20:06,571 --> 00:20:09,274
is the ones who taught
me and my colleagues

462
00:20:09,307 --> 00:20:11,810
how to do this kind of stuff.

463
00:20:11,843 --> 00:20:13,778
But I have to say,
it is really hard.

464
00:20:13,811 --> 00:20:16,481
Mars is very, it
is so irritating.

465
00:20:16,514 --> 00:20:20,185
There's too much too
much atmosphere on Mars

466
00:20:21,319 --> 00:20:22,821
to land like we
do with the moon,

467
00:20:22,854 --> 00:20:25,390
just by taking a vehicle
firing its engine backwards

468
00:20:25,423 --> 00:20:27,158
and landing on its legs.

469
00:20:27,191 --> 00:20:31,430
And then there's there's
too little atmosphere to--

470
00:20:32,897 --> 00:20:33,798

>> Preston: To finish the job.

471
00:20:33,831 --> 00:20:34,733
>> To finish the job, so yeah,

472
00:20:34,766 --> 00:20:37,669
so its atmosphere is too thin.

473
00:20:37,702 --> 00:20:41,373
So to do it like we do on Earth
with big parachute or wings,

474
00:20:41,406 --> 00:20:44,542
like the Soyuz or Apollo
or just Space Shuttle

475
00:20:44,575 --> 00:20:46,044
and so it has this
weird combinations.

476
00:20:46,077 --> 00:20:48,713
You have to kind off
looking like an Earth lander

477
00:20:48,746 --> 00:20:52,250
and then just somehow,
like a transformer,

478
00:20:52,283 --> 00:20:56,255
convert yourself into a
robotic lander which is,

479
00:20:57,455 --> 00:21:00,425
it makes for a very
Rube Goldberg design.

480
00:21:00,458 --> 00:21:03,061
>> Yeah, so let's
actually take a look

481
00:21:03,094 --> 00:21:04,462
at what that looked like.

482
00:21:04,495 --> 00:21:06,998
Let's take a look at
another video that shows

483
00:21:07,031 --> 00:21:11,303
NASA's first attempted
landing on Mars with Viking.

484
00:21:13,171 --> 00:21:14,806
>> Narrator: In the
early morning hours

485
00:21:14,839 --> 00:21:17,108
of July 20th, 1976,

486
00:21:17,141 --> 00:21:20,111
the Viking 1 lander
separated from the orbiter

487
00:21:20,144 --> 00:21:23,882
and began the descent
to the Martian surface.

488
00:21:27,151 --> 00:21:30,455
>> Man: Now, we've
sensed 0.5 g's.

489
00:21:30,488 --> 00:21:32,891
>> Man: Telecom, how's the SF?

490
00:21:32,924 --> 00:21:34,459
>> Man: It is holding very well.

491
00:21:34,492 --> 00:21:35,493
>> Man: In the atmosphere now.

492
00:21:35,526 --> 00:21:38,063
[men chattering]

493
00:21:38,096 --> 00:21:39,497
>> We have to realize,
this was before

494
00:21:39,530 --> 00:21:43,335
anybody knew about onboard
software, closed-loop guidance,

495
00:21:43,368 --> 00:21:45,404
it had to do a parachute.

496
00:21:46,637 --> 00:21:48,473
>> Man: The chute
has been deployed.

497
00:21:48,506 --> 00:21:49,941
>> Man: Telemetry's in sync.

498
00:21:49,974 --> 00:21:51,676
>> Then it had to do
a terminal descent

499
00:21:51,709 --> 00:21:53,845
and it's radar, it's
four beam radar working

500
00:21:53,878 --> 00:21:55,113
and land softly.

501
00:21:55,146 --> 00:21:56,848
It had to go from
10,000 miles an hour

502
00:21:56,881 --> 00:21:59,017
to between two and
three miles per hour

503
00:21:59,050 --> 00:22:02,420
in just a few minutes that
had never been done before.

504
00:22:02,453 --> 00:22:03,621
[men speaking over each other]

505
00:22:03,654 --> 00:22:05,023
>> But this takes time?

506
00:22:05,056 --> 00:22:07,359
>> Man: 1,200 feet,
140 feet per second.

507
00:22:07,392 --> 00:22:08,193
>> Man: So the engine--

508
00:22:08,226 --> 00:22:10,261
>> Man: 0.6 g's.

509
00:22:10,294 --> 00:22:14,366
>> 20 feet, 366 feet, 73
feet, 73 feet per second.

510
00:22:14,399 --> 00:22:16,568
>> Man: ACS is
close to vertical.

511
00:22:16,601 --> 00:22:17,869
>> Man: Now, we're coming down.

512
00:22:17,902 --> 00:22:19,504
Straight down.

513
00:22:19,537 --> 00:22:21,172
>> Man: Now, it's
green for touchdown.

514
00:22:21,205 --> 00:22:25,643
>> Man: ACS is green, 1.53
per second match, 0.2 g's.

515
00:22:25,676 --> 00:22:26,678
>> Man: Touchdown,
we have touchdown.

516
00:22:26,711 --> 00:22:30,549
[all cheering and applauding]

517
00:22:33,851 --> 00:22:36,521
>> A moment in
every Vikings life

518
00:22:36,554 --> 00:22:38,723
that he or she will never forget

519
00:22:38,756 --> 00:22:41,426
sitting with that television
right in front of them

520
00:22:41,459 --> 00:22:44,129
and watching as the
first lines came down,

521
00:22:44,162 --> 00:22:46,998
it came down line
by line by line.

522
00:22:50,001 --> 00:22:51,803
>> Man: Oh, the rocks.

523
00:22:54,105 --> 00:22:55,607
That's beautiful.

524
00:22:55,640 --> 00:22:59,978
>> The first photograph that
human being has ever seen

525
00:23:00,011 --> 00:23:02,347
from the surface
of another planet.

526
00:23:02,380 --> 00:23:03,848
>> Man: Say something too.

527
00:23:03,881 --> 00:23:05,083
>> Man: Yeah, I'm supposed to
say something at this point.

528
00:23:05,116 --> 00:23:08,353
I just don't feel like talking.

529
00:23:08,386 --> 00:23:10,488
It's just it's just
incredible to see

530
00:23:10,521 --> 00:23:13,024
that the Mars is really there.

531
00:23:14,492 --> 00:23:18,596
>> And we all, five billion
people on the planet Earth,

532
00:23:18,629 --> 00:23:21,366
saw Mars for the
very first time.

533
00:23:23,901 --> 00:23:24,736
>> Wow.

534
00:23:26,637 --> 00:23:30,208
So Viking provides a
really good demonstration

535
00:23:30,241 --> 00:23:34,145
of how our space robots have

become increasingly autonomous

536
00:23:34,178 --> 00:23:37,682
or increasingly capable
of operating on their own

537
00:23:37,715 --> 00:23:39,083
for periods of time.

538
00:23:39,116 --> 00:23:43,421
So what are some of the factors
that have made spacecraft

539
00:23:43,454 --> 00:23:45,990
able to be more
autonomous over the years?

540
00:23:46,023 --> 00:23:47,325
>> Well, computers.

541
00:23:47,358 --> 00:23:48,793
>> Computers.

542
00:23:48,826 --> 00:23:52,964
>> The ability to change from
analog relays and hardware

543
00:23:52,997 --> 00:23:56,334
to digital to
reprogrammable to if oops,

544
00:23:57,869 --> 00:24:00,839
I didn't do that right,
I can reprogram that.

545
00:24:00,872 --> 00:24:03,241
So a lot of it has
been the computers,

546

00:24:03,274 --> 00:24:07,045
better cameras, faster
data rates, faster speeds,

547
00:24:07,078 --> 00:24:08,580
faster processing.

548
00:24:10,381 --> 00:24:12,650
But mostly, computers
and software.

549
00:24:12,683 --> 00:24:15,253
>> That enabled it but we
really had to do it right

550
00:24:15,286 --> 00:24:16,788
because sometimes,

551
00:24:19,423 --> 00:24:21,659
your vehicle is on its own

552
00:24:21,692 --> 00:24:23,328
and if something weird happens--

553
00:24:23,361 --> 00:24:25,430
>> Julie: It has to
take care of itself.

554
00:24:25,463 --> 00:24:28,366
>> Yeah, and so, of course,
with introduced at landing,

555
00:24:28,399 --> 00:24:31,002
you can't really joystick
the thing from Earth

556
00:24:31,035 --> 00:24:32,470
because it's so far away.

557

00:24:32,503 --> 00:24:35,607
The time your signal gets
there, you've already landed.

558
00:24:35,640 --> 00:24:40,645
So you need to program it all
in and in the case of landing,

559
00:24:41,512 --> 00:24:43,315
it's a bit more complicated

560
00:24:44,515 --> 00:24:45,550
than just dealing
with the failure.

561
00:24:45,583 --> 00:24:47,385
>> Well, we've got a Voyager.

562
00:24:47,418 --> 00:24:50,121
>> Yeah, I wanted
it to put a point

563
00:24:50,154 --> 00:24:52,290
on the not just the
power of the computers

564
00:24:52,323 --> 00:24:54,392
but it's the size too, right?

565
00:24:54,425 --> 00:24:56,361
I mean the computers
got smaller over time.

566
00:24:56,394 --> 00:24:57,862
>> Well, everything got smaller.

567
00:24:57,895 --> 00:24:58,796
>> Preston: Everything
got smaller.

568
00:24:58,829 --> 00:25:00,064
>> Everything got smaller.

569
00:25:00,097 --> 00:25:02,400
Although if you look
at the basic design,

570
00:25:02,433 --> 00:25:05,236
you saw those Mariners,
they were six-sided

571
00:25:05,269 --> 00:25:06,738
and then we went to eight sided

572
00:25:06,771 --> 00:25:09,307
and then we went to
12 sided on Cassini

573
00:25:09,340 --> 00:25:13,011
but the basic design,
it builds on the back.

574
00:25:14,278 --> 00:25:15,747
Everything builds on.

575
00:25:15,780 --> 00:25:18,383
So you learn the lessons
and you relearn them

576
00:25:18,416 --> 00:25:19,717
and you re-relearn them.

577
00:25:19,750 --> 00:25:21,252
>> Yeah, exactly.

578
00:25:21,285 --> 00:25:23,688
And part of the way how they
got these computers smaller

579
00:25:23,721 --> 00:25:27,425
to do something, to fit
in those those eight side

580
00:25:27,458 --> 00:25:30,728
or 12 sided base is that
one computer, for example,

581
00:25:30,761 --> 00:25:33,998
would process all its
information one bit at a time.

582
00:25:34,031 --> 00:25:35,967
So they weren't
presses and we do now,

583
00:25:36,000 --> 00:25:39,103
we want our computers execute

584
00:25:39,136 --> 00:25:41,439
full multi bit
instructions that each time

585
00:25:41,472 --> 00:25:43,541
so when you look at your
phone and so though I'm a,

586
00:25:43,574 --> 00:25:46,077
it's a five gigahertz--

587
00:25:46,110 --> 00:25:48,179
>> You can have some seven
windows at the same time

588
00:25:48,212 --> 00:25:50,748
instead of, you can talk
and now, you can talk

589
00:25:50,781 --> 00:25:51,649

and now, you can talk.
>> So basically it does,

590
00:25:51,682 --> 00:25:53,952
should add two numbers together,

591
00:25:53,985 --> 00:25:56,020
you had to add all the
individual bits together

592
00:25:56,053 --> 00:25:57,155
one at a time.

593
00:25:57,188 --> 00:25:58,890
To add the number five,

594
00:25:58,923 --> 00:26:00,858
you would have to
add a one, zero, one.

595
00:26:00,891 --> 00:26:02,594
And one at a time
into the computer

596
00:26:02,627 --> 00:26:05,063
and that would come back out,

597
00:26:06,364 --> 00:26:08,366
more more bits would
come out one at a time

598
00:26:08,399 --> 00:26:09,701
and eventually, you
get the job done.

599
00:26:09,734 --> 00:26:11,669
So you'd have to
wait an eternity

600

00:26:11,702 --> 00:26:13,871
for the thing to do
any some calculation

601
00:26:13,904 --> 00:26:15,373
that you needed to do.

602
00:26:15,406 --> 00:26:17,041
>> Preston: So they learned
how to multitask, essentially.

603
00:26:17,074 --> 00:26:18,509
>> Rob: Well--

604
00:26:18,542 --> 00:26:19,677
>> Preston: I think, to keep
more than one thought going on.

605
00:26:19,710 --> 00:26:21,112
>> Rob: They weren't that smart.

606
00:26:21,145 --> 00:26:24,215
>> Preston: I'm antrophomizing
a little too much, okay.

607
00:26:24,248 --> 00:26:26,184
>> But gradually,
they did over time.

608
00:26:26,217 --> 00:26:28,319
Multitasking became part of it.

609
00:26:28,352 --> 00:26:31,122
In fact, Galileo and
Cassini were two examples

610
00:26:31,155 --> 00:26:34,092
of missions that we had
to do this, multitasking.

611
00:26:34,125 --> 00:26:35,893
Which means with a
better processor,

612
00:26:35,926 --> 00:26:37,395
now he can go, you
can think a little bit

613
00:26:37,428 --> 00:26:39,230
about this part of the problem

614
00:26:39,263 --> 00:26:40,698
and then a little bit
more in this problem.

615
00:26:40,731 --> 00:26:42,233
>> A little background
process over the computer.

616
00:26:42,266 --> 00:26:46,337
>> Right, and that was true
a little bit with the lander,

617
00:26:46,370 --> 00:26:47,538
Viking lander.

618
00:26:47,571 --> 00:26:49,574
They had a very simple,
very simple computer

619
00:26:49,607 --> 00:26:52,977
but it was actually very
power hog back in those days.

620
00:26:53,010 --> 00:26:57,548
They used bipolar parts and
it really screened for its day

621
00:26:57,581 --> 00:26:59,450

but we couldn't
fly our other stuff

622
00:26:59,483 --> 00:27:01,119
because it just took
too much electricity.

623
00:27:01,152 --> 00:27:05,289
And so, but when it did its
job over that period of time,

624
00:27:05,322 --> 00:27:09,360
it was first checking this
sensor, then this the sensor

625
00:27:09,393 --> 00:27:11,329
figuring out what
calculation to make

626
00:27:11,362 --> 00:27:13,231
to figure out how much
to change the thrusters

627
00:27:13,264 --> 00:27:16,134
to make sure it wouldn't tip
over and control its velocity,

628
00:27:16,167 --> 00:27:17,502
take more data from the radar.

629
00:27:17,535 --> 00:27:18,736
>> Julie: Figure out the radar.

630
00:27:18,769 --> 00:27:20,772
>> And figure out where
it was and so quickly,

631
00:27:20,805 --> 00:27:22,006
I have to change
this a little bit.

632
00:27:22,039 --> 00:27:24,042
And would do this
on a cycle of about,

633
00:27:24,075 --> 00:27:27,111
I think was 64 times
a second at that time

634
00:27:27,144 --> 00:27:29,113
with the time which is
considered really fast

635
00:27:29,146 --> 00:27:30,214
back in the 1970s.

636
00:27:30,247 --> 00:27:31,649
>> That was pretty fancy.

637
00:27:31,682 --> 00:27:34,652
>> Or homemade kind of a small
especially built computer.

638
00:27:34,685 --> 00:27:37,055
>> So there's another milestone

639
00:27:37,088 --> 00:27:38,890
on the path to
smarter spacecraft

640
00:27:38,923 --> 00:27:40,858
and it's something
called fault protection.

641
00:27:40,891 --> 00:27:43,494
So can you talk a little
bit about what that is

642
00:27:43,527 --> 00:27:44,762

and what it's good for.

643
00:27:44,795 --> 00:27:46,030
>> Yeah, fault protection.

644
00:27:46,063 --> 00:27:47,265
What you have to do
is these spacecraft

645
00:27:47,298 --> 00:27:49,267
have to be able to
take care of themselves

646
00:27:49,300 --> 00:27:51,769
and that's what you were
talking when you're in cruise,

647
00:27:51,802 --> 00:27:53,871
you can take care of
yourself for a long time.

648
00:27:53,904 --> 00:27:57,275
The first time I heard this
term was on Mars Observer

649
00:27:57,308 --> 00:28:00,311
but we have what we
call sun comm power.

650
00:28:00,344 --> 00:28:04,515
So your spacecraft, if it
doesn't know where it's at,

651
00:28:04,548 --> 00:28:07,852
it finds us, as Rob said, the
brightest thing in the sky

652
00:28:07,885 --> 00:28:09,153
and if it has solar panels,

653
00:28:09,186 --> 00:28:11,756
it tries to get its
panels on the sun

654
00:28:11,789 --> 00:28:15,593
and then it tries to establish
communications with Earth.

655
00:28:15,626 --> 00:28:19,397
So it knows in advance
if Earth is over this way

656
00:28:19,430 --> 00:28:22,767
or over that way and to
choose the right antenna

657
00:28:22,800 --> 00:28:24,168
for which way.

