



1
00:00:01,000 --> 00:00:07,000
[music playing]

2
00:00:16,800 --> 00:00:22,000
- Welcome to the 2016
NASA Ames Summer Series.

3
00:00:22,000 --> 00:00:24,333
When going camping
for a day--

4
00:00:24,333 --> 00:00:26,366
when you go camping for a day,

5
00:00:26,366 --> 00:00:28,800
you get up,
maybe the night before,

6
00:00:28,800 --> 00:00:30,733
and you figure
what you need to take.

7
00:00:30,733 --> 00:00:34,933
The food, the drinks, music,

8
00:00:34,933 --> 00:00:37,766
whatever you need,
you pack in the car

9
00:00:37,766 --> 00:00:40,733
and you go for a day trip.

10
00:00:40,733 --> 00:00:42,366
When going for a week,

11
00:00:42,366 --> 00:00:44,533
well, that's a little bit
more difficult.

12

00:00:44,533 --> 00:00:49,633

You start thinking, "What do I really need to take with me?"

13

00:00:49,633 --> 00:00:51,600

And in all those cases,

14

00:00:51,600 --> 00:00:54,233

if you're close to society,
a restaurant,

15

00:00:54,233 --> 00:00:56,000

or anything like that,
if you forgot something,

16

00:00:56,000 --> 00:00:58,633

you can just go and get it.

17

00:00:58,633 --> 00:01:00,800

But what do you do
when you go on a trip

18

00:01:00,800 --> 00:01:03,700

that lasts a year
or two or three?

19

00:01:03,700 --> 00:01:07,000

How much stuff
do you take with you?

20

00:01:07,000 --> 00:01:10,000

The concept
of on-demand manufacturing,

21

00:01:10,000 --> 00:01:12,033

on-demand production,

22

00:01:12,033 --> 00:01:13,800

sort of like "The Jetsons,"

23

00:01:13,800 --> 00:01:18,500
is really critical
when you do long-term trips.

24

00:01:18,500 --> 00:01:20,800
Today's presentation
is entitled,

25

00:01:20,800 --> 00:01:23,066
"The Future of Making Things
in Space,"

26

00:01:23,066 --> 00:01:27,266
and will give--will be given
by Mr. Jason Dunn.

27

00:01:27,266 --> 00:01:31,266
He is the Chief Technology
Officer and co-founder

28

00:01:31,266 --> 00:01:33,333
of Made In Space,

29

00:01:33,333 --> 00:01:36,000
and, as you guessed it,
they are the first company

30

00:01:36,000 --> 00:01:37,933
to have a 3-D printer in space

31

00:01:37,933 --> 00:01:40,866
on the International
Space Station.

32

00:01:40,866 --> 00:01:43,166
He is working with NASA
to enable

33

00:01:43,166 --> 00:01:48,033
in-space robotic manufacturing
and assembly of small

34
00:01:48,033 --> 00:01:51,100
and large space structures.

35
00:01:51,100 --> 00:01:52,766
And they are located here,

36
00:01:52,766 --> 00:01:56,366
on the campus
of NASA Ames Research Center.

37
00:01:56,366 --> 00:02:00,166
He serves on the UCF College
of Engineering

38
00:02:00,166 --> 00:02:02,966
and Computer Science
Dean's Advisory Board,

39
00:02:02,966 --> 00:02:06,933
the Advisory Council to
the Wav--Waypaver Foundation,

40
00:02:06,933 --> 00:02:08,200
and on the Board of Directors

41
00:02:08,200 --> 00:02:11,766
for the Future Space Leaders
Foundation.

42
00:02:11,766 --> 00:02:13,433
He earned a Bachelor's
of Science

43
00:02:13,433 --> 00:02:16,733
and a Master's of Science
in Aerospace Engineering

44

00:02:16,733 --> 00:02:19,966
from the University
of Central Florida.

45

00:02:19,966 --> 00:02:23,766
But the last point
is that the company,

46

00:02:23,766 --> 00:02:26,300
he and his co-founders, in 2014,

47

00:02:26,300 --> 00:02:29,700
were recognized by "Forbes"
on the prestigious

48

00:02:29,700 --> 00:02:33,266
"30 Under 30" list
for manufacturing.

49

00:02:33,266 --> 00:02:36,800
So please join me
in welcoming Mr. Dunn.

50

00:02:36,800 --> 00:02:38,700
[applause]

51

00:02:38,700 --> 00:02:40,833
- Thank you, Dr. Cohen,
I appreciate it.

52

00:02:44,000 --> 00:02:45,833
Hi, everybody.

53

00:02:45,833 --> 00:02:48,966
I'm going to just
switch over the slides.

54

00:02:55,566 --> 00:02:57,733

All right.

55

00:02:57,733 --> 00:02:59,966

All right,
how's everybody doing?

56

00:02:59,966 --> 00:03:01,233

Can you hear me okay?

57

00:03:01,233 --> 00:03:02,833

So I understand there's

58

00:03:02,833 --> 00:03:04,600

quite a bit of students
in the crowd.

59

00:03:04,600 --> 00:03:07,000

Just show of hands,
who's intern or students?

60

00:03:07,000 --> 00:03:08,533

Okay, quite a bit.
All right.

61

00:03:08,533 --> 00:03:11,966

So you're all going back
to school pretty soon?

62

00:03:11,966 --> 00:03:14,766

Great. Well, hopefully today
can be educational.

63

00:03:14,766 --> 00:03:18,200

I'd love to give--
to just share kind of the views

64

00:03:18,200 --> 00:03:20,733

of why we started Made In Space
and what we're doing,

65

00:03:20,733 --> 00:03:22,966

and we'll use that,
more or less,

66

00:03:22,966 --> 00:03:24,933

as a lens to look
at what the future

67

00:03:24,933 --> 00:03:26,866

of making things looks like,
and that's--

68

00:03:26,866 --> 00:03:28,700

really kind of at the core
of Made In Space

69

00:03:28,700 --> 00:03:31,366

is thinking about the future
of making things,

70

00:03:31,366 --> 00:03:34,333

and we believe that
that future is in space--

71

00:03:34,333 --> 00:03:38,566

primarily that space
should be thought of not just

72

00:03:38,566 --> 00:03:42,000

as a place to have really
amazing scientific discovery

73

00:03:42,000 --> 00:03:43,533

but also as a place
for business

74

00:03:43,533 --> 00:03:46,533

and for industry
and for making things,

75

00:03:46,533 --> 00:03:48,433

and that's why we started
Made In Space.