658
00:28:24,201 --> 00:28:27,004
And then it goes to
a communication style

659
00:28:27,037 --> 00:28:29,674
that it just sits
there and waits for,

660
00:28:29,707 --> 00:28:31,576
kind of waits for
the Earth to tell,

661
00:28:31,609 --> 00:28:33,911
to press to call home.

662
00:28:33,944 --> 00:28:35,880
And then it's sun comm power,

663
00:28:35,913 --> 00:28:38,449
then you turn everything

off that's not necessary.

664
00:28:38,482 --> 00:28:39,917
Obviously, if you're in trouble

665
00:28:39,950 --> 00:28:41,085
and don't know where you are,

666
00:28:41,118 --> 00:28:43,121
you're not taking science.

667
00:28:43,154 --> 00:28:45,289
So you turn off
unnecessary parts

668
00:28:45,322 --> 00:28:48,359
and then you just wait for
the ground to intervene

669
00:28:48,392 --> 00:28:51,095
and fault protection,
that's one of the things

670
00:28:51,128 --> 00:28:53,765
that's gotten more and
more and more sophisticated

671
00:28:53,798 --> 00:28:55,233
as time's gone on.

672
00:28:55,266 --> 00:28:56,467
>> Preston: So you guys
have learned an engineering,

673
00:28:56,500 --> 00:28:58,269
an aerospace engineering
term tonight.

674
00:28:58,302 --> 00:29:00,071

>> Sun comm power.
>> Sun comm power.

675
00:29:00,104 --> 00:29:01,272
>> Sun communications power.

676
00:29:01,305 --> 00:29:02,573
Sun comm power.

677
00:29:02,606 --> 00:29:04,075
So let's actually
take a look at that.

678
00:29:04,108 --> 00:29:07,178
Let's go back to August of 1977

679
00:29:07,211 --> 00:29:09,347
and the launch of the
Voyager 2 spacecraft

680
00:29:09,380 --> 00:29:13,985
to see this kind of autonomy
and action for the first time.

681
00:29:14,018 --> 00:29:16,621
>> Announcer: Three, two, one.

682
00:29:18,055 --> 00:29:21,592
We have ignition and we
have lift off of the Titan

683
00:29:21,625 --> 00:29:24,562
sent off carrying the first
of two Voyager spacecraft

684
00:29:24,595 --> 00:29:27,632
to extend men's senses
farther into the solar system

685

00:29:27,665 --> 00:29:29,267
than ever before.

686
00:29:29,300 --> 00:29:30,535
>> Narrator: Voyager's
programmers

687
00:29:30,568 --> 00:29:31,502
had taught the
spacecraft

688
00:29:31,535 --> 00:29:34,005
that if it sensed
anything unusual

689
00:29:34,038 --> 00:29:36,440
to switch to backup systems

690
00:29:36,473 --> 00:29:39,744
and that's exactly what
had already occurred.

691
00:29:39,777 --> 00:29:43,014
Engineers call this
fault protection.

692
00:29:43,047 --> 00:29:46,851
>> The fault protection
started doing its thing

693
00:29:46,884 --> 00:29:48,286
reconfiguring the system,

694
00:29:48,319 --> 00:29:50,755
are still attached to
the launch vehicle.

695
00:29:50,788 --> 00:29:53,858
It's in the early
stages of its flight

696
00:29:53,891 --> 00:29:58,496
and the first thing we see
here the gyros being swapped.

697
00:29:58,529 --> 00:30:00,431
>> Narrator: Gyros
provide a sense of balance

698
00:30:00,464 --> 00:30:02,567
and orientation.

699
00:30:02,600 --> 00:30:07,271
And Voyager 2's gyros
believed something was wrong.

700
00:30:07,304 --> 00:30:10,374
That was because JPL engineers
had not prepared Voyager

701
00:30:10,407 --> 00:30:14,512
for how rough a ride
the launch would be.

702
00:30:14,545 --> 00:30:17,215
>> The launch vehicle as
part of its powered flight

703
00:30:17,248 --> 00:30:18,917
went through a roll.

704
00:30:20,284 --> 00:30:22,119
And the spacecraft would never
have done that on its own

705
00:30:22,152 --> 00:30:24,722
so spacecraft thought
that was a fault.

706

00:30:24,755 --> 00:30:27,558
>> So it went through this
whole sequence of trying things

707
00:30:27,591 --> 00:30:29,627
and we, holy mackerel,
this spacecraft

708
00:30:29,660 --> 00:30:31,996
looks like it's going bonkers.

709
00:30:32,029 --> 00:30:34,432
And we thought that we'd
lost the spacecraft.

710
00:30:34,465 --> 00:30:35,800
>> Chris: Finally,
we got to separate

711
00:30:35,833 --> 00:30:37,368
from the launch vehicle

712
00:30:37,401 --> 00:30:40,304
and we were on our own but
the problems weren't over.

713
00:30:40,337 --> 00:30:42,473
>> Narrator: The boom
holding science instruments

714
00:30:42,506 --> 00:30:45,743
appeared not to have
locked into place.

715
00:30:47,144 --> 00:30:51,583
And far worse, the spacecraft
was now slowly tumbling.

716
00:30:55,853 --> 00:30:57,655
A last-ditch suggestion was made

717
00:30:57,688 --> 00:31:00,658
to stop the computer and reboot.

718
00:31:00,691 --> 00:31:02,960
But Chris Jones knew
that then the spacecraft

719
00:31:02,993 --> 00:31:05,129
would be unable to
lock on to the Sun

720
00:31:05,162 --> 00:31:08,399
to properly orient itself
to head on to Jupiter

721
00:31:08,432 --> 00:31:10,968
and that would mean
a lost mission.

722
00:31:11,001 --> 00:31:13,237
>> When I heard
the recommendation

723
00:31:13,270 --> 00:31:13,938
come from Pasadena

724
00:31:13,971 --> 00:31:16,040
that let's send that to error,

725
00:31:16,073 --> 00:31:18,976
I knew instantly that that
was the wrong thing to do.

726
00:31:19,009 --> 00:31:21,178
Now, I had to convince people
who were still mystified

727
00:31:21,211 --> 00:31:23,514

as to why anything was happening

728
00:31:23,547 --> 00:31:26,884
but I think Glen believed
in me as did John

729
00:31:26,917 --> 00:31:28,085
that we shouldn't do that

730
00:31:28,118 --> 00:31:31,956
and so that was the
decision that was made.

731
00:31:31,989 --> 00:31:33,457
>> Narrator: The
Voyagers were designed

732
00:31:33,490 --> 00:31:37,261
to take care of themselves
in the far reaches of space.

733
00:31:37,294 --> 00:31:39,530
No one thought the first
test of its ability

734
00:31:39,563 --> 00:31:42,166
to survive on its own would
happen in the early hours

735
00:31:42,199 --> 00:31:43,668
of the mission.

736
00:31:43,701 --> 00:31:46,170
But that is exactly what it did.

737
00:31:46,203 --> 00:31:50,174
After swapping thrusters, gyros
and finally, the computers,

738

00:31:50,207 --> 00:31:51,943
Voyager 2 stabilized.

739
00:31:54,545 --> 00:31:57,381
>> Well, it's good they
listened to that young engineer.

740
00:31:57,414 --> 00:32:00,618
Let the spacecraft do what
it was programmed to do.

741
00:32:00,651 --> 00:32:01,852
>> That's right.

742
00:32:01,885 --> 00:32:03,154
We still try to do
it that way too.

743
00:32:03,187 --> 00:32:05,923
I mean, the whole idea
is to train these things

744
00:32:05,956 --> 00:32:07,725
to deal with these responses.

745
00:32:07,758 --> 00:32:10,127
If we go around from Earth
and start mucking with it,

746
00:32:10,160 --> 00:32:13,397
there's like having two
people in charge of your robot

747
00:32:13,430 --> 00:32:16,901
at the same time and you
end up with bad results,

748
00:32:16,934 --> 00:32:19,503
when we you have two
people in charge, as know.

749
00:32:19,536 --> 00:32:21,939
>> That's exactly right.

750
00:32:21,972 --> 00:32:23,808
>> Well, okay, so yeah.

751
00:32:23,841 --> 00:32:26,877
Let's leap forward
another 20 years

752
00:32:26,910 --> 00:32:28,646
to another important milestone

753
00:32:28,679 --> 00:32:31,916
which was the first
rover on Mars.

754
00:32:31,949 --> 00:32:33,618
Rob, you were there.

755
00:32:34,551 --> 00:32:36,487
We've established that.

756
00:32:37,688 --> 00:32:38,756
>> Julie: I'm off to
into a big mission.

757
00:32:38,789 --> 00:32:39,590
>> Yeah, yeah.

758
00:32:39,623 --> 00:32:40,758
>> Preston: Ooh, ooh.

759
00:32:40,791 --> 00:32:42,159
[laughing]

760
00:32:42,192 --> 00:32:43,094

>> I built your computers
for your mission.

761
00:32:43,127 --> 00:32:45,596
>> Here we go, here we go.

762
00:32:45,629 --> 00:32:49,200
Seriously, this required
a new level of autonomy

763
00:32:49,233 --> 00:32:50,568
and complexity, didn't it?

764
00:32:50,601 --> 00:32:53,738
>> Yeah, as a matter
of fact, so we stole

765
00:32:53,771 --> 00:32:56,440
a lot of technology
from Cassini project

766
00:32:56,473 --> 00:32:58,876
and we stuck it with
some new technology

767
00:32:58,909 --> 00:33:00,745
that we hadn't had before.

768
00:33:00,778 --> 00:33:01,979
It had some decent,

769
00:33:02,012 --> 00:33:04,015
first time, some really
decent computer power

770
00:33:04,048 --> 00:33:05,783
and some decent computer memory.

771
00:33:05,816 --> 00:33:08,586

And we stuffed it
into a little lander.

772
00:33:08,619 --> 00:33:11,989
For the first time, a fully
centralized computing system

773
00:33:12,022 --> 00:33:13,357
because before, they
were distributed

774
00:33:13,390 --> 00:33:15,326
with little computers
here and there,

775
00:33:15,359 --> 00:33:16,327
we had to put it
all in one space.

776
00:33:16,360 --> 00:33:17,795
Not because I wanted it,

777
00:33:17,828 --> 00:33:21,032
we needed it centralized,
just we had no room to put it.

778
00:33:21,065 --> 00:33:22,266
We only a little tiny space

779
00:33:22,299 --> 00:33:26,203
inside a tetrahedral
shaped Mars lander

780
00:33:26,236 --> 00:33:29,540
that was headed to Mars in 1997.

781
00:33:29,573 --> 00:33:31,709
And then later, in
the 4th of July.

782
00:33:31,742 --> 00:33:33,010
>> That was was a
good day around here.

783
00:33:33,043 --> 00:33:34,812
>> Julie: It was a good day.

784
00:33:34,845 --> 00:33:37,782
>> So the irony is that
many the technology

785
00:33:37,815 --> 00:33:39,984
we took and stole from Cassini,

786
00:33:40,017 --> 00:33:42,787
we actually got a chance to
launch before Cassini did

787
00:33:42,820 --> 00:33:45,289
so we got a chance to
test her spacecrafts.

788
00:33:45,322 --> 00:33:47,425
>> That's exactly
true, actually.

789
00:33:47,458 --> 00:33:49,026
>> Rob: Yeah, that's fine.

790
00:33:49,059 --> 00:33:51,028
>> Well, we have we
have another video here

791
00:33:51,061 --> 00:33:53,764
of what it was like
here at NASA JPL

792
00:33:53,797 --> 00:33:56,667
at the time that

Pathfinder landed

793
00:33:56,700 --> 00:34:00,104
and let's take a look
at that dramatic moment.

794
00:34:00,137 --> 00:34:04,342
>> Narrator: Friday morning,
the 4th of July, 1997.

795
00:34:05,509 --> 00:34:08,012
[tense music]

796
00:34:12,282 --> 00:34:15,319
>> Man: The Pathfinder in
it's first stage separation.

797
00:34:15,352 --> 00:34:17,621
>> Man: Right, this is the Mars
Pathfinder flight director,

798
00:34:17,654 --> 00:34:22,660
we have confirmed that first
stage separation has occurred.

799
00:34:23,393 --> 00:34:24,629
30 seconds till entry.

800
00:34:26,830 --> 00:34:29,867
Spacecraft is now slowing
down very rapidly.

801
00:34:29,900 --> 00:34:34,739
We expect that the parachute
will deploy about 15 seconds.

802
00:34:40,210 --> 00:34:42,279
Parachute have now deployed.

803

00:34:42,312 --> 00:34:45,049
[exciting music]

804
00:34:54,391 --> 00:34:58,963
Lander separation should have
occurred right about now.

805
00:35:00,264 --> 00:35:02,433
Airbag should be inflated.

806
00:35:04,735 --> 00:35:07,338
[moving music]

807
00:35:19,850 --> 00:35:23,854
[muffled speaking through radio]

808
00:35:23,887 --> 00:35:24,688
>> Yes!
>> That ought to do that.

809
00:35:24,721 --> 00:35:25,623
>> Yes, yes!

810
00:36:00,290 --> 00:36:01,859
>> Man: We have a
confirmed signal.

811
00:36:01,892 --> 00:36:05,796
[all cheering and applauding]

812
00:36:15,772 --> 00:36:17,074
>> Rob: Yeah.

813
00:36:17,107 --> 00:36:19,210
>> You recognize this guy.

814
00:36:20,210 --> 00:36:23,147
>> I haven't changed, am I?

815
00:36:23,180 --> 00:36:26,317
No, it's important to point
out when you see these videos

816
00:36:26,350 --> 00:36:30,188
of Viking, Pathfinder,
Spirit and Opportunity,

817
00:36:31,421 --> 00:36:33,757
Curiosity, all these
other things that land,

818
00:36:33,790 --> 00:36:36,827
all these people are leaping
up in just joy, right?

819
00:36:36,860 --> 00:36:38,196
No, it's relief.

820
00:36:39,696 --> 00:36:43,167
It's relief because
you're having nightmares

821
00:36:43,200 --> 00:36:46,604
right up to the morning,
what did we forget to test?

822
00:36:46,637 --> 00:36:49,273
What is it I don't
know about this thing?

823
00:36:49,306 --> 00:36:50,507
>> Julie: We've gone
through every path

824
00:36:50,540 --> 00:36:51,442
of fault protection.
>> We've gone through

825

00:36:51,475 --> 00:36:52,977
every path of fault protection.

826
00:36:53,010 --> 00:36:56,313
And so interesting
about Pathfinder

827
00:36:56,346 --> 00:36:58,616
because it's based
a lot of the same,

828
00:36:58,649 --> 00:37:00,417
the fault protection
architectures and things,

829
00:37:00,450 --> 00:37:04,788
so the kinds of things
that we basically adapted

830
00:37:04,821 --> 00:37:08,592
the architectures from
Cassini and Voyager

831
00:37:08,625 --> 00:37:10,394
and gave it a little
bit more smarts.

832
00:37:10,427 --> 00:37:13,063
It's kinda like we're
adding layers of complexity

833
00:37:13,096 --> 00:37:16,500
on the existing architecture
because this little rover,

834
00:37:16,533 --> 00:37:19,370
on this land er, I'm sorry
I had to fly itself to Mars,

835
00:37:19,403 --> 00:37:22,439

do the landing process
and open up like a flower

836
00:37:22,472 --> 00:37:26,577
and begin the process of
controlling the vehicle.

837
00:37:28,011 --> 00:37:32,483
but it's but you couldn't
actually do it clockwork

838
00:37:32,516 --> 00:37:34,518
because you didn't know exactly

839
00:37:34,551 --> 00:37:36,020
when you're gonna
hit the atmosphere.

840
00:37:36,053 --> 00:37:37,788
You didn't know exactly
when to open the parachute.

841
00:37:37,821 --> 00:37:40,124
So it had to be more reactive
with its environment.

842
00:37:40,157 --> 00:37:43,927
It had to sense the
deceleration of the atmosphere

843
00:37:43,960 --> 00:37:46,130
and the sense how far we
are as respect to the ground

844
00:37:46,163 --> 00:37:48,065
just like the
Viking missions did.

845
00:37:48,098 --> 00:37:49,767
And those, of course,

they taught us

846
00:37:49,800 --> 00:37:51,168
most of what we needed to know

847
00:37:51,201 --> 00:37:54,571
because we were a pretty
young team here at JPL.

848
00:37:54,604 --> 00:37:59,443
So but we used the same
concepts and architectures

849
00:37:59,476 --> 00:38:02,212
that Cassini and the fault
tolerance we used there,

850
00:38:02,245 --> 00:38:03,614
you used to.

851
00:38:03,647 --> 00:38:07,384
We're trying to mill the
concept of doing things

852
00:38:07,417 --> 00:38:10,954
on a schedule versus
interacting with dynamic things

853
00:38:10,987 --> 00:38:12,623
that happen and
events that happen.

854
00:38:12,656 --> 00:38:14,925
>> But you still had to
take care of yourself.

855
00:38:14,958 --> 00:38:18,362
You had to make decisions
that most of spacecraft

856
00:38:18,395 --> 00:38:20,230
that are just flying
through don't have to make.

857
00:38:20,263 --> 00:38:21,465
>> That's right.

858
00:38:21,498 --> 00:38:23,734
>> And that was
all before it even,

859
00:38:23,767 --> 00:38:26,270
the rover even rove
off the lander.

860
00:38:26,303 --> 00:38:30,307
So what's the big difference
in operating a rover,

861
00:38:30,340 --> 00:38:32,743
a robot that has to move around

862
00:38:32,776 --> 00:38:35,846
versus your stationary lander?

863
00:38:35,879 --> 00:38:38,682
>> In some sense, it's that
same thing on steroids.

864
00:38:38,715 --> 00:38:41,719
Now, it's you have
everything you do

865
00:38:43,053 --> 00:38:45,522
is interactive with
respect to the ground.

866
00:38:45,555 --> 00:38:47,958
And little Sojourner

which had a little ATC-85

867
00:38:47,991 --> 00:38:51,295
8-bit microprocessor,
very simple little machine

868
00:38:51,328 --> 00:38:53,297
and it didn't have
complex software,

869
00:38:53,330 --> 00:38:56,934
had simple behaviors but
it was these behaviors

870
00:38:56,967 --> 00:38:58,569
are very closed
loop in the sense

871
00:38:58,602 --> 00:39:00,904
that it would try to
drive, it would stop,

872
00:39:00,937 --> 00:39:03,874
it would send these lasers
stripes on the ground

873
00:39:03,907 --> 00:39:05,743
and depending what
where those stripes

874
00:39:05,776 --> 00:39:06,910
ended up in the ground,

875
00:39:06,943 --> 00:39:08,512
all to the camera
pictures it would take,

876
00:39:08,545 --> 00:39:11,582
it would deduce if there was
a either a hole or a rock

877
00:39:11,615 --> 00:39:13,617
and if it was a rock,
he would try to turn

878
00:39:13,650 --> 00:39:15,552
to the left or the
right and go around it

879
00:39:15,585 --> 00:39:17,454
if it was trying to
get to destination.

880
00:39:17,487 --> 00:39:19,423
So it became much more
of an interactive process

881
00:39:19,456 --> 00:39:22,092
but it still wasn't
radio controlled.

882
00:39:22,125 --> 00:39:25,362
It was basically
following a script.

883
00:39:25,395 --> 00:39:27,464
The difference is instead
of using clock work,

884
00:39:27,497 --> 00:39:29,566
it had to be
event-driven in the sense

885
00:39:29,599 --> 00:39:31,769
that it once would
finish getting that far,

886
00:39:31,802 --> 00:39:33,737
the next step, not
based on a clock

887
00:39:33,770 --> 00:39:36,507
but based on success
would make another step

888
00:39:36,540 --> 00:39:39,410
and try to do the next thing
in its list of things to do

889
00:39:39,443 --> 00:39:43,414
and that architecture is
something that we had to add on,

890
00:39:43,447 --> 00:39:44,882
a little bit to Pathfinder.

891
00:39:44,915 --> 00:39:48,886
We continued doing that as
we added more complexity

892
00:39:48,919 --> 00:39:50,788
going to our next
generation of rovers.

893
00:39:50,821 --> 00:39:52,489
After that, Spirit
and Opportunity.

894
00:39:52,522 --> 00:39:55,159
>> So we talked about
this before the show

895
00:39:55,192 --> 00:39:57,928
that Pathfinder and the
missions of its era,

896
00:39:57,961 --> 00:39:59,830
the 90s and going forward,

897

00:39:59,863 --> 00:40:03,333
represented a shift in the
way that robotic missions

898
00:40:03,366 --> 00:40:07,104
were developed and built
and operated, right?

899
00:40:08,371 --> 00:40:09,273
>> Rob: Yeah, yeah.

900
00:40:09,306 --> 00:40:10,541
Huge shift.

901
00:40:10,574 --> 00:40:11,542
>> A little bit.

902
00:40:11,575 --> 00:40:12,476
There's more,

903
00:40:12,509 --> 00:40:13,844
it's kinda leads towards,

904
00:40:13,877 --> 00:40:15,279
Cassini was still--

905
00:40:15,312 --> 00:40:16,213
>> Preston: You mentioned
the learning curve.

906
00:40:16,246 --> 00:40:17,848
>> Oh, a huge learning curve.

907
00:40:17,881 --> 00:40:19,550
But one of the things
we talked about

908
00:40:19,583 --> 00:40:21,685
when we were

preparing this program

909
00:40:21,718 --> 00:40:23,887
was how much the humans,

910
00:40:23,920 --> 00:40:26,957
it was still like cabled
by the same person

911
00:40:26,990 --> 00:40:29,293
and the same mechanics
would put it together.

912
00:40:29,326 --> 00:40:32,596
So the the precision
and the difference

913
00:40:34,064 --> 00:40:36,200
between Spirit and Opportunity,

914
00:40:36,233 --> 00:40:39,236
how they how they
handled life differently

915
00:40:39,269 --> 00:40:41,805
and Spirit was lost
several years ago.

916
00:40:41,838 --> 00:40:45,609
So just the whole process
of where you are in time

917
00:40:45,642 --> 00:40:48,579
and what you're facing and
what you're gonna do next.

918
00:40:48,612 --> 00:40:51,982
>> That's right, it is build
up on those experiences

919
00:40:52,015 --> 00:40:53,250
and there are really layers.

920
00:40:53,283 --> 00:40:57,054
I mean, although there
was a big change,

921
00:40:57,087 --> 00:41:00,090
it wasn't like it had
to throw away the old,

922
00:41:00,123 --> 00:41:01,492
throw away the old
to get to the new.

923
00:41:01,525 --> 00:41:03,927
We actually added on.

924
00:41:03,960 --> 00:41:06,363
Very much like kind
of natural evolution

925
00:41:06,396 --> 00:41:08,665
when you add on the layers
and layers of things

926
00:41:08,698 --> 00:41:11,835
and the layers we added more,

927
00:41:11,868 --> 00:41:14,404
which really, the biggest
change was not in our vehicles

928
00:41:14,437 --> 00:41:17,207
but it was in our
brains because again,

929
00:41:17,240 --> 00:41:22,079
we were so used to the idea

if it's 8:05 a.m. right now,

930
00:41:22,112 --> 00:41:24,348
I know exactly what
instruction my computer,

931
00:41:24,381 --> 00:41:26,283
my spacecraft is
running on this computer

932
00:41:26,316 --> 00:41:27,818
millions of miles away.

933
00:41:27,851 --> 00:41:30,454
Now, it's kinda like
it's, well in this case,

934
00:41:30,487 --> 00:41:33,423
10:30 in the morning
on Mars time.

935
00:41:33,456 --> 00:41:35,759
It should be waking
up about now,

936
00:41:35,792 --> 00:41:37,261
we'll send a list
of things to do

937
00:41:37,294 --> 00:41:40,464
and I hope it gets it
done this afternoon.

938
00:41:40,497 --> 00:41:42,366
And we would send the message.

939
00:41:42,399 --> 00:41:45,669
It's more like an email message
with a list of things to do

940
00:41:45,702 --> 00:41:48,605
as opposed to a very
prescribed script.

941
00:41:48,638 --> 00:41:50,007
And so, which is interesting

942
00:41:50,040 --> 00:41:51,308
because it's kind of creepy now.

943
00:41:51,341 --> 00:41:53,577
You don't really know if
it's gonna get it done

944
00:41:53,610 --> 00:41:55,078
and so you have to think
about what what happens,

945
00:41:55,111 --> 00:41:57,281
well, what happens if
it runs out of energy

946
00:41:57,314 --> 00:41:59,750
halfway through the drive?

947
00:41:59,783 --> 00:42:00,717
What to do?

948
00:42:00,750 --> 00:42:02,286
Well, we gotta program that in.

949
00:42:02,319 --> 00:42:05,889
It's now fault protection
has been morphed

950
00:42:05,922 --> 00:42:08,392
into kind of like
the kind of things

951
00:42:08,425 --> 00:42:10,928
that you would do as a human
being taking care of yourself

952
00:42:10,961 --> 00:42:12,396
and normal everyday.

953
00:42:12,429 --> 00:42:13,330
Is it really a fault that
you ran out of energy

954
00:42:13,363 --> 00:42:14,598
because you drove too long?

955
00:42:14,631 --> 00:42:16,133
Not really.

956
00:42:16,166 --> 00:42:18,702
>> And when you say energy,
we should really point out,

957
00:42:18,735 --> 00:42:20,437
I mean one of the
fascinating things about this

958
00:42:20,470 --> 00:42:23,941
is how little power
these things are run on.

959
00:42:23,974 --> 00:42:27,211
Cassini started out
less than 800 watts

960
00:42:28,511 --> 00:42:31,081
and wound up 600 watts
at the end of it,

961
00:42:31,114 --> 00:42:32,716
it's half a hair dryer.

962
00:42:32,749 --> 00:42:35,152
I always throw that fact in.

963
00:42:35,185 --> 00:42:37,788
And you were working
with solar panels

964
00:42:37,821 --> 00:42:40,624
so if you ran out of energy
because you took too much time,

965
00:42:40,657 --> 00:42:42,125
you had to stop.

966
00:42:42,158 --> 00:42:46,296
>> We did and in fact, if it
goes dark for a few months

967
00:42:46,329 --> 00:42:48,899
because there's a
dust storm raging,

968
00:42:48,932 --> 00:42:50,767
you're pretty much toast.

969
00:42:50,800 --> 00:42:53,470
Actually not toast because
it's kind of chilly.

970
00:42:53,503 --> 00:42:55,505
[attendees laughing]

971
00:42:55,538 --> 00:42:56,673
So your vehicle is--

972
00:42:56,706 --> 00:42:57,641
>> Julie: You're deep freeze.

973
00:42:57,674 --> 00:42:58,909
>> You're kinda deep freeze.

974
00:42:58,942 --> 00:42:59,876
Well, good news is
actually dust storms

975
00:42:59,909 --> 00:43:01,311
are not as cold as normally

976
00:43:01,344 --> 00:43:03,814
so this vehicle,
I'm actually hopeful

977
00:43:03,847 --> 00:43:07,317
that opportunity will come
back and please root for me

978
00:43:07,350 --> 00:43:09,553
but opportunity is not,

979
00:43:09,586 --> 00:43:11,955
it's not freezing
cold but it's actually

980
00:43:11,988 --> 00:43:13,490
completely out of energy.

981
00:43:13,523 --> 00:43:15,158
There's virtually nothing,

982
00:43:15,191 --> 00:43:16,727
hardly anything left.

983
00:43:16,760 --> 00:43:18,695
Now, gradually, the
lights been coming back,

984

00:43:18,728 --> 00:43:20,664
the sky is no
longer pitch-black.

985
00:43:20,697 --> 00:43:21,932
It's got a little bit,

986
00:43:21,965 --> 00:43:23,433
it's got enough of a
glow so the battery

987
00:43:23,466 --> 00:43:26,169
is charging up every day.

988
00:43:26,202 --> 00:43:27,671
>> And hopefully, the wind's
blowing so get those dust up--

989
00:43:27,704 --> 00:43:29,039
>> Hopefully, yes, right.

990
00:43:29,072 --> 00:43:30,540
And there are expectations

991
00:43:30,573 --> 00:43:32,275
that the dust isn't really
accumulating too thickly

992
00:43:32,308 --> 00:43:33,677
on the solar panels.

993
00:43:33,710 --> 00:43:35,078
But it is.

994
00:43:35,111 --> 00:43:37,814
I mean, and even big vehicles
like Curiosity rover,

995
00:43:37,847 --> 00:43:41,785

the big one, one the size
of a car, it only operates,

996
00:43:41,818 --> 00:43:44,921
it only gets about 100
watts electricity every day.

997
00:43:44,954 --> 00:43:48,058
I mean 100 watts
power all the time.

998
00:43:48,091 --> 00:43:50,227
That's like 2,400 because Mars

999
00:43:50,260 --> 00:43:52,930
has a 24 hour and 39 minute day.

1000
00:43:54,297 --> 00:43:56,700
Very convenient for
operating on this planet.

1001
00:43:56,733 --> 00:43:58,468
>> Julie: It's not
convenient because it's,

1002
00:43:58,501 --> 00:43:59,736
you've gotta--

1003
00:43:59,769 --> 00:44:01,271
>> Rob: We could sleep
in 39 minutes every day.

1004
00:44:01,304 --> 00:44:03,240
I think it's great.

1005
00:44:03,273 --> 00:44:04,775
>> Well, guys, I hope
your spacecraft

1006

00:44:04,808 --> 00:44:05,709
never run out of power.

1007
00:44:05,742 --> 00:44:06,910
>> Thank you.

1008
00:44:06,943 --> 00:44:08,378
>> That's about all
the time we have

1009
00:44:08,411 --> 00:44:09,713
for our first segment here I
think it's a great place to end

1010
00:44:09,746 --> 00:44:11,381
so thank you both.

1011
00:44:11,414 --> 00:44:12,649
We have more in store.

1012
00:44:12,682 --> 00:44:14,651
So coming up after
this brief video,

1013
00:44:14,684 --> 00:44:16,219
we'll be taking a look forward

1014
00:44:16,252 --> 00:44:19,823
into what's coming up in
the future so stick around.

1015
00:44:19,856 --> 00:44:23,093
[attendees applauding]

1016
00:44:23,126 --> 00:44:25,696
[mellow music]

1017
00:44:34,003 --> 00:44:36,740
[exciting music]

1018
00:44:45,014 --> 00:44:47,317
>> We are inquisitive, we
wanna understand things,

1019
00:44:47,350 --> 00:44:50,554
we wanna understand
more about our place

1020
00:44:50,587 --> 00:44:54,992
in the galaxy and our place,
really, in the universe.

1021
00:45:07,203 --> 00:45:10,107
>> NASA's always been the
leader in space exploration.

1022
00:45:10,140 --> 00:45:12,809
In fact, NASA's been
the first agency

1023
00:45:12,842 --> 00:45:15,779
to explore each and every
one of the major bodies

1024
00:45:15,812 --> 00:45:17,581
in the solar system.

1025
00:45:17,614 --> 00:45:19,349
>> It used to be that
we were completely bound

1026
00:45:19,382 --> 00:45:21,719
to the surface of the Earth.

1027
00:45:23,319 --> 00:45:25,255
Now, we actually have
spacecraft that have orbited

1028

00:45:25,288 --> 00:45:26,523
Mercury and Venus.

1029
00:45:26,556 --> 00:45:27,958
We've been around
Jupiter and Saturn

1030
00:45:27,991 --> 00:45:29,426
and all the way to
the outer planets,

1031
00:45:29,459 --> 00:45:31,194
all the way out to
Pluto and beyond.

1032
00:45:31,227 --> 00:45:32,696
Think about that.

1033
00:45:32,729 --> 00:45:35,432
In 60 years, we went from
just standing on the surface

1034
00:45:35,465 --> 00:45:37,667
underneath our
atmosphere looking up

1035
00:45:37,700 --> 00:45:40,637
to actually visiting
these places.

1036
00:45:48,511 --> 00:45:50,814
>> Human exploration
is not Star Trek.

1037
00:45:50,847 --> 00:45:53,750
It's not go where no
human has gone before.

1038
00:45:53,783 --> 00:45:56,386
Planetary scientists

actually go first.

1039
00:45:56,419 --> 00:45:58,722
They study the body, they
study the environment,

1040
00:45:58,755 --> 00:46:01,825
they look at the risks,
they look at the resources

1041
00:46:01,858 --> 00:46:06,463
and then human exploration
with that knowledge moves out

1042
00:46:06,496 --> 00:46:11,067
leaving low Earth orbit, going
the moon and then on to Mars.

1043
00:46:11,100 --> 00:46:13,170
>> Obviously, we wanna
take humans to Mars.

1044
00:46:13,203 --> 00:46:16,173
Obviously, we want somebody
walking on that surface

1045
00:46:16,206 --> 00:46:18,508
but our prime missions
are helping us understand

1046
00:46:18,541 --> 00:46:20,443
more about Mars and
helping us understand

1047
00:46:20,476 --> 00:46:22,445
how to create oxygen and
helping us understand

1048
00:46:22,478 --> 00:46:24,414
about the atmosphere

and the wind

1049
00:46:24,447 --> 00:46:28,018
so that we can actually
have a living life on Mars.

1050
00:46:28,051 --> 00:46:30,053
>> The areas that we
are most interested in

1051
00:46:30,086 --> 00:46:31,955
where we're putting
most of our resources

1052
00:46:31,988 --> 00:46:35,425
are the areas where there
is a potential for life.

1053
00:46:35,458 --> 00:46:37,460
So when you think
about Enceladus

1054
00:46:37,493 --> 00:46:38,662
which is a
moon of Saturn

1055
00:46:38,695 --> 00:46:41,731
and you think about Europa
which is a moon of Jupiter,

1056
00:46:41,764 --> 00:46:44,301
these are water worlds
where we're talking about

1057
00:46:44,334 --> 00:46:47,804
entire oceans with ice
shelves and ultimately,

1058
00:46:47,837 --> 00:46:50,807
the question is it possible

that we could find life

1059
00:46:50,840 --> 00:46:53,543
on those worlds that are
moons of other planets

1060
00:46:53,576 --> 00:46:55,913
within our own solar system?