76

00:03:48,433 --> 00:03:51,166

So I'll start with maybe

77

00:03:51,166 --> 00:03:53,566

kind of putting things
into perspective.

78

00:03:53,566 --> 00:03:55,166

That's us.

79

00:03:55,166 --> 00:03:56,833

We maybe sometimes forget this

80

00:03:56,833 --> 00:03:58,700

when we're--when we're working

81

00:03:58,700 --> 00:04:01,266

on big space missions
and thinking about,

82

00:04:01,266 --> 00:04:04,200

"How do we go back to the Moon
or go to Mars?"

83

00:04:04,200 --> 00:04:07,066

But we're all in this together.

84

00:04:07,066 --> 00:04:10,466

We're all in that little,
little spot on the planet,

85

00:04:10,466 --> 00:04:11,900

all here, together,
thinking about how

86

00:04:11,900 --> 00:04:15,066

to solve big problems
for going to space.

87

00:04:15,066 --> 00:04:17,666

And, for me and for us
at Made In Space,

88

00:04:17,666 --> 00:04:20,366

we think a lot about--
we think a lot about

89

00:04:20,366 --> 00:04:23,033

our home planet
as we design things

90

00:04:23,033 --> 00:04:24,800

for making things
off of the planet.

91

00:04:24,800 --> 00:04:28,466

So to try and capture
today's talk

92

00:04:28,466 --> 00:04:30,733

and for you to have
some takeaways,

93

00:04:30,733 --> 00:04:33,533

I like to always point out
these three things,

94

00:04:33,533 --> 00:04:37,200

and this is how we've driven
the development of our company

95

00:04:37,200 --> 00:04:39,866

and the way we think about
what we do.

96

00:04:39,866 --> 00:04:41,433

It's doing--making sure

97

00:04:41,433 --> 00:04:43,366

that you're doing
meaningful work.

98

00:04:43,366 --> 00:04:46,233

That's really important in life.

99

00:04:46,233 --> 00:04:47,600

To innovate disruptively--

100

00:04:47,600 --> 00:04:50,133

and that's a really good key
to success,

101

00:04:50,133 --> 00:04:51,633

and I'll talk about
what that means.

102

00:04:51,633 --> 00:04:54,933

And then the idea
of starting small--

103

00:04:54,933 --> 00:04:57,533

small projects
but having big vision.

104

00:04:57,533 --> 00:05:00,066

And so hopefully these
three points can stick with you

105

00:05:00,066 --> 00:05:02,266

as you go through the talk
with me

106

00:05:02,266 --> 00:05:05,500

and you can notice how we've

done that at Made In Space.

107

00:05:05,500 --> 00:05:09,966

So one of--
part of doing this--

108

00:05:09,966 --> 00:05:11,833

and, for myself,
I like to ask really,

109

00:05:11,833 --> 00:05:15,433

really big questions
that help drive our focus.

110

00:05:15,433 --> 00:05:19,400

And one of the biggest questions
that drives

111

00:05:19,400 --> 00:05:22,166

the thought of making things
in space

112

00:05:22,166 --> 00:05:25,033

is really--it really comes down
to this one question of,

113

00:05:25,033 --> 00:05:27,800

"Is a planetary surface
really the best place

114

00:05:27,800 --> 00:05:30,733

for our advancing
industrial needs?"

115

00:05:30,733 --> 00:05:33,733

Today, all of our industry
exists on this planet.

116

00:05:33,733 --> 00:05:35,633

Should it always be that way,

or should one day

117

00:05:35,633 --> 00:05:37,966

it be off of this planet,
in space,

118

00:05:37,966 --> 00:05:40,633

and is it better suited
to be off of this planet?

119

00:05:40,633 --> 00:05:42,100

So that's a driving question

120

00:05:42,100 --> 00:05:45,300

that we are always searching
for answers to.

121

00:05:45,300 --> 00:05:48,066

And, you know,
when we think about--

122

00:05:48,066 --> 00:05:49,700

when we think about
what we've done in space,

123

00:05:49,700 --> 00:05:51,000

we've done some amazing things.

124

00:05:51,000 --> 00:05:53,933

We've sent people
to the Moon, right?

125

00:05:53,933 --> 00:05:56,500

We've built vehicles
that drive

126

00:05:56,500 --> 00:05:58,966

across the lunar surface.

127

00:05:58,966 --> 00:06:01,566
When we started this company,

128
00:06:01,566 --> 00:06:03,766
thi--it was things
like this that brought

129
00:06:03,766 --> 00:06:05,366
my co-founders and I together.

130
00:06:05,366 --> 00:06:07,800
It was the--it was us

131
00:06:07,800 --> 00:06:10,366
asking big questions
to each other.

132
00:06:10,366 --> 00:06:12,500
Why haven't we been back
to the Moon

133
00:06:12,500 --> 00:06:15,400
in our lifetime--
in, like, the co-founders'

134
00:06:15,400 --> 00:06:17,633
and probably a lot of you
in the room's lifetime?

135
00:06:17,633 --> 00:06:19,800
Why haven't we put people
on Mars yet?

136
00:06:19,800 --> 00:06:24,266
Why are there only six people
at a time, more or less,

137
00:06:24,266 --> 00:06:26,066
living off of Planet Earth

138

00:06:26,066 --> 00:06:27,500

on the International
Space Station?

139

00:06:27,500 --> 00:06:30,533

Why isn't it more people, right?

140

00:06:30,533 --> 00:06:32,066

You all know this number
pretty well,

141

00:06:32,066 --> 00:06:34,500

but most people around the world

142

00:06:34,500 --> 00:06:36,200

are shocked
when they find out that,

143

00:06:36,200 --> 00:06:38,366

for the history
of space exploration,

144

00:06:38,366 --> 00:06:40,533

for over half of a century,

145

00:06:40,533 --> 00:06:44,466

only 555 people have
actually gone to space.