1061
00:47:03,453 --> 00:47:05,655
>> My job is to go
look and use the tools

1062
00:47:05,688 --> 00:47:07,324
that NASA has provided

1063
00:47:07,357 --> 00:47:09,426
so that we can learn
what's out there.

1064
00:47:09,459 --> 00:47:10,627
How does everything work?

1065
00:47:10,660 --> 00:47:13,063
The Sun, the Earth,
the planets, the stars.

1066
00:47:13,096 --> 00:47:15,866
All of these things are
space science for us.

1067
00:47:15,899 --> 00:47:19,369
Galaxies or clouds of stars,
hundreds of billions of stars

1068
00:47:19,402 --> 00:47:21,238
are going away from
us with a speed

1069

00:47:21,271 --> 00:47:23,240
proportional to distance.

1070
00:47:23,273 --> 00:47:24,674
Well what made that happen?

1071
00:47:24,707 --> 00:47:26,743
You divide the speed
into the distance,

1072
00:47:26,776 --> 00:47:28,378
you get the age of the universe.

1073
00:47:28,411 --> 00:47:33,350
So that was the first time we
knew the universe had an age.

1074
00:47:42,458 --> 00:47:43,960
>> Questions like
where do we come from

1075
00:47:43,993 --> 00:47:46,930
and how do we get here and
the big one are we alone?

1076
00:47:46,963 --> 00:47:48,531
As much as we've learned
about the cosmos,

1077
00:47:48,564 --> 00:47:50,634
there's still so much
that we don't know

1078
00:47:50,667 --> 00:47:52,469
and that's why NASA
build telescopes

1079
00:47:52,502 --> 00:47:54,004
to answer those big questions

1080
00:47:54,037 --> 00:47:55,972
that we haven't been
able to answer yet.

1081
00:47:56,005 --> 00:47:58,408
>> We can do more than
we've ever done before

1082
00:47:58,441 --> 00:48:00,577
because of capabilities
that exist today.

1083
00:48:00,610 --> 00:48:03,546
So the next 60 years, I
think is just gonna be

1084
00:48:03,579 --> 00:48:07,017
an exponential growth of our
knowledge and understanding

1085
00:48:07,050 --> 00:48:10,988
which is really what NASA
was created for 1958.

1086
00:48:19,762 --> 00:48:23,333
>> Well, let's shift our
focus now to the future.

1087
00:48:23,366 --> 00:48:24,801
We're gonna spend a
little time talking

1088
00:48:24,834 --> 00:48:27,637
about how our robotic
spacecraft are likely to change

1089
00:48:27,670 --> 00:48:29,339
in the next couple of decades.

1090

00:48:29,372 --> 00:48:31,474
So joining us now are
a couple of NASA people

1091
00:48:31,507 --> 00:48:32,909
who spend a lot of their time

1092
00:48:32,942 --> 00:48:36,012
thinking about
future spacecraft.

1093
00:48:36,045 --> 00:48:38,515
Dr. Charles Norton, works
for NASA Headquarters

1094
00:48:38,548 --> 00:48:41,084
advising the agency
on small spacecraft

1095
00:48:41,117 --> 00:48:42,886
missions and strategy.

1096
00:48:42,919 --> 00:48:45,121
He's managed numerous
SmallSat missions

1097
00:48:45,154 --> 00:48:48,658
and we'll be talking about
SmallSats in just a few minutes.

1098
00:48:48,691 --> 00:48:52,529
And Dr. Anne Marinan who is a
systems engineer here at JPL.

1099
00:48:52,562 --> 00:48:55,298
She works on what
we call formulation

1100
00:48:55,331 --> 00:48:57,434
leading a team that

looks at the feasibility

1101
00:48:57,467 --> 00:48:59,502
of new mission concepts.

1102
00:48:59,535 --> 00:49:01,538
She's also working on a
couple of SmallSat missions

1103
00:49:01,571 --> 00:49:03,940
right now including one
that's on its way to Mars

1104
00:49:03,973 --> 00:49:05,175
which she'll tell us about.

1105
00:49:05,208 --> 00:49:09,279
So guys, to get started,
let's talk about what

1106
00:49:09,312 --> 00:49:12,082
new sorts of environments

1107
00:49:12,115 --> 00:49:15,151
we expect to be spending
our spacecraft to.

1108
00:49:15,184 --> 00:49:20,090
>> Yeah, so the first panel
talked a lot about flying by

1109
00:49:20,123 --> 00:49:22,359
a planet then orbiting a planet
then landing on a planet.

1110
00:49:22,392 --> 00:49:24,194
So now, a lot of people are
talking about what happens

1111

00:49:24,227 --> 00:49:28,431
if you go deeper, so inside
caves or inside lava tubes

1112
00:49:28,464 --> 00:49:32,168
or under these giant ice
sheets and into oceans

1113
00:49:32,201 --> 00:49:36,206
or flying around on planets or
moons that have atmospheres.

1114
00:49:36,239 --> 00:49:38,708
So it's really, the next,

1115
00:49:38,741 --> 00:49:41,845
one new environment
is like the next step

1116
00:49:41,878 --> 00:49:45,281
after just landing and
roving around on a planet.

1117
00:49:45,314 --> 00:49:47,183
>> Exactly, and these
environments

1118
00:49:47,216 --> 00:49:48,184
are really introducing

1119
00:49:48,217 --> 00:49:50,620
new types of challenges
that we have to address

1120
00:49:50,653 --> 00:49:52,889
but what's exciting
is these challenges

1121
00:49:52,922 --> 00:49:54,591
are driven by new

scientific opportunities

1122
00:49:54,624 --> 00:49:56,626
that we want to explore.

1123
00:49:58,027 --> 00:50:01,164
>> And so, one that excites
me the most is crevices

1124
00:50:01,197 --> 00:50:03,366
and caves on the moon
and things like that.

1125
00:50:03,399 --> 00:50:04,868
So climbing robots.

1126
00:50:04,901 --> 00:50:07,037
So we've got a video right now

1127
00:50:07,070 --> 00:50:11,041
that provides a great example
of a type of environment

1128
00:50:11,074 --> 00:50:13,910
that we might send a spacecraft
to and that's a comet.

1129
00:50:13,943 --> 00:50:17,280
So here's a video on
the Hedgehog Rover.

1130
00:50:22,852 --> 00:50:23,753
>> Robert: Comets and asteroids

1131
00:50:23,786 --> 00:50:25,321
are very fascinating places.

1132
00:50:25,354 --> 00:50:27,057
They may contain building blocks

1133
00:50:27,090 --> 00:50:30,593
or reminisce of the building
blocks of the solar system.

1134
00:50:30,626 --> 00:50:31,828
However, to explore,

1135
00:50:31,861 --> 00:50:33,863
they present a unique
set of challenges.

1136
00:50:33,896 --> 00:50:35,498
There is the low
gravity environment

1137
00:50:35,531 --> 00:50:37,267
or microgravity as we call it.

1138
00:50:37,300 --> 00:50:38,902
For example, a
person here on Earth

1139
00:50:38,935 --> 00:50:40,603
would weigh as
little as a paperclip

1140
00:50:40,636 --> 00:50:42,138
on the surface of a comet.

1141
00:50:42,171 --> 00:50:45,041
So rover like Curiosity which
is currently exploring Mars

1142
00:50:45,074 --> 00:50:46,976
would actually only weigh
a couple of kilograms.

1143
00:50:47,009 --> 00:50:49,179

It wouldn't be able to
generate much traction

1144
00:50:49,212 --> 00:50:51,514
and in fact, as it
turns its wheels,

1145
00:50:51,547 --> 00:50:54,084
it would probably just push
itself away from the surface.

1146
00:50:54,117 --> 00:50:56,186
It's actually quite
likely to end up rotating

1147
00:50:56,219 --> 00:50:57,720
and landing upside down,

1148
00:50:57,753 --> 00:50:59,856
at which point, it's end of
the mission for the rover.

1149
00:50:59,889 --> 00:51:01,324
So we set together,
JPL and Stanford

1150
00:51:01,357 --> 00:51:04,060
have been working on a totally
different rover concept

1151
00:51:04,093 --> 00:51:06,896
that is well suited to these
environments called Hedgehog.

1152
00:51:06,929 --> 00:51:08,531
Instead of rolling
around on wheels,

1153
00:51:08,564 --> 00:51:11,034
the Hedgehog design actually

puts three flywheels

1154
00:51:11,067 --> 00:51:14,237
on the inside of a cube by
spinning these flywheels up

1155
00:51:14,270 --> 00:51:17,073
very slowly and then very
quickly applying a brake

1156
00:51:17,106 --> 00:51:19,375
which transfers all the
momentum from the flywheels,

1157
00:51:19,408 --> 00:51:23,947
we're able to cause Hedgehog
to either hop or tumble

1158
00:51:23,980 --> 00:51:25,949
or perform small adjustments.

1159
00:51:25,982 --> 00:51:27,884
We've done many
tests here on Earth

1160
00:51:27,917 --> 00:51:29,953
in gravity offloading test bits.

1161
00:51:29,986 --> 00:51:32,956
Recently, we've flown
two Hedgehog prototypes

1162
00:51:32,989 --> 00:51:34,324
on a Zero-G aircraft.

1163
00:51:34,357 --> 00:51:36,025
In these tests, we demonstrated

1164
00:51:36,058 --> 00:51:39,295

that we would be able to perform
on a comet or an asteroid.

1165
00:51:39,328 --> 00:51:40,730
Hedgehog doesn't
have a right way up.

1166
00:51:40,763 --> 00:51:42,565
Instead, it can tumble
over the surface

1167
00:51:42,598 --> 00:51:45,135
and come to rest on
any one of its faces

1168
00:51:45,168 --> 00:51:46,603
and still work perfectly.

1169
00:51:46,636 --> 00:51:47,904
The Rosetta mission
has sent back

1170
00:51:47,937 --> 00:51:50,273
lots of very fascinating
images from the surface

1171
00:51:50,306 --> 00:51:52,909
of Comet 67P and
these images show us

1172
00:51:52,942 --> 00:51:54,511
some incredibly rugged terrain

1173
00:51:54,544 --> 00:51:57,046
including large sinkholes
where a traditional rover

1174
00:51:57,079 --> 00:51:58,515
would get terribly stuck.

1175
00:51:58,548 --> 00:52:00,250
So we've even tested
Hedgehog performing

1176
00:52:00,283 --> 00:52:02,752
a type of escape maneuver
where it spins itself up

1177
00:52:02,785 --> 00:52:04,854
and does this
tornado-like maneuver

1178
00:52:04,887 --> 00:52:07,123
where it can actually
launch itself vertically

1179
00:52:07,156 --> 00:52:08,592
out of a sandpit.

1180
00:52:10,526 --> 00:52:12,428
In our future work, we're
looking at increasingly

1181
00:52:12,461 --> 00:52:14,364
level autonomy giving
the Hedgehog Rovers

1182
00:52:14,397 --> 00:52:16,032
the ability to think for himself

1183
00:52:16,065 --> 00:52:17,934
and to navigate from
one point to another.

1184
00:52:17,967 --> 00:52:19,669
The Hedgehog Rover's
ability to move around

1185
00:52:19,702 --> 00:52:21,604

on the surface of
comets and asteroids

1186
00:52:21,637 --> 00:52:23,540
could enable a wide
range of applications

1187
00:52:23,573 --> 00:52:25,642
in science in the future.

1188
00:52:28,144 --> 00:52:30,180
>> Very cool concept.

1189
00:52:30,213 --> 00:52:33,716
So there are clearly lots
of potential destinations

1190
00:52:33,749 --> 00:52:35,451
where you could send a robot

1191
00:52:35,484 --> 00:52:37,687
and even at a single
body like the moon,

1192
00:52:37,720 --> 00:52:39,255
there are lots of
places you could go

1193
00:52:39,288 --> 00:52:40,790
and things you could do.

1194
00:52:40,823 --> 00:52:45,095
So how do you determine where
you actually need a spacecraft

1195
00:52:46,529 --> 00:52:49,732
to go and what capabilities
it'll need when it gets there?

1196

00:52:49,765 --> 00:52:52,101
>> Right, well, the
scientific community

1197
00:52:52,134 --> 00:52:55,004
has a very well-defined
process that they use

1198
00:52:55,037 --> 00:52:58,608
to try to assess
what's important,

1199
00:52:58,641 --> 00:53:01,511
how we should make decisions
about where we want to go

1200
00:53:01,544 --> 00:53:06,416
and as a community, they
prioritize what should be done.

1201
00:53:06,449 --> 00:53:08,885
And there are
mechanisms that involve,

1202
00:53:08,918 --> 00:53:13,256
not just NASA scientists but
also international partners.

1203
00:53:13,289 --> 00:53:17,961
And as part of that is really
shown here with the Hedgehog.

1204
00:53:17,994 --> 00:53:20,830
It's a community which has
a great desire to innovate.

1205
00:53:20,863 --> 00:53:22,999
So a lot of what people
are thinking about

1206

00:53:23,032 --> 00:53:25,034
when they're looking at
what are the new place

1207
00:53:25,067 --> 00:53:27,670
that we should go on new types
of missions we should develop

1208
00:53:27,703 --> 00:53:30,707
are really focused
on how can we bring

1209
00:53:30,740 --> 00:53:33,409
in our ingenuity
forward in a way

1210
00:53:33,442 --> 00:53:35,578
to advance scientific objectives

1211
00:53:35,611 --> 00:53:37,580
that the community
has agreed upon.

1212
00:53:37,613 --> 00:53:39,649
But once you do that,
you have to figure out

1213
00:53:39,682 --> 00:53:41,184
how do we really make this work,

1214
00:53:41,217 --> 00:53:42,785
what type of studies
so we have to do.

1215
00:53:42,818 --> 00:53:46,689
The trade-off, what's the best
way of achieving these goals.

1216
00:53:46,722 --> 00:53:47,991
And I know Anne, you

spend a lot of time

1217
00:53:48,024 --> 00:53:49,492
thinking about that.

1218
00:53:49,525 --> 00:53:52,061
>> Yeah, so at formulation,
we take these science answers

1219
00:53:52,094 --> 00:53:53,763
or questions that
we want to answer

1220
00:53:53,796 --> 00:53:55,732
and figure out how
we're gonna answer them.

1221
00:53:55,765 --> 00:53:59,035
So where do you have to go to
answer the science question

1222
00:53:59,068 --> 00:54:00,536
like is there life on Mars?

1223
00:54:00,569 --> 00:54:02,572
And so obviously,
you're going to Mars

1224
00:54:02,605 --> 00:54:04,807
and then what kinds
of vehicle do you need

1225
00:54:04,840 --> 00:54:07,677
or depending on what kind of
question you want to answer,

1226
00:54:07,710 --> 00:54:10,013
you choose what kind of
measurements you want to make

1227
00:54:10,046 --> 00:54:11,948
and so then what kind
of instruments you need

1228
00:54:11,981 --> 00:54:14,617
to take those measurements and
then what does the spacecraft

1229
00:54:14,650 --> 00:54:17,754
that bringing these measurements
to Mars have to look like.

1230
00:54:17,787 --> 00:54:18,888
And if you're landing
or if you're going

1231
00:54:18,921 --> 00:54:20,490
into a new environment,

1232
00:54:20,523 --> 00:54:23,326
what new challenges does the
spacecraft have to overcome

1233
00:54:23,359 --> 00:54:26,429
and what new capabilities
that does that have to do?

1234
00:54:26,462 --> 00:54:28,364
Do we have the
technology to do that?

1235
00:54:28,397 --> 00:54:31,367
And then if we don't,
who needs to build it

1236
00:54:31,400 --> 00:54:34,671
and where are we gonna get it?

1237
00:54:34,704 --> 00:54:37,974

>> And so, there are a
lot of these capabilities

1238
00:54:38,007 --> 00:54:39,776
that you're talking
about are constantly

1239
00:54:39,809 --> 00:54:42,912
continuously in this cycle
of development and testing

1240
00:54:42,945 --> 00:54:45,181
and there are new ones
being developed today

1241
00:54:45,214 --> 00:54:49,118
such as robots that can climb,
new types of instruments.

1242
00:54:49,151 --> 00:54:52,288
I'm sure Charles, there are
a lot that are on the horizon

1243
00:54:52,321 --> 00:54:53,589
that you're interested in.

1244
00:54:53,622 --> 00:54:56,993
So one example that we
have here in the room

1245
00:54:57,026 --> 00:54:59,195
of one of these exciting
capabilities for the future

1246
00:54:59,228 --> 00:55:01,531
is powered flight
on another planet

1247
00:55:01,564 --> 00:55:02,899
and I know it sounds

like science fiction

1248
00:55:02,932 --> 00:55:04,567
but it's a real thing.