146

00:06:44,466 --> 00:06:47,300

That's not--really not
a lot of people, right,

147

00:06:47,300 --> 00:06:48,766

when you think about it.

148

00:06:48,766 --> 00:06:51,666

And the reason why
comes down to a lot

149

00:06:51,666 --> 00:06:54,166
of what Dr. Cohen was saying.

150

00:06:54,166 --> 00:06:58,866
Today's version of exploration
is a lot like a camping trip.

151

00:06:58,866 --> 00:07:01,766
It's a lot like the goldfish
in the fishbowl.

152

00:07:01,766 --> 00:07:03,033
That's how we go to space today.

153

00:07:03,033 --> 00:07:05,666
We have to bottle up
a little bit of Earth,

154

00:07:05,666 --> 00:07:08,366
and we sh--we put an astronaut
in that little bottle of Earth,

155

00:07:08,366 --> 00:07:11,366
and we send the little bottle
elsewhere in space.

156

00:07:11,366 --> 00:07:12,500
So it's a camping trip.

157

00:07:12,500 --> 00:07:14,200
We have to bring everything
we need with us,

158

00:07:14,200 --> 00:07:15,333
and if something goes wrong,

159

00:07:15,333 --> 00:07:18,233
we have to create

an emergency fix or,

160

00:07:18,233 --> 00:07:19,866

at worst case,
abort the whole mission.

161

00:07:19,866 --> 00:07:22,900

Think about Apollo 13.

162

00:07:22,900 --> 00:07:24,933

So when we started this company,

163

00:07:24,933 --> 00:07:26,133

we were thinking a lot about,

164

00:07:26,133 --> 00:07:27,566

"How do we solve that problem?"

165

00:07:27,566 --> 00:07:31,466

How do we make it so people
can live off of Planet Earth,

166

00:07:31,466 --> 00:07:33,200

independent from Earth--

167

00:07:33,200 --> 00:07:35,166

be able to be sustainable
wherever we go,

168

00:07:35,166 --> 00:07:39,333

whether it's Mars or the Moon
or in free space?"

169

00:07:39,333 --> 00:07:41,666

And the more we thought
about that problem,

170

00:07:41,666 --> 00:07:43,800

the problems of sustainability,

171

00:07:43,800 --> 00:07:47,600
the problems of making it safer

172

00:07:47,600 --> 00:07:49,566
to live in space
and more enjoyable,

173

00:07:49,566 --> 00:07:54,033
the more we realized
that space--

174

00:07:54,033 --> 00:07:55,900
that when we--when we solve
those problems,

175

00:07:55,900 --> 00:07:58,366
we're actually looking at how
to solve similar problems

176

00:07:58,366 --> 00:08:00,233
we have on Earth,

177

00:08:00,233 --> 00:08:01,966
because life onboard
a spaceship

178

00:08:01,966 --> 00:08:05,033
is not unlike life on Earth.

179

00:08:05,033 --> 00:08:06,433
It's just that we're making

180

00:08:06,433 --> 00:08:09,333
all the systems Earth has
much smaller.

181

00:08:09,333 --> 00:08:11,466
And when we think about life

onboard a spaceship,

182

00:08:11,466 --> 00:08:14,700

we realize that all of us
already live on a spaceship.

183

00:08:14,700 --> 00:08:16,500

Earth is a pretty good
spaceship,

184

00:08:16,500 --> 00:08:18,733

and the only difference
is most of us

185

00:08:18,733 --> 00:08:21,133

have never left the ship, right?

186

00:08:21,133 --> 00:08:22,433

And that's what
we want to change.

187

00:08:22,433 --> 00:08:26,600

We want more people to be able
to leave the spaceship.

188

00:08:26,600 --> 00:08:31,033

So I'll tell a quick story
that helps encapsulate

189

00:08:31,033 --> 00:08:33,333

how Made In Space has been
trying to solve this problem.

190

00:08:33,333 --> 00:08:36,233

It's one of my favorite stories
of what we've done.

191

00:08:36,233 --> 00:08:39,733

The story starts
with astronaut Butch Wilmore.

192

00:08:39,733 --> 00:08:42,133

So Butch was the commander
of the space station

193

00:08:42,133 --> 00:08:44,700

in the Fall of 2014,

194

00:08:44,700 --> 00:08:48,400

and the interesting thing
about the Fall of 2014

195

00:08:48,400 --> 00:08:51,300

is that's when Made In Space
and NASA

196

00:08:51,300 --> 00:08:53,666

sent the first 3-D printer
into space.

197

00:08:53,666 --> 00:08:56,833

So Butch was--Butch was one
of the astronauts onboard

198

00:08:56,833 --> 00:08:58,900

when the printer arrived,

199

00:08:58,900 --> 00:09:00,300

and he ended up being

200

00:09:00,300 --> 00:09:02,000

the first person
to use the printer.

201

00:09:02,000 --> 00:09:04,100

So if you check
his Wikipedia page,

202

00:09:04,100 --> 00:09:06,166

it now says that Butch
was the first person ever

203

00:09:06,166 --> 00:09:07,733
to manufacture off Planet Earth,

204

00:09:07,733 --> 00:09:10,766
and that's--that makes him
one of my favorite astronauts.

205

00:09:10,766 --> 00:09:12,866
So we did a lot

206

00:09:12,866 --> 00:09:16,066
of really interesting things
with the printer,

207

00:09:16,066 --> 00:09:18,500
and I'll--I'm gonna tell you
one of--one specific story

208

00:09:18,500 --> 00:09:20,133
of what we've printed.

209

00:09:20,133 --> 00:09:21,400
And it all came down to--

210

00:09:21,400 --> 00:09:24,566
one day,
we're operating the printer

211

00:09:24,566 --> 00:09:26,766
from a little
mission control room

212

00:09:26,766 --> 00:09:28,266
that's not far away from here,

213

00:09:28,266 --> 00:09:30,300

at Made In Space headquarters,

214

00:09:30,300 --> 00:09:32,300
and we're constantly
on the loop,

215

00:09:32,300 --> 00:09:34,966
talking to NASA,
listening to the astronauts,

216

00:09:34,966 --> 00:09:40,033
and we had just printed
a toolhead,

217

00:09:40,033 --> 00:09:41,700
a crowfoot wrench head,

218

00:09:41,700 --> 00:09:43,266
that would go on the end of a--

219

00:09:43,266 --> 00:09:47,933
of a--of a wrench on a tool.

220

00:09:47,933 --> 00:09:49,466
And we printed it,

221

00:09:49,466 --> 00:09:50,800
and Butch takes it out
of the printer,

222

00:09:50,800 --> 00:09:52,433
and he says over the loop, "Wow.

223

00:09:52,433 --> 00:09:54,800
If I had my ratchet right now,

224

00:09:54,800 --> 00:09:56,800
I would try this tool out,"

225
00:09:56,800 --> 00:09:59,333
and later on,
we were talking to NASA

226
00:09:59,333 --> 00:10:00,666
and they had--
they had mentioned that,

227
00:10:00,666 --> 00:10:02,833
you know--you know,

228
00:10:02,833 --> 00:10:07,733
sometimes astronauts misplace
things, and we were thinking,

229
00:10:07,733 --> 00:10:10,333
"Well, how can an astronaut
misplace a tool?"

230
00:10:10,333 --> 00:10:12,233
Like, that seems like
a really important thing.

231
00:10:12,233 --> 00:10:13,600
How do tools go missing?

232
00:10:13,600 --> 00:10:14,966
And this happens
quite frequently,

233
00:10:14,966 --> 00:10:16,666
and it takes a lot of time
to figure out,

234
00:10:16,666 --> 00:10:19,266
"Where could a tool be?"
And we're thinking,

235
00:10:19,266 --> 00:10:20,933

"Well, how could they
misplace a tool?"

236

00:10:20,933 --> 00:10:23,433

And then--and then we look
at pictures like this one,

237

00:10:23,433 --> 00:10:24,833

and we realize
that the space station

238

00:10:24,833 --> 00:10:26,466

is actually
a very cluttered place.

239

00:10:26,466 --> 00:10:28,466

There's--it's not
that sleek-walled,

240

00:10:28,466 --> 00:10:30,233

"2001: A Space Odyssey"

241

00:10:30,233 --> 00:10:32,466

space station
that we all dream of.

242

00:10:32,466 --> 00:10:34,766

It's, in fact,
very cramped and cluttered.

243

00:10:34,766 --> 00:10:36,966

There's space suits.

244

00:10:36,966 --> 00:10:38,933

Maybe an astronaut

245

00:10:38,933 --> 00:10:40,566

lets go of the tool
and turns around,

246

00:10:40,566 --> 00:10:42,566

and it floats away

inside of a space suit

247

00:10:42,566 --> 00:10:46,566

or gets hidden behind the tangle

of wires down in the bottom.

248

00:10:46,566 --> 00:10:49,233

So nonetheless,

tools go missing.

249

00:10:49,233 --> 00:10:50,766

So that was

a perfect opportunity

250

00:10:50,766 --> 00:10:51,766

for us to think about,

251

00:10:51,766 --> 00:10:54,066

"How could we make Butch

a tool?"

252

00:10:54,066 --> 00:10:58,333

So what the printer looks like

is--it's basically

253

00:10:58,333 --> 00:11:01,066

maybe the size of a small

microwave oven.

254

00:11:01,066 --> 00:11:04,066

It's really designed

and optimized

255

00:11:04,066 --> 00:11:05,633

for the space station,

256

00:11:05,633 --> 00:11:08,300

and to Butch
and to the astronauts,

257
00:11:08,300 --> 00:11:09,900
it's this, like, magic box,

258
00:11:09,900 --> 00:11:12,100
where we control it
from the ground,

259
00:11:12,100 --> 00:11:13,366
and whatever we build,

260
00:11:13,366 --> 00:11:15,033
they open the door,
and it's inside.

261
00:11:15,033 --> 00:11:16,533
They take that thing out.

262
00:11:16,533 --> 00:11:18,466
They close the door.
It's an empty box,

263
00:11:18,466 --> 00:11:19,800
and the next time
we call them over

264
00:11:19,800 --> 00:11:21,666
to remove something,
there's something inside.

265
00:11:21,666 --> 00:11:24,666
So for them it's this excitement
of the magic box,

266
00:11:24,666 --> 00:11:27,066
and every time they open it,
something new is inside.

267

00:11:27,066 --> 00:11:29,500

The last time

Butch opened the box,

268

00:11:29,500 --> 00:11:31,100

he had the tool head,

and he said,

269

00:11:31,100 --> 00:11:32,566

"I--you know,

I wish I had a ratchet,"

270

00:11:32,566 --> 00:11:35,033

and he closed

an empty box and left,

271

00:11:35,033 --> 00:11:38,300

and we had about five days

272

00:11:38,300 --> 00:11:41,233

until the next command window

to operate the printer.

273

00:11:41,233 --> 00:11:44,333

So, working with NASA,

we designed a ratchet.

274

00:11:44,333 --> 00:11:46,266

NASA gave us

the kind of requirements.

275

00:11:46,266 --> 00:11:47,766

They said, "You know,

it has to have

276

00:11:47,766 --> 00:11:49,566

a real ratcheting mechanism,"

277

00:11:49,566 --> 00:11:53,800

which means, you know,
a leaf spring and a gear.

278

00:11:53,800 --> 00:11:55,800

"It needs to have no
assembly required.

279

00:11:55,800 --> 00:11:57,166

Butch should be able
to reach into the printer

280

00:11:57,166 --> 00:11:59,000

and take out a functioning tool.

281

00:11:59,000 --> 00:12:01,266

So it has to have moving parts
but no assembly,

282

00:12:01,266 --> 00:12:03,766

and it, more than anything,
has to be safe."

283

00:12:03,766 --> 00:12:06,433

We have to qualify it
through NASA's safety review.

284

00:12:06,433 --> 00:12:08,166

So we got to work,

285

00:12:08,166 --> 00:12:12,500

and in one day
we designed the tool,

286

00:12:12,500 --> 00:12:16,000

and we designed it
in CAD software.