1249
00:55:04,600 --> 00:55:08,805
This is the Mars Helicopter and
as you'll see in this video,

1250
00:55:08,838 --> 00:55:11,874
it's slated to become reality
in just a couple of years.

1251
00:55:11,907 --> 00:55:13,410
Let's take a look.

1252
00:55:14,910 --> 00:55:18,415
[dramatic exciting music]

1253
00:55:59,155 --> 00:56:01,391
>> Woman: 2200, 2400, 2600.

1254
00:56:03,859 --> 00:56:07,364
[dramatic exciting music]

1255
00:56:34,557 --> 00:56:36,526
>> Another wow.

1256
00:56:36,559 --> 00:56:37,760
That's something that certainly

1257
00:56:37,793 --> 00:56:38,895
would have seemed
like science fiction

1258
00:56:38,928 --> 00:56:40,997
when NASA was
founded 60 years ago.

1259
00:56:41,030 --> 00:56:44,667
The Mars Helicopter slated
to fly to Mars in 2020

1260
00:56:44,700 --> 00:56:46,202
with the next NASA rover.

1261
00:56:46,235 --> 00:56:48,204
So let's change topics.

1262
00:56:48,237 --> 00:56:50,239
You both have done a
significant amount of work

1263
00:56:50,272 --> 00:56:53,676
on what we call
small spacecraft,

1264
00:56:53,709 --> 00:56:55,044
SmallSats and CubeSats.

1265
00:56:55,945 --> 00:56:57,413
Let's talk a bit about those.

1266
00:56:57,446 --> 00:57:00,516
So first of all, what are
they and what kind of role

1267
00:57:00,549 --> 00:57:03,953
do you expect them to
play going forward?

1268
00:57:03,986 --> 00:57:07,590
>> Yes, well, CubeSats, it's
very similar to the name.

1269
00:57:07,623 --> 00:57:09,559
You could think of a small box

1270
00:57:09,592 --> 00:57:12,762
which is roughly four
centimeters on a side.

1271
00:57:12,795 --> 00:57:16,966
They were developed primarily
as ways for students to learn

1272
00:57:16,999 --> 00:57:20,636
how to develop and
fly space missions.

1273
00:57:20,669 --> 00:57:23,906
But what has really happened
over the last few years

1274
00:57:23,939 --> 00:57:27,143
is due to advances in
consumer electronics,

1275
00:57:27,176 --> 00:57:29,445
advances in miniaturization,

1276
00:57:29,478 --> 00:57:31,314
people have been able
to become very creative

1277
00:57:31,347 --> 00:57:34,016
with what you can do with
this type of capability.

1278
00:57:34,049 --> 00:57:38,254
And by their very design,
they're very amenable

1279
00:57:38,287 --> 00:57:40,990
to easy access to
space and launch.

1280

00:57:41,023 --> 00:57:43,392
So you now have an
incredible capability

1281
00:57:43,425 --> 00:57:45,828
to conceive of new missions,

1282
00:57:45,861 --> 00:57:48,231
conceive of new
science experiments,

1283
00:57:48,264 --> 00:57:51,734
fit those capabilities
into the small cubes

1284
00:57:51,767 --> 00:57:54,036
or conglomerations
of these cubes

1285
00:57:54,069 --> 00:57:55,872
and make slightly
larger systems,

1286
00:57:55,905 --> 00:57:57,573
get them to
space quickly

1287
00:57:57,606 --> 00:58:01,110
and really just have
an incredible ability

1288
00:58:02,278 --> 00:58:04,480
to think about what are
the types of missions

1289
00:58:04,513 --> 00:58:06,816
that are uniquely
enabled by these systems

1290
00:58:06,849 --> 00:58:10,786

that are not so easy
to do with the large

1291
00:58:10,819 --> 00:58:13,823
spacecraft that we even
see around in this room.

1292
00:58:13,856 --> 00:58:16,859
>> With the small missions,
er, small spacecraft

1293
00:58:16,892 --> 00:58:19,495
and it's not just CubeSats,
it's anything basically

1294
00:58:19,528 --> 00:58:22,198
under the size of a washing
machine, we consider small.

1295
00:58:22,231 --> 00:58:23,733
>> That's right.

1296
00:58:23,766 --> 00:58:25,935
>> So the things you can do
with these small satellites,

1297
00:58:25,968 --> 00:58:30,172
typically they're very
focused like single mind

1298
00:58:30,205 --> 00:58:32,775
oriented kinds of spacecraft.

1299
00:58:32,808 --> 00:58:35,077
And so they're really
good for very specific

1300
00:58:35,110 --> 00:58:38,147
technology demonstrations or
flying something brand new

1301
00:58:38,180 --> 00:58:40,283
that could be used
on a larger mission

1302
00:58:40,316 --> 00:58:43,419
where someone wants to
use on a future mission

1303
00:58:43,452 --> 00:58:45,221
but they want to make
sure it actually works

1304
00:58:45,254 --> 00:58:47,123
in space before they fly it.

1305
00:58:47,156 --> 00:58:50,626
So these are really good
like test platforms in space

1306
00:58:50,659 --> 00:58:52,628
in a relevant
environment, basically.

1307
00:58:52,661 --> 00:58:54,931
>> You're working on just
such a mission right now.

1308
00:58:54,964 --> 00:58:56,232
>> I am, yes.

1309
00:58:56,265 --> 00:58:57,800
So this is,

1310
00:58:57,833 --> 00:59:00,269
it's a mini model of MarCO,

1311
00:59:00,302 --> 00:59:02,972
so MarCO stands

for Mars Cube One

1312
00:59:03,005 --> 00:59:04,507
although there are two of them

1313
00:59:04,540 --> 00:59:06,075
and they're on their
way to Mars right now

1314
00:59:06,108 --> 00:59:08,010
and it is a technology
demonstration mission.

1315
00:59:08,043 --> 00:59:11,013
There's no science
payload on it.

1316
00:59:11,046 --> 00:59:13,015
Instead, we're flying a
bunch of new technologies

1317
00:59:13,048 --> 00:59:15,685
that have never been
flown in deep space before

1318
00:59:15,718 --> 00:59:17,587
and one of them is
a radio an antenna

1319
00:59:17,620 --> 00:59:19,589
that were developed by
JPL and one of the things

1320
00:59:19,622 --> 00:59:23,326
we hope to demonstrate is a
communications relay capability

1321
00:59:23,359 --> 00:59:25,661
as the InSight lander
which is supposed to land

1322
00:59:25,694 --> 00:59:29,231
on Cyber Monday goes through,
it's seven minutes of terror

1323
00:59:29,264 --> 00:59:32,602
so we can get that data back
to Earth as soon as possible.

1324
00:59:32,635 --> 00:59:34,537
>> And Charles, you
have an example here

1325
00:59:34,570 --> 00:59:36,606
of how a SmallSat is
also bringing another

1326
00:59:36,639 --> 00:59:38,774
really cool new
capability to the table.

1327
00:59:38,807 --> 00:59:40,042
What's that?

1328
00:59:40,075 --> 00:59:42,812
>> Exactly, I mean right
over here is a CubeSat.

1329
00:59:42,845 --> 00:59:46,048
It's called a 6U CubeSat
because it's largely made

1330
00:59:46,081 --> 00:59:49,018
of six of these units
called RainCube.

1331
00:59:49,051 --> 00:59:51,954
So it's a radar in a CubeSat.

1332

00:59:51,987 --> 00:59:55,825
And what's amazing here
is it's a instrument

1333
00:59:55,858 --> 00:59:59,962
that could measure
precipitation profiles

1334
00:59:59,995 --> 01:00:01,564
through Earth's atmosphere.

1335
01:00:01,597 --> 01:00:03,566
And what's really
incredible about it

1336
01:00:03,599 --> 01:00:06,102
is that a number of key
technologies report forward

1337
01:00:06,135 --> 01:00:08,004
to enable this capability

1338
01:00:08,037 --> 01:00:10,873
where many in the community
thought you can never make

1339
01:00:10,906 --> 01:00:13,142
a radar this small.

1340
01:00:13,175 --> 01:00:16,545
You'll see this umbrella
looking like structure

1341
01:00:16,578 --> 01:00:17,914
which is a mesh.

1342
01:00:19,214 --> 01:00:23,352
What it is actually is a
Ka-band transmitter and receiver

1343
01:00:23,385 --> 01:00:26,022
so we can send radar pulses
through the atmosphere

1344
01:00:26,055 --> 01:00:28,391
and through clouds,
receive the signal back

1345
01:00:28,424 --> 01:00:31,661
and measure profiles
of precipitation.

1346
01:00:31,694 --> 01:00:34,664
And in addition, there is a
very sophisticated electronics

1347
01:00:34,697 --> 01:00:37,133
and algorithms within the box

1348
01:00:37,166 --> 01:00:40,136
that I allow you to do the
processing to interpret

1349
01:00:40,169 --> 01:00:43,039
and turn that data into science.

1350
01:00:43,072 --> 01:00:45,307
And it's just an
incredible capability

1351
01:00:45,340 --> 01:00:48,110
which was just launched
a few weeks ago

1352
01:00:48,143 --> 01:00:51,514
and has just been
returning data lately.

1353
01:00:51,547 --> 01:00:53,916

That's one of the important
aspects these small missions,

1354
01:00:53,949 --> 01:00:55,418
you can do things rapidly.

1355
01:00:55,451 --> 01:00:58,254
>> And also, they've
been able to miniaturize,

1356
01:00:58,287 --> 01:01:00,256
a capability that you
would expect to see

1357
01:01:00,289 --> 01:01:01,757
on a much larger spacecraft.

1358
01:01:01,790 --> 01:01:03,859
In the past, you had to
have a big spacecraft

1359
01:01:03,892 --> 01:01:05,761
if you wanted to
send a radar, right?

1360
01:01:05,794 --> 01:01:08,297
>> They would require
large power system

1361
01:01:08,330 --> 01:01:10,666
so you'd have much
larger solar panels

1362
01:01:10,699 --> 01:01:12,601
than the ones that you see here.

1363
01:01:12,634 --> 01:01:14,403
Very large antennas.

1364

01:01:14,436 --> 01:01:17,039
And one of the benefits again
of these smaller systems

1365
01:01:17,072 --> 01:01:19,041
is that you can
deploy many of them.

1366
01:01:19,074 --> 01:01:21,911
So what we expect to do
is to have constellations

1367
01:01:21,944 --> 01:01:25,414
of these systems where we
could have very rapid revisit

1368
01:01:25,447 --> 01:01:29,118
and almost near real-time
measurements of precipitation.

1369
01:01:29,151 --> 01:01:31,420
>> Cool, let's talk a
bit about how spacecraft

1370
01:01:31,453 --> 01:01:33,456
will communicate
in different ways.

1371
01:01:33,489 --> 01:01:36,425
We already touched
on having SmallSats

1372
01:01:36,458 --> 01:01:38,027
could act as
communications relays

1373
01:01:38,060 --> 01:01:41,130
but there's this other
idea of using lasers

1374

01:01:41,163 --> 01:01:43,265
which really interest me.

1375
01:01:43,298 --> 01:01:45,401
Instead of rate radio
waves to communicate.

1376
01:01:45,434 --> 01:01:46,902
What's that all about?

1377
01:01:46,935 --> 01:01:48,571
>> So optical communication
or laser communication.

1378
01:01:48,604 --> 01:01:52,074
And so, instead of using
a radio, you use a laser

1379
01:01:52,107 --> 01:01:53,976
and send data over
beams of light.

1380
01:01:54,009 --> 01:01:55,478
And so one of the
advantages of that

1381
01:01:55,511 --> 01:01:57,780
is as radio propagates
just naturally

1382
01:01:57,813 --> 01:01:59,348
through an environment
or through space,

1383
01:01:59,381 --> 01:02:02,051
it expands a lot
which is great for not

1384
01:02:02,084 --> 01:02:04,386
really having to control where

your spacecraft is pointing

1385
01:02:04,419 --> 01:02:06,689
because chances are
if it's wide enough,

1386
01:02:06,722 --> 01:02:09,759
you're gonna get the Earth
within the beam something.

1387
01:02:09,792 --> 01:02:12,428
For a laser, it's
much more focused.

1388
01:02:12,461 --> 01:02:13,662
So while it's,

1389
01:02:13,695 --> 01:02:15,431
you have to point
it a lot better,

1390
01:02:15,464 --> 01:02:19,602
you gain all that efficiency
of having your entire beam

1391
01:02:19,635 --> 01:02:22,605
or at least most of
your beam and compass.

1392
01:02:22,638 --> 01:02:23,773
>> Concentrated in the compass.

1393
01:02:23,806 --> 01:02:25,107
>> Yeah, concentrated
on your receiver

1394
01:02:25,140 --> 01:02:26,542
because with the
expanded signal,

1395
01:02:26,575 --> 01:02:28,911
you lose a lot of that power

1396
01:02:29,878 --> 01:02:31,413
propagated around it.

1397
01:02:31,446 --> 01:02:35,084
And so if you focus most of
the beam on your receiver,

1398
01:02:35,117 --> 01:02:37,586
you can get more data
back for the same power.

1399
01:02:37,619 --> 01:02:39,421
And because it's a
different frequency,

1400
01:02:39,454 --> 01:02:41,023
it's a higher frequency
than radio waves,

1401
01:02:41,056 --> 01:02:43,425
you can also send a
lot more data through.

1402
01:02:43,458 --> 01:02:46,028
So in terms of
like what is that?

1403
01:02:46,061 --> 01:02:48,030
It's more like
ethernet or gigabit

1404
01:02:48,063 --> 01:02:50,166
kind of communications
from space.

1405
01:02:50,199 --> 01:02:51,567

Right now, we're kind of limited

1406
01:02:51,600 --> 01:02:53,068
to the megabit per second range.

1407
01:02:53,101 --> 01:02:54,970
And we're talking about
hundreds of megabits per second

1408
01:02:55,003 --> 01:02:59,441
to gigabit so it really
is like a broadband.

1409
01:02:59,474 --> 01:03:00,743
>> Enabling capability really

1410
01:03:00,776 --> 01:03:02,511
for future missions
going forward.

1411
01:03:02,544 --> 01:03:05,614
I mean we're developing much
more sophisticated instruments

1412
01:03:05,647 --> 01:03:09,852
to take much more data
that do many more tasks

1413
01:03:09,885 --> 01:03:12,888
and we have in the
past and laser comm

1414
01:03:12,921 --> 01:03:15,524
is absolutely going to be
needed to take advantage

1415
01:03:15,557 --> 01:03:17,526
of these capabilities.

1416

01:03:17,559 --> 01:03:20,129
>> Yeah, it's not just
coming, it's here.

1417
01:03:20,162 --> 01:03:21,964
We've tried it out
from the space station,

1418
01:03:21,997 --> 01:03:24,967
we've tested it out from the
moon with the LADEE mission.

1419
01:03:25,000 --> 01:03:26,669
And we're now sending,

1420
01:03:26,702 --> 01:03:28,704
we're planning to
send one to deep space

1421
01:03:28,737 --> 01:03:30,673
with an upcoming
mission called Psyche

1422
01:03:30,706 --> 01:03:34,577
that's going to an
asteroid so very cool.

1423
01:03:34,610 --> 01:03:38,080
Yeah, let's talk about
another cool change

1424
01:03:38,113 --> 01:03:41,383
coming to spacecraft in the
future and that is 3D printing.

1425
01:03:41,416 --> 01:03:44,753
So 3D printed parts
and whole structures.

1426
01:03:44,786 --> 01:03:46,589

How do you think
that 3D printing

1427
01:03:46,622 --> 01:03:50,559
is likely to play a role in
spacecraft going forward?

1428
01:03:50,592 --> 01:03:53,462
>> Yeah, again, I think it's
another essential capability.

1429
01:03:53,495 --> 01:03:56,799
I mean with 3D printing,
you really have the ability

1430
01:03:56,832 --> 01:04:00,502
to customize very exactly
the types of structures

1431
01:04:00,535 --> 01:04:03,572
and components and
even in some cases,

1432
01:04:03,605 --> 01:04:06,208
full systems that you
would like to develop.

1433
01:04:06,241 --> 01:04:10,512
And an important aspect of 3D
printing is another capability

1434
01:04:10,545 --> 01:04:12,481
called additive manufacturing

1435
01:04:12,514 --> 01:04:16,085
where as you are printing
these parts in these devices,

1436
01:04:16,118 --> 01:04:18,954
you can actually add more

sophisticated components

1437
01:04:18,987 --> 01:04:21,591
into the system and essentially

1438
01:04:22,658 --> 01:04:25,160
be able to replicate
very rapidly

1439
01:04:25,193 --> 01:04:28,230
and they're very
repeatable fashion,

1440
01:04:28,263 --> 01:04:31,467
the types of instruments
or spacecraft of the future

1441
01:04:31,500 --> 01:04:33,969
that we would definitely
want to develop

1442
01:04:34,002 --> 01:04:36,639
and it's also happening now.

1443
01:04:36,672 --> 01:04:38,507
>> Well, we have a
couple of examples here

1444
01:04:38,540 --> 01:04:41,010
that I thought were pretty cool.