287

00:12:16,000 --> 00:12:18,066

What's really incredible
is that,

288

00:12:18,066 --> 00:12:21,500
while this tool could exist
here on Earth,

289

00:12:21,500 --> 00:12:23,033
in the bigger picture of,

290

00:12:23,033 --> 00:12:24,900
"Why manufacture in space?"

291

00:12:24,900 --> 00:12:26,733
it never really has to exist
on Earth.

292

00:12:26,733 --> 00:12:30,633
It only has to exist
in software and in space.

293

00:12:30,633 --> 00:12:34,966
So that's an important point
that I'll come back to later.

294

00:12:34,966 --> 00:12:38,166
But for this tool, we--
it exists here on Earth,

295

00:12:38,166 --> 00:12:40,266
and we have printers in our lab

296

00:12:40,266 --> 00:12:41,766
that are identical
to what's in space.

297

00:12:41,766 --> 00:12:43,033
So as we design the tool,

298

00:12:43,033 --> 00:12:45,033
we constantly are

printing prototypes out

299

00:12:45,033 --> 00:12:46,933
and making sure it will work,

300

00:12:46,933 --> 00:12:49,933
and by the end of the day,
we had a tool that worked.

301

00:12:49,933 --> 00:12:53,000
It passed all of NASA's
requirements they gave us.

302

00:12:53,000 --> 00:12:56,800
We had iterated on that tool
many times in the lab.

303

00:12:56,800 --> 00:12:59,166
And we took the--
we took a--the tool,

304

00:12:59,166 --> 00:13:01,133
we shipped it to NASA
for a safety review.

305

00:13:01,133 --> 00:13:02,633
They got it the next day,

306

00:13:02,633 --> 00:13:03,833
and this was the first time

307

00:13:03,833 --> 00:13:05,666
that NASA would hold a tool

308

00:13:05,666 --> 00:13:07,633
in their hand to certify

309

00:13:07,633 --> 00:13:09,100
to go to the space station

310

00:13:09,100 --> 00:13:11,900

that wasn't really the tool
that would go.

311

00:13:11,900 --> 00:13:14,733

It was a representation
of the tool.

312

00:13:14,733 --> 00:13:16,300

The only way that we would make

313

00:13:16,300 --> 00:13:17,600

the real tool
is to print it in space.

314

00:13:17,600 --> 00:13:19,166

So we said, "Trust us.

315

00:13:19,166 --> 00:13:20,766

It's exact--it will
come out in space

316

00:13:20,766 --> 00:13:23,000

just like it came out
on the printer in the lab."

317

00:13:23,000 --> 00:13:25,400

So we went through the--
what you can imagine,

318

00:13:25,400 --> 00:13:28,133

a lengthy safety
review process,

319

00:13:28,133 --> 00:13:32,200

and it was certified for what
we called digital launch,

320

00:13:32,200 --> 00:13:34,766
and this was the first time
in history NASA

321
00:13:34,766 --> 00:13:36,200
would take--do that process,

322
00:13:36,200 --> 00:13:39,733
and so it was really amazing
for us to see that happen.

323
00:13:39,733 --> 00:13:42,033
Once it was approved,
we're about day five,

324
00:13:42,033 --> 00:13:44,133
and it's time to print the tool.

325
00:13:44,133 --> 00:13:47,633
So it starts in our--
in our mission control room.

326
00:13:47,633 --> 00:13:49,733
It's a nice, small, little room

327
00:13:49,733 --> 00:13:51,866
with a couple computer monitors

328
00:13:51,866 --> 00:13:54,833
and software that NASA installs
on the computer

329
00:13:54,833 --> 00:13:57,900
to allow us to communicate
to the 3-D printer.

330
00:13:57,900 --> 00:14:01,733
So it's a lot like
a remote desktop to space.

331
00:14:01,733 --> 00:14:05,733
So here we are,
taking the digital file

332
00:14:05,733 --> 00:14:08,566
and sending it through
the NASA system to space.

333
00:14:08,566 --> 00:14:09,900
It first goes over

334
00:14:09,900 --> 00:14:12,466
to the payload operation
center in Huntsville,

335
00:14:12,466 --> 00:14:15,233
where then it's uplinked
to the space station,

336
00:14:15,233 --> 00:14:16,433
and when it gets there,

337
00:14:16,433 --> 00:14:18,933
it's installed
on a laptop computer,

338
00:14:18,933 --> 00:14:20,933
and it--in the image,
it's the laptop

339
00:14:20,933 --> 00:14:23,133
in the front of the screen--

340
00:14:23,133 --> 00:14:25,833
so they--NASA installs
the file there,

341
00:14:25,833 --> 00:14:27,833
and then once it's there,

they say,

342

00:14:27,833 --> 00:14:30,366

"You're cleared for printing."

343

00:14:30,366 --> 00:14:33,200

Inside this glove box
is the printer.

344

00:14:33,200 --> 00:14:35,033

If you remember
the image of the printer,

345

00:14:35,033 --> 00:14:37,200

you can see it in the--
right here,

346

00:14:37,200 --> 00:14:40,600

there's the printer,
and this, right there,

347

00:14:40,600 --> 00:14:42,966

is our electronics
and power supply.

348

00:14:42,966 --> 00:14:44,633

So it's inside of a glove box

349

00:14:44,633 --> 00:14:47,833

because this first printer
was a science experiment.

350

00:14:47,833 --> 00:14:49,366

We were trying to figure out
what would happen

351

00:14:49,366 --> 00:14:50,600

if you 3-D-printed in space.

352

00:14:50,600 --> 00:14:53,900
So keeping it behind a glove box

353
00:14:53,900 --> 00:14:55,900
with some levels of containment

354
00:14:55,900 --> 00:14:57,733
was really important.

355
00:14:57,733 --> 00:15:00,233
So now we're ready to print.
We take over.

356
00:15:00,233 --> 00:15:03,066
We send the file to the printer.
We hit print.

357
00:15:03,066 --> 00:15:07,200
It takes about two hours
for that tool to be printed.

358
00:15:07,200 --> 00:15:09,066
Two hours later, it's printed,

359
00:15:09,066 --> 00:15:11,433
and we call Butch over.

360
00:15:11,433 --> 00:15:12,733
We tell NASA it's ready.

361
00:15:12,733 --> 00:15:14,233
Butch comes over
to remove the part.

362
00:15:14,233 --> 00:15:15,933
Here he is, opening the door.

363
00:15:15,933 --> 00:15:17,833
Remember, the last time we he--

364

00:15:17,833 --> 00:15:19,733
we even heard from Butch,

365

00:15:19,733 --> 00:15:22,933
he had mentioned that he wished
he had that tool,

366

00:15:22,933 --> 00:15:26,000
and he went off for five days,
working on all the other things

367

00:15:26,000 --> 00:15:28,133
that astronauts do in space,

368

00:15:28,133 --> 00:15:30,333
and he left an empty box,

369

00:15:30,333 --> 00:15:32,366
and he came back
to open the door.

370

00:15:32,366 --> 00:15:34,933
No idea what's inside
the magic box this time--

371

00:15:34,933 --> 00:15:36,466
and then this is
a picture immediately

372

00:15:36,466 --> 00:15:38,966
after he removes his ratchet.

373

00:15:38,966 --> 00:15:41,966
I like to call this picture,
"Happy Butch."

374

00:15:41,966 --> 00:15:45,000
You can imagine the surprise

that he's going through

375

00:15:45,000 --> 00:15:46,966
when the thing he asked
for five days ago

376

00:15:46,966 --> 00:15:48,333
is now in his hands,

377

00:15:48,333 --> 00:15:51,033
and that went down
as the fastest anything

378

00:15:51,033 --> 00:15:54,133
has ever gone
from design concept

379

00:15:54,133 --> 00:15:56,700
to being in an astronaut's hand
in space.

380

00:15:56,700 --> 00:15:59,766
Nothing has ever been sent
to space that fast,

381

00:15:59,766 --> 00:16:02,700
and had Butch been on Mars,

382

00:16:02,700 --> 00:16:06,233
the story I'm telling would
almost be identical, right?

383

00:16:06,233 --> 00:16:08,933
The way we design the tool
would be very similar.

384

00:16:08,933 --> 00:16:11,133
Even if it were a different
manufacturing process,

385

00:16:11,133 --> 00:16:12,800

if it were metal 3-D printing,

386

00:16:12,800 --> 00:16:16,266

it would still be,

really, a similar story,

387

00:16:16,266 --> 00:16:18,600

and definitely the way we went
through a safety review

388

00:16:18,600 --> 00:16:20,533

and then sending the information
to a printer.

389

00:16:20,533 --> 00:16:23,533

So what we did was,

390

00:16:23,533 --> 00:16:24,966

NASA and Made In Space
demonstrated

391

00:16:24,966 --> 00:16:28,200

that you can get hardware
into space very,

392

00:16:28,200 --> 00:16:29,866

very quickly

with this technology,

393

00:16:29,866 --> 00:16:31,500

and that was the really
important part

394

00:16:31,500 --> 00:16:33,133

about this story.

395

00:16:33,133 --> 00:16:36,500

The tool itself was brought back

to Earth.

396

00:16:36,500 --> 00:16:40,066

It's gone through a lot
of really amazing analysis

397

00:16:40,066 --> 00:16:42,433

at NASA to understand
the properties

398

00:16:42,433 --> 00:16:44,333

and compare it
to what it would be like

399

00:16:44,333 --> 00:16:46,166

if it were printed
on the ground.

400

00:16:46,166 --> 00:16:48,866

So that's a--
that's a really good story

401

00:16:48,866 --> 00:16:51,333

that explains kind of how we--
how we're thinking

402

00:16:51,333 --> 00:16:53,433

about manufacturing in space.

403

00:16:53,433 --> 00:16:56,333

I'd like to walk you through
how we got to this point.

404

00:16:56,333 --> 00:16:58,100

How did we--how did
we even get to the point

405

00:16:58,100 --> 00:17:00,600

where we could put a 3-D printer
on the space station?

406

00:17:00,600 --> 00:17:03,466

It's a different type
of device, right?

407

00:17:03,466 --> 00:17:08,200

So it started in 2011,
here at--

408

00:17:08,200 --> 00:17:09,700

where we were setting up
our office

409

00:17:09,700 --> 00:17:12,133

in the research park
at NASA Ames,

410

00:17:12,133 --> 00:17:14,066

and we won a contract

411

00:17:14,066 --> 00:17:16,233

through the Flight Opportunities
program,

412

00:17:16,233 --> 00:17:18,866

which is run out
of here at NASA,

413

00:17:18,866 --> 00:17:20,400

and through that we were able

414

00:17:20,400 --> 00:17:23,366

to take 3-D printers
into zero gravity,

415

00:17:23,366 --> 00:17:26,933

and this was definitely one of
the most fun parts of the job,

416

00:17:26,933 --> 00:17:28,100
and if any of you
ever get a chance

417
00:17:28,100 --> 00:17:30,633
to go into zero gravity,
I highly recommend it.

418
00:17:30,633 --> 00:17:34,133
So we had--through
the Summer of 2011,

419
00:17:34,133 --> 00:17:38,433
we flew on this
parabolic airplane ten times,

420
00:17:38,433 --> 00:17:41,533
which is actually
quite a bit of flight,

421
00:17:41,533 --> 00:17:42,933
right--of flight data.

422
00:17:42,933 --> 00:17:45,633
So every flight--every one
of those ten flights,

423
00:17:45,633 --> 00:17:47,133
you get about 40 parabolas,

424
00:17:47,133 --> 00:17:50,933
and each parabola is about
20 seconds of zero gravity.

425
00:17:50,933 --> 00:17:55,833
So we started out by taking
some commercial 3-D printers,

426
00:17:55,833 --> 00:17:58,466
as well as some ones

that we designed ourselves,

427

00:17:58,466 --> 00:18:00,633
into zero gravity.

428

00:18:00,633 --> 00:18:02,500
The hope was
that a commercial 3-D printer

429

00:18:02,500 --> 00:18:04,100
would work,
because if it did

430

00:18:04,100 --> 00:18:06,066
then it would make our jobs
a lot easier.

431

00:18:06,066 --> 00:18:07,666
All we wanted to do
was put the printer

432

00:18:07,666 --> 00:18:09,266
into the space station.