1445
01:04:41,043 --> 01:04:46,048
This is a 3D printed piece
of what we call space fabric.

1446
01:04:47,182 --> 01:04:48,450
This is all one
single piece here.

1447

01:04:48,483 --> 01:04:51,987
It looks like chain
mail but it's an example

1448
01:04:52,020 --> 01:04:54,990
of something you could 3D
print an exterior covering

1449
01:04:55,023 --> 01:04:57,326
for a spacecraft out
of a single piece

1450
01:04:57,359 --> 01:04:59,461
and then there's
another one here.

1451
01:04:59,494 --> 01:05:00,796
This is a whole,

1452
01:05:00,829 --> 01:05:03,232
an example of printing
a whole structure,

1453
01:05:03,265 --> 01:05:04,633
a whole spacecraft structure.

1454
01:05:04,666 --> 01:05:07,436
I think this is meant
to be a hard lander

1455
01:05:07,469 --> 01:05:09,872
for the surface of an
icy moon like Europa

1456
01:05:09,905 --> 01:05:14,443
but the idea being, I
guess instead of making

1457
01:05:14,476 --> 01:05:16,812
multiple pieces and having

to put them together,

1458
01:05:16,845 --> 01:05:20,215
you would print the
entire structure

1459
01:05:20,248 --> 01:05:21,850
and then you could
add stuff on to it.

1460
01:05:21,883 --> 01:05:23,319
And you had a cool,

1461
01:05:23,352 --> 01:05:24,720
there was a cool
footnote about that

1462
01:05:24,753 --> 01:05:26,956
where you mentioned
printing other stuff like--

1463
01:05:26,989 --> 01:05:29,625
>> Yeah, so instead of
just having a structure

1464
01:05:29,658 --> 01:05:31,126
with additive manufacturing

1465
01:05:31,159 --> 01:05:33,929
and being able to combine
different kinds of materials

1466
01:05:33,962 --> 01:05:36,799
into one structure
like simultaneously,

1467
01:05:36,832 --> 01:05:39,368
you could build circuit
boards into this structure.

1468
01:05:39,401 --> 01:05:42,571
And so instead of having
to integrate cards,

1469
01:05:42,604 --> 01:05:44,540
you could be much
more volume efficient

1470
01:05:44,573 --> 01:05:46,742
which is a huge thing for
sending things to space

1471
01:05:46,775 --> 01:05:50,212
and actually build in
electronics components

1472
01:05:50,245 --> 01:05:53,949
and circuits and instruments
inside the structure itself.

1473
01:05:53,982 --> 01:05:57,987
So you could kind of print
an entire spacecraft.

1474
01:05:59,154 --> 01:06:00,255
>> In one piece,

1475
01:06:00,288 --> 01:06:01,190
in one go.
>> You could print

1476
01:06:01,223 --> 01:06:02,358
an entire spacecraft, yeah.

1477
01:06:02,391 --> 01:06:03,759
>> So this, I
guess that's where,

1478
01:06:03,792 --> 01:06:07,096

your jobs are going to
robots, Rob and Julie, sorry.

1479
01:06:07,129 --> 01:06:09,298
[laughing]

1480
01:06:09,331 --> 01:06:12,201
So it sounds like
from a lot of things

1481
01:06:12,234 --> 01:06:14,136
we're talking about
tonight that our robots

1482
01:06:14,169 --> 01:06:16,839
are gonna need increasing
levels of autonomy

1483
01:06:16,872 --> 01:06:19,708
to do some of the things
we're gonna be asking of them.

1484
01:06:19,741 --> 01:06:21,643
So are they gonna
keep getting smarter?

1485
01:06:21,676 --> 01:06:23,345
How smart do we need them to be?

1486
01:06:23,378 --> 01:06:25,047
Is there a sweet spot?

1487
01:06:25,080 --> 01:06:26,582
>> Oh, they're going
to keep getting smarter

1488
01:06:26,615 --> 01:06:28,851
and we need them they
get much smarter.

1489
01:06:28,884 --> 01:06:30,185
That's just the reality.

1490
01:06:30,218 --> 01:06:32,488
I mean, as we talked
about even earlier

1491
01:06:32,521 --> 01:06:34,323
in the earlier session,

1492
01:06:34,356 --> 01:06:37,059
a lot of the missions
are developed today

1493
01:06:37,092 --> 01:06:40,796
are very much programmed
and planned in advance.

1494
01:06:40,829 --> 01:06:43,198
We know what to do,
we know what to expect

1495
01:06:43,231 --> 01:06:46,168
and even as we learn, we can
give the some flexibility

1496
01:06:46,201 --> 01:06:47,703
to what will happen.

1497
01:06:47,736 --> 01:06:49,571
But if we think about
the missions you wanna do

1498
01:06:49,604 --> 01:06:50,839
in the future.

1499
01:06:50,872 --> 01:06:53,642
If we want to look at
interstellar missions,

1500
01:06:53,675 --> 01:06:55,377
if we want to look at
missions in environments

1501
01:06:55,410 --> 01:06:58,047
where we don't completely
understand where we're going

1502
01:06:58,080 --> 01:06:59,548
and what we expect to see,

1503
01:06:59,581 --> 01:07:01,316
we're going to
require the spacecraft

1504
01:07:01,349 --> 01:07:05,587
to do much more intelligent
thinking on its own

1505
01:07:05,620 --> 01:07:10,059
and autonomy and
information system advances

1506
01:07:10,092 --> 01:07:14,196
are going be essential
to enabling that.

1507
01:07:14,229 --> 01:07:17,699
And I foresee there would
be great discoveries

1508
01:07:17,732 --> 01:07:19,368
that will be
produced as a result

1509
01:07:19,401 --> 01:07:21,170
of the capability of
that kind different.

1510
01:07:21,203 --> 01:07:22,404
>> And it's putting a
different spin on it.

1511
01:07:22,437 --> 01:07:24,306
The idea of being
able to reconfigure

1512
01:07:24,339 --> 01:07:26,208
your spacecraft internally,

1513
01:07:26,241 --> 01:07:27,376
like be able to reprogram it.

1514
01:07:27,409 --> 01:07:29,011
So instead of using,

1515
01:07:29,044 --> 01:07:33,282
instead of using like a radio
for just for communications,

1516
01:07:33,315 --> 01:07:34,883
what if could do signs out of it

1517
01:07:34,916 --> 01:07:37,419
or tune it to a slightly
different frequency

1518
01:07:37,452 --> 01:07:38,921
so I can make a
different measurement.

1519
01:07:38,954 --> 01:07:43,959
This idea of having a much more
malleable internal structure

1520
01:07:45,127 --> 01:07:46,061
of the spacecraft that
as you'd make more,

1521
01:07:46,094 --> 01:07:47,629
as you make new discoveries,

1522
01:07:47,662 --> 01:07:49,231
you can make
different measurements

1523
01:07:49,264 --> 01:07:53,235
and have it learn and
evolve based on what you see

1524
01:07:53,268 --> 01:07:54,470
in the environment.

1525
01:07:54,503 --> 01:07:55,637
>> Yeah, I mean, as
even some thought,

1526
01:07:55,670 --> 01:07:57,239
again, turning
back to 3D printing

1527
01:07:57,272 --> 01:07:59,908
and additive manufacturing
that you may embed

1528
01:07:59,941 --> 01:08:04,947
in the spacecraft design itself
a capability for self-repair

1529
01:08:06,348 --> 01:08:08,650
if you're an environment
where you cannot actually

1530
01:08:08,683 --> 01:08:10,285
either retrieve the spacecraft

1531
01:08:10,318 --> 01:08:13,222

or have certain types
of fault tolerance

1532
01:08:13,255 --> 01:08:14,490
that would be amenable

1533
01:08:14,523 --> 01:08:17,693
to certain types of
hardware failures.

1534
01:08:17,726 --> 01:08:20,762
>> We're about out of time
so I'd like to wrap up.

1535
01:08:20,795 --> 01:08:22,097
I'd like to ask you this.

1536
01:08:22,130 --> 01:08:24,233
Are there new developments
on the horizon

1537
01:08:24,266 --> 01:08:25,701
that when you guys
think about them,

1538
01:08:25,734 --> 01:08:28,604
they really get you
excited for the future?

1539
01:08:28,637 --> 01:08:29,972
>> Yeah, so the thing
that really excites me

1540
01:08:30,005 --> 01:08:31,540
is it's less of a technology

1541
01:08:31,573 --> 01:08:33,108
and more of kind
of a paradigm shift

1542
01:08:33,141 --> 01:08:36,178
with these small satellites
and it's easy access to space

1543
01:08:36,211 --> 01:08:39,348
and the accessibility of space
in general for not just NASA

1544
01:08:39,381 --> 01:08:41,350
but the entire global community.

1545
01:08:41,383 --> 01:08:43,785
You see university students

1546
01:08:43,818 --> 01:08:46,755
and the early career
people like me

1547
01:08:46,788 --> 01:08:50,692
being able to build these
satellites in a year or less

1548
01:08:50,725 --> 01:08:53,829
and learn at the very
beginning of their career

1549
01:08:53,862 --> 01:08:56,732
how difficult it is to
launch things into space

1550
01:08:56,765 --> 01:08:58,133
and actually be able to,

1551
01:08:58,166 --> 01:09:00,736
like in grad school, I launched
and was able to operate

1552
01:09:00,769 --> 01:09:02,404
a satellite in space

1553
01:09:02,437 --> 01:09:04,840
and so there's this whole
new generation of engineers

1554
01:09:04,873 --> 01:09:06,875
who have this
hands-on experience

1555
01:09:06,908 --> 01:09:08,744
and has flown
spacecraft

1556
01:09:08,777 --> 01:09:11,246
that we're building
the new ones.

1557
01:09:11,279 --> 01:09:14,883
So it's so different from
how it was done before

1558
01:09:14,916 --> 01:09:17,286
and I mean I'm very
excited about it.

1559
01:09:17,319 --> 01:09:19,454
>> Yeah, and for those of us
that are a little less early

1560
01:09:19,487 --> 01:09:21,490
in their career like me.

1561
01:09:23,692 --> 01:09:27,229
The truth of the matter
is I'm used to seeing

1562
01:09:27,262 --> 01:09:30,832
and working on submissions
where we were really limited

1563
01:09:30,865 --> 01:09:32,668
by the lift capacity
of the rockets

1564
01:09:32,701 --> 01:09:34,703
and we are building
bigger rockets

1565
01:09:34,736 --> 01:09:38,040
but the idea was that we would
build one large spacecraft

1566
01:09:38,073 --> 01:09:39,641
and maybe it had to
make a measurement

1567
01:09:39,674 --> 01:09:42,110
that required a large
deployable system.

1568
01:09:42,143 --> 01:09:44,479
What I see going
forward is the ability

1569
01:09:44,512 --> 01:09:49,084
of using many spacecraft that
are smaller, cooperatively

1570
01:09:49,117 --> 01:09:52,988
which can be used in an
in space assembly sense

1571
01:09:53,021 --> 01:09:55,657
where we could make
very, very large systems

1572
01:09:55,690 --> 01:09:57,726
that could make new
types of measurements

1573
01:09:57,759 --> 01:10:02,097
that are just not capable
to launch from the rockets

1574
01:10:03,198 --> 01:10:05,400
that we have in
development right now.

1575
01:10:05,433 --> 01:10:07,603
And if you think
about the resilience

1576
01:10:07,636 --> 01:10:10,472
and the robustness that
can come from those systems

1577
01:10:10,505 --> 01:10:11,673
where if there is a failure

1578
01:10:11,706 --> 01:10:13,609
or something you
need to replace,

1579
01:10:13,642 --> 01:10:17,713
you can simply replace
that one section of it

1580
01:10:17,746 --> 01:10:19,214
through another launch.

1581
01:10:19,247 --> 01:10:21,850
It's just incredible
to think about

1582
01:10:21,883 --> 01:10:23,418
what the scientific
community could conceive of

1583
01:10:23,451 --> 01:10:25,687

with the capability
of that kind.

1584
01:10:25,720 --> 01:10:26,955
>> Absolutely fantastic.

1585
01:10:26,988 --> 01:10:29,091
Well, I think that's
a good place to end.

1586
01:10:29,124 --> 01:10:32,060
Well, remember, when it comes
to the role of the robots,

1587
01:10:32,093 --> 01:10:35,030
they're an extension of
us and with their help,

1588
01:10:35,063 --> 01:10:37,966
just imagine what we can
accomplish in the next 60 years.

1589
01:10:37,999 --> 01:10:39,868
So thank you to all of
our panelists tonight

1590
01:10:39,901 --> 01:10:42,371
and thanks to all of
you for joining us.

1591
01:10:42,404 --> 01:10:45,741
Remember, you can find out
more about how NASA Explorers

1592
01:10:45,774 --> 01:10:46,742
at nasa.gov.

1593
01:10:47,709 --> 01:10:49,211
Thanks so much for being here.

1594
01:10:49,244 --> 01:10:52,448
[attendees applauding]

1595
01:11:10,332 --> 01:11:13,669
Okay, and we'll go to
set up for Q and A here

1596
01:11:13,702 --> 01:11:15,537
in just a second and
we'll take your questions.

1597
01:11:15,570 --> 01:11:19,875
So there's a microphone in
the center of the aisle.

1598
01:11:19,908 --> 01:11:21,844
Please step up to that.

1599
01:11:22,977 --> 01:11:24,046
>> Man: Preston, you're
going to the lectern.

1600
01:11:24,079 --> 01:11:25,414
>> Preston: Yup.

1601
01:11:43,231 --> 01:11:46,502
[attendees chattering]

1602
01:11:47,535 --> 01:11:49,405
>> Rob: Yup, thank you.

1603
01:11:52,807 --> 01:11:56,011
[attendees chattering]

1604
01:11:56,878 --> 01:12:00,082
[panelists chattering]

1605
01:12:02,183 --> 01:12:05,687

[panelists laughing]

1606
01:12:05,720 --> 01:12:09,858
>> Anne: Oh, yeah,
the present, I got it.

1607
01:12:09,891 --> 01:12:13,128
[panelists chattering]

1608
01:12:17,365 --> 01:12:19,167
>> Rob: I keep
wondering about this.

1609
01:12:19,200 --> 01:12:21,136
>> Okay, it looks like
we're getting some questions

1610
01:12:21,169 --> 01:12:22,604
queued up here.

1611
01:12:22,637 --> 01:12:24,506
I'm glad you guys have some
good ones ready for us.

1612
01:12:24,539 --> 01:12:26,541
We'll also be taking some
questions from the folks

1613
01:12:26,574 --> 01:12:29,678
watching live online
on YouTube and Facebook

1614
01:12:29,711 --> 01:12:33,782
and let everybody join
the conversation here, so.

1615
01:12:36,084 --> 01:12:37,920
If you guys are ready.

1616

01:12:39,921 --> 01:12:40,922
We'll take our first question.

1617
01:12:40,955 --> 01:12:41,790
Hi, there.

1618
01:12:42,690 --> 01:12:44,760
>> Hi, I was wondering if,

1619
01:12:46,127 --> 01:12:47,362
is this on?

1620
01:12:47,395 --> 01:12:50,132
Okay, I was wondering
if there's a potential

1621
01:12:50,165 --> 01:12:54,770
for virtual reality integration
for the Mars Helicopter

1622
01:12:56,271 --> 01:13:00,909
because I feel like maybe if
you are able to at your age

1623
01:13:02,177 --> 01:13:05,881
be able to have a spacecraft,
then maybe anyone,

1624
01:13:07,282 --> 01:13:10,919
anywhere in the world can
be part of the process.

1625
01:13:14,422 --> 01:13:15,857
>> Is that for me?

1626
01:13:15,890 --> 01:13:17,159
>> Anyone of us?

1627
01:13:18,059 --> 01:13:19,628

>> I'd be happy to try.

1628
01:13:19,661 --> 01:13:22,431
So the VR experience,
you can do.

1629
01:13:23,865 --> 01:13:25,534
I think, we've been trying
to do this for example,

1630
01:13:25,567 --> 01:13:27,903
our rovers collect

1631
01:13:27,936 --> 01:13:30,239
a high-resolution
stereo data imagery

1632
01:13:31,639 --> 01:13:34,910
and from this stereo
pairs, we can reconstruct

1633
01:13:34,943 --> 01:13:38,313
the shape of the surface
and here on Earth,

1634
01:13:38,346 --> 01:13:42,751
we can either don 3D
goggles and look around

1635
01:13:42,784 --> 01:13:45,454
and kind of walk around
as if you're on Mars.

1636
01:13:45,487 --> 01:13:49,858
Or just even look and
play with it with one eye

1637
01:13:49,891 --> 01:13:52,828
on a normal computer screen.

1638
01:13:52,861 --> 01:13:56,565
But the helicopter, it
has the same problem

1639
01:13:56,598 --> 01:13:57,833
we've almost all of our stuff

1640
01:13:57,866 --> 01:14:00,936
is that the whole
helicopter flight

1641
01:14:00,969 --> 01:14:03,538
is over in just a few minutes

1642
01:14:03,571 --> 01:14:06,508
and then the imagery
we do get back

1643
01:14:06,541 --> 01:14:08,877
and not a lot of it's video,

1644
01:14:08,910 --> 01:14:11,112
it takes a while for
that to come back

1645
01:14:11,145 --> 01:14:13,415
and so it's not an
immersive environment

1646
01:14:13,448 --> 01:14:14,916
when it's happening.

1647
01:14:14,949 --> 01:14:18,720
Now, in the other hand,
you can do what you said.

1648
01:14:18,753 --> 01:14:22,924
By visualizing in advance,
we can create models of it

1649
01:14:22,957 --> 01:14:24,192
from the
three-dimensional terrain.

1650
01:14:24,225 --> 01:14:27,195
We can imagine it
and have the computer

1651
01:14:27,228 --> 01:14:30,332
generate a prediction
of the flight

1652
01:14:30,365 --> 01:14:31,800
that we've designed for it

1653
01:14:31,833 --> 01:14:35,003
that might be planned for
tomorrow and see how it goes.

1654
01:14:35,036 --> 01:14:36,771
Just like we do when
we drive the rover.

1655
01:14:36,804 --> 01:14:38,773
We actually drive it in advance,

1656
01:14:38,806 --> 01:14:41,676
kinda like you're figuring
out where you want it to go

1657
01:14:41,709 --> 01:14:46,081
and see it in 3D and then
the things that we see

1658
01:14:46,114 --> 01:14:48,617
become the very instructions
we send to the vehicle

1659

01:14:48,650 --> 01:14:52,120
the next morning and order
the helicopter the next day.

1660
01:14:52,153 --> 01:14:54,623
So it's close but
it doesn't have

1661
01:14:54,656 --> 01:14:56,491
that kind of intuitive reaction.

1662
01:14:56,524 --> 01:14:58,627
After the fact or
even before the fact,

1663
01:14:58,660 --> 01:15:00,195
we could share that information

1664
01:15:00,228 --> 01:15:03,031
and so you could actually
see what that flight was,

1665
01:15:03,064 --> 01:15:04,666
either what it look like or
what it's going to look like

1666
01:15:04,699 --> 01:15:08,537
through a simulated
flight of the helicopter.

1667
01:15:08,570 --> 01:15:09,671
Does that make sense?

1668
01:15:09,704 --> 01:15:11,172
So, yeah.

1669
01:15:11,205 --> 01:15:15,510
And remarkably, there are
apps so you can do it today,

1670
01:15:15,543 --> 01:15:16,745
you can do it today.

1671
01:15:16,778 --> 01:15:17,979
You can actually go
look and see the 3D

1672
01:15:18,012 --> 01:15:20,282
and see what's going on on Mars.

1673
01:15:20,315 --> 01:15:21,816
It's really cool.

1674
01:15:21,849 --> 01:15:23,585
>> Julie: On other planets too.

1675
01:15:23,618 --> 01:15:25,120
>> Rob: On other
planets, Cassini?

1676
01:15:25,153 --> 01:15:26,588
>> Julie: Yeah.

1677
01:15:26,621 --> 01:15:28,523
>> Rob: Yeah, oh, you could fly
through the rings of Saturn.

1678
01:15:28,556 --> 01:15:32,127
>> The first Eric de
Young going over Venus.

1679
01:15:34,162 --> 01:15:36,164
[chuckles]

1680
01:15:36,197 --> 01:15:36,998
>> Preston: Thanks a lot.

1681
01:15:37,031 --> 01:15:38,867

>> You're welcome.

1682
01:15:38,900 --> 01:15:42,404
>> Hi, so I'm wondering
in the coming years

1683
01:15:43,605 --> 01:15:45,407
for robotics at NASA,

1684
01:15:45,440 --> 01:15:48,310
will robots like
have a broader role

1685
01:15:48,343 --> 01:15:49,744
in addition to just exploring?

1686
01:15:49,777 --> 01:15:53,448
So maybe like have construction
robots land on Mars

1687
01:15:53,481 --> 01:15:54,883
and start building
a little house

1688
01:15:54,916 --> 01:15:57,052
so that when humans get
there, there's like something,

1689
01:15:57,085 --> 01:15:59,754
there's a place to live.

1690
01:15:59,787 --> 01:16:02,357
So is that like a possibility

1691
01:16:02,390 --> 01:16:06,528
or do you see that as
something robotics at NASA

1692
01:16:06,561 --> 01:16:08,029

can take in the future?

1693
01:16:08,062 --> 01:16:11,566
>> It's on the future half
of the table here, I guess.

1694
01:16:11,599 --> 01:16:13,101
>> I mean I don't
make NASA policy

1695
01:16:13,134 --> 01:16:16,838
but I mean that's definitely
a role that robots could do

1696
01:16:16,871 --> 01:16:18,540
and would be well suited to.

1697
01:16:18,573 --> 01:16:22,644
Instead of sending people
to have to build their own

1698
01:16:22,677 --> 01:16:24,879
habitats for them,
send exploring,

1699
01:16:24,912 --> 01:16:27,215
kind of the same way that
there were pathfinders

1700
01:16:27,248 --> 01:16:30,452
to the moon to Mars, kind of
understanding the environment

1701
01:16:30,485 --> 01:16:32,887
in preparation for
a human mission,

1702
01:16:32,920 --> 01:16:35,256
it would make sense to
do something like that

1703
01:16:35,289 --> 01:16:36,825
where a robot would
go ahead of time

1704
01:16:36,858 --> 01:16:39,828
and kind of set the stage and
put a lot of things in motion

1705
01:16:39,861 --> 01:16:42,163
so by the time the
humans got there,

1706
01:16:42,196 --> 01:16:44,699
there is an infrastructure
already in place.

1707
01:16:44,732 --> 01:16:47,435
>> Yeah, we have some aspects
of that happening now.

1708
01:16:47,468 --> 01:16:52,140
There are missions that are
going to launch with the SLS

1709
01:16:53,307 --> 01:16:56,378
in a couple of years
which their whole goal

1710
01:16:56,411 --> 01:16:59,547
is to address some of these
strategic knowledge gaps

1711
01:16:59,580 --> 01:17:02,784
that will pave the way
for human exploration.

1712
01:17:02,817 --> 01:17:06,388
For example, looking for
resources and consumables

1713
01:17:06,421 --> 01:17:07,822
in the lunar environment.

1714
01:17:07,855 --> 01:17:11,026
And you could imagine
that going forward

1715
01:17:11,059 --> 01:17:14,229
as other capabilities
are developed

1716
01:17:14,262 --> 01:17:18,066
such as a lunar gateway
and other systems

1717
01:17:18,099 --> 01:17:20,468
that you would want
to have the capability

1718
01:17:20,501 --> 01:17:22,804
to have robots
interact with humans

1719
01:17:22,837 --> 01:17:26,241
and to provide those
types of environments

1720
01:17:26,274 --> 01:17:28,243
in a way that would
be beneficial.

1721
01:17:28,276 --> 01:17:30,111
>> And in fact, the
design reference missions,

1722
01:17:30,144 --> 01:17:33,148
the human design
reference missions

1723
01:17:33,181 --> 01:17:34,883
that NASA's been studying

1724
01:17:34,916 --> 01:17:39,521
have a robotically controlled
system landing in advance

1725
01:17:40,722 --> 01:17:44,059
before humans get there
where that actually does

1726
01:17:44,092 --> 01:17:45,527
in situ resource utilization

1727
01:17:45,560 --> 01:17:48,029
where it actually processes
the atmosphere of Mars,

1728
01:17:48,062 --> 01:17:51,332
takes the C from the O2
of the CO2 atmosphere

1729
01:17:51,365 --> 01:17:52,834
and creates oxygen.

1730
01:17:52,867 --> 01:17:56,905
And so there are ways of
doing that robotically.

1731
01:17:56,938 --> 01:17:59,908
It doesn't actually look
like an R2-D2 kind of rover

1732
01:17:59,941 --> 01:18:01,376
vehicle doing it.

1733
01:18:01,409 --> 01:18:02,844
It was like a machine
that's just sitting there

1734
01:18:02,877 --> 01:18:04,446
going to [imitating clicking].

1735
01:18:04,479 --> 01:18:06,181
Doing that work
and processing it

1736
01:18:06,214 --> 01:18:08,883
but when the
astronauts get there,

1737
01:18:08,916 --> 01:18:10,485
they will have
this resource there

1738
01:18:10,518 --> 01:18:14,756
already prepared and ready for
them to use on their mission.

1739
01:18:14,789 --> 01:18:17,325
>> So do you see robots doing
more kind of manipulation

1740
01:18:17,358 --> 01:18:18,793
of space in the future?

1741
01:18:18,826 --> 01:18:21,963
So like pushing asteroids around
or like drilling into moons

1742
01:18:21,996 --> 01:18:22,997
and things like that?

1743
01:18:23,030 --> 01:18:23,832
>> Rob: Sure.

1744
01:18:25,533 --> 01:18:24,699
>> Yeah.

1745
01:18:25,566 --> 01:18:26,367
>> Yes.

1746
01:18:26,400 --> 01:18:27,202
>> Yeah.

1747
01:18:27,235 --> 01:18:28,670
>> It could do it.

1748
01:18:30,104 --> 01:18:32,373
>> Something I'm curious
about as you're talking about

1749
01:18:32,406 --> 01:18:36,077
how earlier craft would
use stars for navigation

1750
01:18:36,110 --> 01:18:37,612
but also they didn't really have

1751
01:18:37,645 --> 01:18:39,781
digital cameras or computers,

1752
01:18:39,814 --> 01:18:42,417
so how could they see
around and figure out

1753
01:18:42,450 --> 01:18:45,253
enough about
navigation with stars

1754
01:18:45,286 --> 01:18:48,957
that actually use and see any
information from the stars?

1755
01:18:48,990 --> 01:18:51,960
>> So what did
what they did was,

1756
01:18:51,993 --> 01:18:56,431
like the Voyager, has a tracker
that's looks at Canopus star

1757
01:18:56,464 --> 01:18:58,600
which is a bright southern star

1758
01:18:58,633 --> 01:19:03,572
and if the vehicle starts
drifting away from it like this,

1759
01:19:05,072 --> 01:19:07,942
the sensor will say hey, the
star's moving to the left.

1760
01:19:07,975 --> 01:19:11,412
Oh, so it basically has to
either use its reaction wheel

1761
01:19:11,445 --> 01:19:14,749
or its thrusters to go to
[clicking] push it back in.

1762
01:19:14,782 --> 01:19:16,251
The rover does,

1763
01:19:16,284 --> 01:19:18,753
I mean the vehicle doesn't
really know its orientation.

1764
01:19:18,786 --> 01:19:23,358
You can't ask it but it
has this simple behavior

1765
01:19:23,391 --> 01:19:26,027
that effectively puts it in
the right orientation in space.

1766

01:19:26,060 --> 01:19:29,664
Later on Galileo and then
Cassini, we added the capability

1767
01:19:29,697 --> 01:19:31,166
where the vehicle actually says,

1768
01:19:31,199 --> 01:19:33,701
hmm, I know those stars.

1769
01:19:33,734 --> 01:19:36,004
I recognize that,
I have a star map.

1770
01:19:36,037 --> 01:19:38,706
And so they actually keep a
star map and they go, yeah,

1771
01:19:38,739 --> 01:19:40,008
I know where I am.

1772
01:19:40,041 --> 01:19:41,242
>> They do now.

1773
01:19:41,275 --> 01:19:44,279
There are cameras
but even like 1989,

1774
01:19:45,780 --> 01:19:48,617
Magellan used
basically a sextant.

1775
01:19:50,184 --> 01:19:51,786
We went out and
looked at one star

1776
01:19:51,819 --> 01:19:54,055
and then we looked
at another star

1777
01:19:54,088 --> 01:19:57,458
and navigated like
the ancient mariners.

1778
01:19:57,491 --> 01:20:01,997
They were comparing them
with the brightness of a star

1779
01:20:03,464 --> 01:20:07,268
and then every once in a while,
it would swallow a bad star

1780
01:20:07,301 --> 01:20:08,102
because it would get a--

1781
01:20:10,305 --> 01:20:08,937
>> A lot.

1782
01:20:10,338 --> 01:20:13,975
But yeah, the newer ones
are star scanners now.

1783
01:20:14,008 --> 01:20:17,045
And if you know you're gonna
blind the star scanner,

1784
01:20:17,078 --> 01:20:20,515
or yeah, like with bright
objects like the sun,

1785
01:20:20,548 --> 01:20:23,685
you need to tell it to stop
and go on gyros for a while.

1786
01:20:23,718 --> 01:20:26,521
>> Right, and these vehicles
know their orientation

1787
01:20:26,554 --> 01:20:30,124

but it wasn't until Cassini
that we actually had a vehicle

1788
01:20:30,157 --> 01:20:31,893
that actually had,

1789
01:20:31,926 --> 01:20:35,730
it knew where it was around
the Sun and where Earth was.

1790
01:20:35,763 --> 01:20:39,000
So that was a very
gradual development.

1791
01:20:40,468 --> 01:20:44,005
So we've gradually added more
intelligence to the vehicle

1792
01:20:44,038 --> 01:20:48,209
so, more self-awareness of
its own state and where it is

1793
01:20:48,242 --> 01:20:49,410
in the solar system.

1794
01:20:49,443 --> 01:20:50,678
>> Attendee: So
these early sensors

1795
01:20:50,711 --> 01:20:51,646
we're almost like
a digital camera

1796
01:20:51,679 --> 01:20:52,680
with just a few little pixels?

1797
01:20:52,713 --> 01:20:53,648
>> They are.
>> They are.

1798
01:20:53,681 --> 01:20:54,849
>> They are digital cameras.

1799
01:20:54,882 --> 01:20:55,817
They see these--
>> They take pictures.

1800
01:20:55,850 --> 01:20:57,852
>> That run through pictures

1801
01:20:57,885 --> 01:20:59,854
and then they'll look
for the brightest stars

1802
01:20:59,887 --> 01:21:02,190
in the star map and
they'll match up

1803
01:21:02,223 --> 01:21:04,292
three best or five best.

1804
01:21:04,325 --> 01:21:08,796
Juno does that, as it's going
even as its rotating today,

1805
01:21:08,829 --> 01:21:11,266
that's the way it
knows where it's at.

1806
01:21:11,299 --> 01:21:12,767
>> Anne: Now, they make
them that are these big.

1807
01:21:12,800 --> 01:21:14,002
>> Exactly.

1808
01:21:14,035 --> 01:21:16,004
They're both champing
at the bit to say that.

1809
01:21:16,037 --> 01:21:16,871
>> To say it, I know.

1810
01:21:16,904 --> 01:21:18,339
[laughing]

1811
01:21:18,372 --> 01:21:19,941
>> If you look at the
spacecraft over here,

1812
01:21:19,974 --> 01:21:22,744
that whole integrated
avionic system,

1813
01:21:22,777 --> 01:21:26,080
star tracker, the maps, the
computer, the telescope,

1814
01:21:26,113 --> 01:21:30,452
the baffles, all of it is
about the size of my fist.

1815
01:21:31,419 --> 01:21:34,122
Now, inside that space craft.

1816
01:21:34,155 --> 01:21:35,056
>> Preston: Thanks
for your question.

1817
01:21:35,089 --> 01:21:37,492
>> Attendee: Well, thank you.

1818
01:21:37,525 --> 01:21:40,495
>> Hi, so I know
that every rover

1819
01:21:40,528 --> 01:21:45,066
has to be specifically

suited for its environment.

1820
01:21:45,099 --> 01:21:48,202
Like when you're
building a rover,

1821
01:21:48,235 --> 01:21:51,406
do you go off one design
and then just modify it

1822
01:21:51,439 --> 01:21:52,840
to suit it for the environment

1823
01:21:52,873 --> 01:21:55,310
or you just completely
start from scratch?

1824
01:21:55,343 --> 01:21:56,210
>> Julie: Oh.

1825
01:21:56,243 --> 01:21:57,045
>> Rob: Great question.

1826
01:21:57,078 --> 01:21:58,813
>> Mariner, Mariner.

1827
01:21:58,846 --> 01:22:01,082
We try not to
start from scratch.

1828
01:22:01,115 --> 01:22:03,017
[laughing]

1829
01:22:03,050 --> 01:22:04,719
So one of the things

1830
01:22:06,020 --> 01:22:08,589
that we've never been
able to do completely

1831
01:22:08,622 --> 01:22:11,292
at JPL, we tried to do it
with a Mariner program,

1832
01:22:11,325 --> 01:22:14,829
we tried to do it
was Mariner Mark.

1833
01:22:14,862 --> 01:22:18,666
Cassini was supposed
to be Mariner Mark III.

1834
01:22:18,699 --> 01:22:19,600
>> Rob: Yeah.

1835
01:22:19,633 --> 01:22:21,636
>> And we were getting two?

1836
01:22:21,669 --> 01:22:23,405
Two, Mariner Mark II.