433

00:18:09,266 --> 00:18:10,866
Right off the bat,
we found out

434

00:18:10,866 --> 00:18:13,133
that the commercial printers
just--they don't work.

435

00:18:13,133 --> 00:18:16,000
There's--the issues are--
go from the mechanical--

436

00:18:16,000 --> 00:18:17,833
they're designed with gravity
in mind

437

00:18:17,833 --> 00:18:19,966

to hold things in place,
belts and pulleys

438

00:18:19,966 --> 00:18:24,033

and build platforms--to things
like the thermal conditions.

439

00:18:24,033 --> 00:18:27,366

We're well aware
that hot air rises in this room,

440

00:18:27,366 --> 00:18:29,433

and that's because
of the buoyancy effect

441

00:18:29,433 --> 00:18:32,233

that is only there
because of gravity,

442

00:18:32,233 --> 00:18:35,166

but if we remove gravity,
we remove buoyancy,

443

00:18:35,166 --> 00:18:39,900

and now hot air doesn't rise
through natural conduction,

444

00:18:39,900 --> 00:18:41,766

and we have to create
forced convection

445

00:18:41,766 --> 00:18:44,233

and other means of thermally
controlling things.

446

00:18:44,233 --> 00:18:46,100

In 3-D printing,

447

00:18:46,100 --> 00:18:48,266
it's a--very much
a thermal process.

448
00:18:48,266 --> 00:18:49,966
So you have to keep
hot things hot

449
00:18:49,966 --> 00:18:52,433
and cold things cold
and keep that uniform.

450
00:18:52,433 --> 00:18:54,500
So we had to do a lot of work
to figure that out

451
00:18:54,500 --> 00:18:56,000
so that we not only can print

452
00:18:56,000 --> 00:18:57,700
but we get a print
that's reliable

453
00:18:57,700 --> 00:18:59,933
and as robust as something
you might find

454
00:18:59,933 --> 00:19:01,733
on a ground 3-D printer.

455
00:19:01,733 --> 00:19:03,566
So we did a lot of this work.

456
00:19:03,566 --> 00:19:06,366
What was--what was
really amazing for us

457
00:19:06,366 --> 00:19:08,300
is that we flew
those ten flights--

458

00:19:08,300 --> 00:19:09,866

the first flight,
nothing worked.

459

00:19:09,866 --> 00:19:11,800

The second flight, we were
trying out different things,

460

00:19:11,800 --> 00:19:14,000

building new experiments.
Every single night,

461

00:19:14,000 --> 00:19:17,600

we would take our experiment
out of the plane, change it,

462

00:19:17,600 --> 00:19:19,100

make it--in the hotel room,

463

00:19:19,100 --> 00:19:22,000

try to make it better,
then fly it again,

464

00:19:22,000 --> 00:19:24,733

and we would come back every
three weeks to fly again,

465

00:19:24,733 --> 00:19:26,766

and were going in Houston.

466

00:19:26,766 --> 00:19:29,300

We were there
on the very last week

467

00:19:29,300 --> 00:19:31,700

of our Flight
Opportunities campaign

468

00:19:31,700 --> 00:19:34,066
in September of 2011,

469
00:19:34,066 --> 00:19:38,333
and we had four flights.

470
00:19:38,333 --> 00:19:41,166
We did the first three flights
of the week.

471
00:19:41,166 --> 00:19:42,366
We learned a little bit,

472
00:19:42,366 --> 00:19:43,666
but we still didn't get
the printer to work,

473
00:19:43,666 --> 00:19:44,966
and we were down to the--
literally

474
00:19:44,966 --> 00:19:47,166
the last flight
of the last week

475
00:19:47,166 --> 00:19:49,466
of our last chance
to ever figure this out,

476
00:19:49,466 --> 00:19:51,166
and we made
the last bit of changes

477
00:19:51,166 --> 00:19:53,900
we could come up with,
and it worked,

478
00:19:53,900 --> 00:19:57,233
and it was this amazing moment
where we, like--

479

00:19:57,233 --> 00:20:01,000

some people may have given up
after the very first flight

480

00:20:01,000 --> 00:20:02,400

and seeing that it didn't work,

481

00:20:02,400 --> 00:20:04,000

and we just kept going
the whole time,

482

00:20:04,000 --> 00:20:05,733

and it got all the way
to literally

483

00:20:05,733 --> 00:20:07,633

our last chance
to make it happen,

484

00:20:07,633 --> 00:20:11,300

and we figured out
how to make a printer work.

485

00:20:11,300 --> 00:20:13,033

And this video right--
that image

486

00:20:13,033 --> 00:20:14,866

is actually from
a later test flight

487

00:20:14,866 --> 00:20:16,766

where we actually took
the 3-D printer

488

00:20:16,766 --> 00:20:18,166

that was going
to the space station

489

00:20:18,166 --> 00:20:21,000

into the flights
and tested it out.

490

00:20:21,000 --> 00:20:24,966

Because of that, we were able
to then go back to NASA

491

00:20:24,966 --> 00:20:26,800

and say, "We know how to design
3-D printers

492

00:20:26,800 --> 00:20:28,333

that can work
in the space station."

493

00:20:28,333 --> 00:20:30,933

We started to do
that with NASA

494

00:20:30,933 --> 00:20:34,400

to design the printer
and build it for flight.

495

00:20:34,400 --> 00:20:36,833

So it's one thing to make
a printer work in zero gravity.

496

00:20:36,833 --> 00:20:39,200

It's definitely another thing
to make one work

497

00:20:39,200 --> 00:20:41,266

that meets all
of the requirements

498

00:20:41,266 --> 00:20:43,633

in terms of safety
and operational requirements

499

00:20:43,633 --> 00:20:45,000

for the space station.

500

00:20:45,000 --> 00:20:46,566

So that's why it ends up

501

00:20:46,566 --> 00:20:49,433

looking like a very different
type of machine.

502

00:20:49,433 --> 00:20:51,300

So I'll just, maybe briefly,

503

00:20:51,300 --> 00:20:54,133

talk about why it's important
to have the printer there.

504

00:20:54,133 --> 00:20:57,000

Well, we've done a lot of
different types of prints now.