1837
01:22:24,772 --> 01:22:26,007
And it's gonna be one of--
>> As was mentioned,

1838
01:22:26,040 --> 01:22:27,675
we have our historian
here at the audience.

1839
01:22:27,708 --> 01:22:29,677
>> Yey, we knew Eric
would come through.

1840
01:22:29,710 --> 01:22:31,846
>> Charles: It's all
being fact checked.

1841
01:22:31,879 --> 01:22:34,615

>> But it's sort of like,

1842
01:22:34,648 --> 01:22:37,418
I always compare it to trying
to build a street trail bike.

1843
01:22:37,451 --> 01:22:40,254
You either got a street biker
or you got a trail bike.

1844
01:22:40,287 --> 01:22:42,290
You haven't got a
street trail bike.

1845
01:22:42,323 --> 01:22:46,661
So they are adaptable but only
within certain constraints.

1846
01:22:46,694 --> 01:22:48,563
>> Yeah, and almost
all our vehicles,

1847
01:22:48,596 --> 01:22:53,401
you'll recognize the previous
heritage inside the next one.

1848
01:22:53,434 --> 01:22:55,503
And NASA doesn't like
us to start over.

1849
01:22:55,536 --> 01:22:56,704
It's expensive.

1850
01:22:56,737 --> 01:22:58,539
So we try to adapt.

1851
01:22:58,572 --> 01:22:59,507
>> Julie: We reuse parts.

1852

01:22:59,540 --> 01:23:00,742
>> Ee try to use it, yeah, yeah.

1853
01:23:00,775 --> 01:23:02,777
>> Yeah, Cassini flew
Voyager thrusters

1854
01:23:02,810 --> 01:23:06,180
that were already 20
years old at that point.

1855
01:23:06,213 --> 01:23:08,817
And they were Apollo a vintage,

1856
01:23:10,017 --> 01:23:12,120
the main engine was
an Apollo thruster.

1857
01:23:12,153 --> 01:23:13,621
>> Rob: That's right.

1858
01:23:13,654 --> 01:23:14,555
>> Preston: The thruster
that they had on the side

1859
01:23:14,588 --> 01:23:15,790
of the Lunar Module.

1860
01:23:15,823 --> 01:23:17,325
>> On the Lunar Module,
right, that's correct.

1861
01:23:17,358 --> 01:23:18,259
>> Preston: So let's,

1862
01:23:18,292 --> 01:23:19,527
did you have a follow up?

1863
01:23:19,560 --> 01:23:20,528

>> Attendee: No.

1864
01:23:20,561 --> 01:23:21,763
>> Okay, cool.
>> Thank you.

1865
01:23:21,796 --> 01:23:22,697
>> Well, let's--
>> Great question.

1866
01:23:22,730 --> 01:23:24,198
>> Thank you for your question.

1867
01:23:24,231 --> 01:23:27,568
Let's take a question from
social media, actually.

1868
01:23:27,601 --> 01:23:29,637
I'm actually gonna
combine this into a twofer

1869
01:23:29,670 --> 01:23:31,072
because I think they're related.

1870
01:23:31,105 --> 01:23:34,175
So this will be Temple
Cave from YouTube who asks,

1871
01:23:34,208 --> 01:23:36,110
will future robotic missions

1872
01:23:36,143 --> 01:23:40,014
have equipment to detect
evidence of microbial life

1873
01:23:40,047 --> 01:23:42,717
and then that's that goes
along with David's question

1874

01:23:42,750 --> 01:23:44,419
from Facebook where he asks,

1875
01:23:44,452 --> 01:23:47,655
how do you ensure that you don't
spread Earth-based bacteria

1876
01:23:47,688 --> 01:23:48,790
to other worlds?

1877
01:23:48,823 --> 01:23:50,558
They are connected, right?

1878
01:23:50,591 --> 01:23:51,592
>> Yeah.
>> Yeah.

1879
01:23:51,625 --> 01:23:53,128
>> Julie: Sort of.

1880
01:23:54,962 --> 01:23:56,097
>> You wanna go first?
>> I'll go first.

1881
01:23:56,130 --> 01:23:58,399
Well, my wife happens
to work at JPL.

1882
01:23:58,432 --> 01:24:01,769
She's in a group called the
Planetary Protection group.

1883
01:24:01,802 --> 01:24:04,839
And in fact, that is their role,

1884
01:24:04,872 --> 01:24:09,077
to ensure that we do
not forward contaminate

1885

01:24:09,110 --> 01:24:11,746
places where we
might land spacecraft

1886
01:24:11,779 --> 01:24:14,148
and also backward
contaminate the Earth

1887
01:24:14,181 --> 01:24:16,984
from spacecraft that
we would return.

1888
01:24:17,017 --> 01:24:19,053
And it's taken very seriously.

1889
01:24:19,086 --> 01:24:22,290
Actually, I think going
back to the Apollo days,

1890
01:24:22,323 --> 01:24:25,059
there were rules
that NASA established

1891
01:24:25,092 --> 01:24:27,395
for a planetary protection.

1892
01:24:27,428 --> 01:24:30,698
>> Even the early Ranger
spacecraft at JPL built,

1893
01:24:30,731 --> 01:24:33,167
that was supposed
to go to the moon

1894
01:24:33,200 --> 01:24:35,937
and we aimed it multiple
times that there was

1895
01:24:35,970 --> 01:24:37,639
right on this stage,

1896
01:24:38,839 --> 01:24:41,309
six of them failed
one after another,

1897
01:24:41,342 --> 01:24:44,145
month month after month
for different reasons.

1898
01:24:44,178 --> 01:24:45,646
We finally got there,
but one of the reasons

1899
01:24:45,679 --> 01:24:47,081
we thought that made them fail

1900
01:24:47,114 --> 01:24:49,350
because we were cooking
the whole spacecraft

1901
01:24:49,383 --> 01:24:51,486
at 125 degrees centigrade

1902
01:24:53,521 --> 01:24:55,389
and there a lot of people
felt that was actually

1903
01:24:55,422 --> 01:24:58,526
just too much for poor
electronics to take.

1904
01:24:58,559 --> 01:25:00,228
But we've killed the bugs.

1905
01:25:00,261 --> 01:25:02,964
[all laughing]

1906
01:25:02,997 --> 01:25:08,069
The other part of the question

is about detection of life.

1907
01:25:09,236 --> 01:25:10,671
It's really, really
hard for us to detect.

1908
01:25:10,704 --> 01:25:14,308
I mean it's hard to
detect life on this planet

1909
01:25:14,341 --> 01:25:17,745
unless it's sitting
the room waving at you.

1910
01:25:17,778 --> 01:25:20,448
If it's microscopic,
it's very, very tiny,

1911
01:25:20,481 --> 01:25:24,685
it's very, very hard to deduce
especially if it's not alive

1912
01:25:24,718 --> 01:25:28,723
whether or not is actually
or truly an organic structure

1913
01:25:28,756 --> 01:25:31,692
or some sort of
remnant other structure

1914
01:25:31,725 --> 01:25:35,463
from some geomorphic phenomena
that actually occurs.

1915
01:25:35,496 --> 01:25:39,133
In fact, there was an asteroid
that came back in '84.

1916
01:25:39,166 --> 01:25:44,172
I mean actually it was found

in the in Antarctica, ALH84001.

1917
01:25:45,639 --> 01:25:48,709
It landed on Earth
about 13,000 years ago.

1918
01:25:48,742 --> 01:25:50,745
It had been in
orbit around the Sun

1919
01:25:50,778 --> 01:25:53,314
for several million years
and had been kicked off,

1920
01:25:53,347 --> 01:25:55,383
before that, it was
kicked off of Mars

1921
01:25:55,416 --> 01:25:58,052
and so if people thought
hey, there's life there.

1922
01:25:58,085 --> 01:26:01,656
And it turned out,
it's very complex

1923
01:26:01,689 --> 01:26:06,728
quasi-organic structures that
were very reminiscent of life

1924
01:26:08,162 --> 01:26:09,964
but even then, we struggled
in labs here to figure it out.

1925
01:26:09,997 --> 01:26:13,267
So we don't really have
a way yet to detect life

1926
01:26:13,300 --> 01:26:15,770
on another planet very easily

1927
01:26:15,803 --> 01:26:17,171
other than what Viking try to do

1928
01:26:17,204 --> 01:26:19,540
where you actually
pours goop in there

1929
01:26:19,573 --> 01:26:22,610
and you'd kind of hope that
this stuff, you give it food.

1930
01:26:22,643 --> 01:26:23,544
>> Charles: Ferment.

1931
01:26:23,577 --> 01:26:24,478
>> And it starts to ferment.

1932
01:26:24,511 --> 01:26:26,714
And you go, what's that smell?

1933
01:26:26,747 --> 01:26:30,585
And so yeah, so it's
very difficult to detect.

1934
01:26:31,685 --> 01:26:33,221
>> Cool, go ahead.

1935
01:26:33,254 --> 01:26:34,189
>> Yeah, hi.

1936
01:26:35,789 --> 01:26:37,225
I had a question.

1937
01:26:37,258 --> 01:26:40,762
I was wondering whether
or not the remote.

1938

01:26:42,663 --> 01:26:43,498
Remote.

1939
01:26:45,132 --> 01:26:47,702
I have mental block, I'm sorry.

1940
01:26:47,735 --> 01:26:52,740
The remote manipulator system
will increase its function

1941
01:26:53,841 --> 01:26:56,044
beyond that of
grappler, assembly,

1942
01:26:57,945 --> 01:27:01,716
anchoring the spaceman that
are doing the space work

1943
01:27:01,749 --> 01:27:03,384
like the astronauts.

1944
01:27:04,551 --> 01:27:05,920
>> Preston: Are
you asking, maybe,

1945
01:27:05,953 --> 01:27:08,389
are we going to see
additional capabilities

1946
01:27:08,422 --> 01:27:10,558
beyond the basic moving around?

1947
01:27:10,591 --> 01:27:11,492
>> Attendee: Yes.

1948
01:27:11,525 --> 01:27:12,994
>> I thinks there's this idea,

1949
01:27:13,027 --> 01:27:17,432

there's Robonaut and then
there are a variety of other

1950
01:27:18,799 --> 01:27:20,167
systems on the space station.

1951
01:27:20,200 --> 01:27:22,336
>> So it's very, very
dependent on the application.

1952
01:27:22,369 --> 01:27:24,805
They're not making generic ones.

1953
01:27:24,838 --> 01:27:29,277
For example, our robotic arms
and our rovers, for example,

1954
01:27:29,310 --> 01:27:31,012
are getting bigger and
bigger and heavier.

1955
01:27:31,045 --> 01:27:33,514
Mostly, because we're adding
more tools into the arm

1956
01:27:33,547 --> 01:27:35,449
and hope the rover
is gonna go clunk.

1957
01:27:35,482 --> 01:27:36,917
It's so heavy.

1958
01:27:36,950 --> 01:27:38,319
Big chunk of stuff.

1959
01:27:38,352 --> 01:27:41,389
We've added science instruments
and all sorts of things

1960

01:27:41,422 --> 01:27:43,157
are being bolt at the
end of these robotic arms

1961
01:27:43,190 --> 01:27:44,725
but they're just the same,

1962
01:27:44,758 --> 01:27:47,528
conceptually the same multi
degree of freedom robotic arms

1963
01:27:47,561 --> 01:27:51,766
that you see in robots that
you can buy in catalogs

1964
01:27:51,799 --> 01:27:54,302
here on this planet,
architecturally.

1965
01:27:54,335 --> 01:27:58,506
But really, so the application
of the end effector

1966
01:27:59,907 --> 01:28:01,342
is really dependent on what
it is you want it to do

1967
01:28:01,375 --> 01:28:04,012
for a living and so in our case,

1968
01:28:05,312 --> 01:28:07,148
the one that's being
built right now

1969
01:28:07,181 --> 01:28:09,717
and just a few
hundred feet from here

1970
01:28:09,750 --> 01:28:12,286
will be integrated

into our clean room

1971
01:28:12,319 --> 01:28:14,522
for the Mars 2020 mission.

1972
01:28:14,555 --> 01:28:18,393
The hand of this robotic
arm is about this big

1973
01:28:19,593 --> 01:28:21,562
and it's just chock
full of instruments,

1974
01:28:21,595 --> 01:28:25,166
a coring drill system,
a dust removal tool.

1975
01:28:27,301 --> 01:28:30,905
You see blowing air on the
dust or remove dust on rocks.

1976
01:28:30,938 --> 01:28:32,239
It's got sensors, got cameras,

1977
01:28:32,272 --> 01:28:34,275
it's just chock full of stuff.

1978
01:28:34,308 --> 01:28:38,279
So I would say it's very
dependent what it is

1979
01:28:38,312 --> 01:28:40,047
the problem that's
being trying to,

1980
01:28:40,080 --> 01:28:41,482
being solved.

1981
01:28:41,515 --> 01:28:42,416

>> Attendee: Thank you.

1982
01:28:42,449 --> 01:28:44,285
>> Preston: Thank you.

1983
01:28:47,721 --> 01:28:52,327
>> Hi, so I've heard that
Mars is called Earth's sister.

1984
01:28:54,561 --> 01:28:57,798
Like because of its
almost the size.

1985
01:28:57,831 --> 01:29:00,901
Do you think that since
it's almost the same size

1986
01:29:00,934 --> 01:29:05,773
that it may have a good enough
atmosphere to sustain life?

1987
01:29:10,544 --> 01:29:12,680
>> It's a distant sister.

1988
01:29:12,713 --> 01:29:14,715
It's a distant sister.

1989
01:29:14,748 --> 01:29:15,616
>> Julie: An old one.

1990
01:29:15,649 --> 01:29:16,817
>> Yeah, an old sister.

1991
01:29:16,850 --> 01:29:18,085
A very old sister.
>> A very old sister.

1992
01:29:18,118 --> 01:29:21,322
>> So Mars has an

atmosphere only 1%

1993
01:29:21,355 --> 01:29:23,724
of the thickness of our planet.

1994
01:29:23,757 --> 01:29:25,259
So it'd be the same,

1995
01:29:25,292 --> 01:29:29,630
if you were to somehow go up
130,000 feet above sea level

1996
01:29:31,165 --> 01:29:33,834
which is many times
higher than Mount Everest,

1997
01:29:33,867 --> 01:29:35,669
that's how thin the air is.

1998
01:29:35,702 --> 01:29:37,304
And guess what, it's not oxygen.

1999
01:29:37,337 --> 01:29:38,506
Why?

2000
01:29:38,539 --> 01:29:40,040
Because there's no
plants to make oxygen.

2001
01:29:40,073 --> 01:29:41,375
So it's just the carbon dioxide.

2002
01:29:41,408 --> 01:29:43,244
So the interesting is, well,

2003
01:29:43,277 --> 01:29:45,546
could Mars eventually have life?

2004

01:29:45,579 --> 01:29:47,047
I mean with atmosphere.

2005
01:29:47,080 --> 01:29:49,583
Certainly, there's plenty
of evidence that it did

2006
01:29:49,616 --> 01:29:53,854
have a substantial atmosphere
billions of years ago

2007
01:29:53,887 --> 01:29:57,091
but we think today, I
mean certainly not today,

2008
01:29:57,124 --> 01:30:01,629
you need a spacesuit and
a warm jacket and air

2009
01:30:01,662 --> 01:30:05,232
and make sure you
bring thick-soled shoes

2010
01:30:05,265 --> 01:30:09,170
because our wheels get torn
to shreds and so you got to,

2011
01:30:09,203 --> 01:30:11,305
there's sharp rocks.

2012
01:30:11,338 --> 01:30:14,575
So Mars, it's not
that hospitable today

2013
01:30:16,643 --> 01:30:20,247
but we could make
it so in certain way

2014
01:30:20,280 --> 01:30:21,549
so you can bring our

atmosphere with us,

2015
01:30:21,582 --> 01:30:24,185
we can live under dome
cities or dome towns

2016
01:30:24,218 --> 01:30:25,920
so we can actually
do that on Mars.

2017
01:30:25,953 --> 01:30:28,055
So it could be a friendly
place and the best thing,

2018
01:30:28,088 --> 01:30:30,758
the only weigh 1/3 as much.

2019
01:30:30,791 --> 01:30:33,327
So you'll be able to jump in
some great basketball hoops,

2020
01:30:33,360 --> 01:30:35,095
I can tell you.

2021
01:30:35,128 --> 01:30:36,964
>> All right, well I'm afraid
that's all the time we have

2022
01:30:36,997 --> 01:30:38,466
for tonight.

2023
01:30:38,499 --> 01:30:42,570
So thank you to everybody
who brought their questions.

2024
01:30:42,603 --> 01:30:44,238
Thank you to everybody
for watching online

2025

01:30:44,271 --> 01:30:45,773
and for submitting
your questions.

2026
01:30:45,806 --> 01:30:47,575
Sorry, we didn't have
time to get to everybody

2027
01:30:47,608 --> 01:30:50,177
but we always love
having you guys here

2028
01:30:50,210 --> 01:30:52,313
and we're so glad
that you joined us.

2029
01:30:52,346 --> 01:30:53,380
Have a good night.