505

00:20:57,000 --> 00:20:58,933

Different astronauts
are getting to enjoy it,

506

00:20:58,933 --> 00:21:00,833

and they--you know,
they mention that this is one

507

00:21:00,833 --> 00:21:03,833

of the most fun activities
they get to take part of,

508

00:21:03,833 --> 00:21:06,400

but the reason why a 3-D printer
is so important

509

00:21:06,400 --> 00:21:08,633

is because the way we do space,

510

00:21:08,633 --> 00:21:11,200
like Dr. Cohen said,
is a lot like a camping trip.

511

00:21:11,200 --> 00:21:12,933
We bring everything we need
with us.

512

00:21:12,933 --> 00:21:15,233
So there is a lot of redundancy,

513

00:21:15,233 --> 00:21:18,100
a lot of spare parts,
in space right now.

514

00:21:18,100 --> 00:21:22,800
There's entire modules
filled with bags

515

00:21:22,800 --> 00:21:25,400
that have spare parts
in case something goes wrong

516

00:21:25,400 --> 00:21:26,833
if we have to fix something

517

00:21:26,833 --> 00:21:28,933
and we need the spare part
right away.

518

00:21:28,933 --> 00:21:30,800
There's also a lot of waste.

519

00:21:30,800 --> 00:21:34,200
There's--some of these--
some of these duffel bags here

520

00:21:34,200 --> 00:21:35,533

might be filled with garbage.

521

00:21:35,533 --> 00:21:39,033

So we have--we have useful--

522

00:21:39,033 --> 00:21:41,066

we have volume

that would be really useful

523

00:21:41,066 --> 00:21:43,266

for science experiments

or research,

524

00:21:43,266 --> 00:21:45,466

but instead it's being used

for storage,

525

00:21:45,466 --> 00:21:47,833

and if we think about

a journey to Mars,

526

00:21:47,833 --> 00:21:49,833

we really need to move away

from this paradigm

527

00:21:49,833 --> 00:21:52,500

and get to the point where

all of our space

528

00:21:52,500 --> 00:21:54,266

is being used efficiently,

529

00:21:54,266 --> 00:21:56,333

and if we have a 3-D printer,

all we have to do

530

00:21:56,333 --> 00:21:59,000

is have some material feedstock

and the printer,

531
00:21:59,000 --> 00:22:01,533
and we can build the things
we need when we need it.

532
00:22:01,533 --> 00:22:03,466
And then the other piece
of the puzzle

533
00:22:03,466 --> 00:22:06,133
that we're working on
in the company is a recycler,

534
00:22:06,133 --> 00:22:08,566
so you can take the parts
when you're finished with them

535
00:22:08,566 --> 00:22:10,333
and turn them back
into filament.

536
00:22:10,333 --> 00:22:11,666
We call that "redo,"

537
00:22:11,666 --> 00:22:13,266
so it allows you
to redo something

538
00:22:13,266 --> 00:22:14,900
with your printed parts.

539
00:22:14,900 --> 00:22:16,500
But the interesting thing
is that it also

540
00:22:16,500 --> 00:22:17,966
lets you take plastic trash

541
00:22:17,966 --> 00:22:21,733
and turn it into filament

into a 3-D-printed part.

542

00:22:21,733 --> 00:22:23,500

So today, when there--

543

00:22:23,500 --> 00:22:25,800

when there's not a 3-D printer
to use in space,

544

00:22:25,800 --> 00:22:27,466

the astronauts are forced to use

545

00:22:27,466 --> 00:22:29,266

the other things
they have available.

546

00:22:29,266 --> 00:22:32,133

One of the most fascinating
stories was when

547

00:22:32,133 --> 00:22:34,366

Sunita Williams
was on a space walk

548

00:22:34,366 --> 00:22:38,166

and had to fix part
of a power supply

549

00:22:38,166 --> 00:22:40,366

and resorted to building
a new tool

550

00:22:40,366 --> 00:22:42,966

using her toothbrush
and some duct tape

551

00:22:42,966 --> 00:22:44,366

to be able to fix something

552

00:22:44,366 --> 00:22:45,933
as important as a--
you know, the--

553
00:22:45,933 --> 00:22:47,866
part of what's delivering power

554
00:22:47,866 --> 00:22:49,733
to the space station.

555
00:22:49,733 --> 00:22:54,833
So I'm gonna just
kind of explain why,

556
00:22:54,833 --> 00:22:57,100
like--why are we not doing this?

557
00:22:57,100 --> 00:22:59,100
Why are we not manufacturing
in space enough?

558
00:22:59,100 --> 00:23:00,966
Well, it's important
to understand

559
00:23:00,966 --> 00:23:02,633
where we've been, right?

560
00:23:02,633 --> 00:23:06,666
Yuri Gagarin, the first person
to go to space, in 1961,

561
00:23:06,666 --> 00:23:09,466
launched on the pinnacle
of technology of the time,

562
00:23:09,466 --> 00:23:13,800
the Vostok rocket,
out of the Baikonur Cosmodrome.

563

00:23:13,800 --> 00:23:15,833

Now, we fast-forward
a half a century later

564

00:23:15,833 --> 00:23:19,600

to someone like Butch Wilmore,
and how does he get to space?

565

00:23:19,600 --> 00:23:23,433

Well, he gets to space on none
other than the Soyuz rocket.

566

00:23:23,433 --> 00:23:25,666

They almost look identical,
and the reason why

567

00:23:25,666 --> 00:23:29,266

is because it's almost the same
technology in many ways.

568

00:23:29,266 --> 00:23:31,666

The Soyuz was flying
only six years or so

569

00:23:31,666 --> 00:23:34,200

after Yuri's first flight.

570

00:23:34,200 --> 00:23:36,000

And even if we look
at other ways

571

00:23:36,000 --> 00:23:37,966

we've sent things into space--
space shuttle,

572

00:23:37,966 --> 00:23:40,566

maybe Apollo--
they may look different,

573

00:23:40,566 --> 00:23:42,600
but it all comes down
to chemical propulsion.

574
00:23:42,600 --> 00:23:45,066
We're using the same
basic technology

575
00:23:45,066 --> 00:23:47,766
to send things into space
as we always have.

576
00:23:47,766 --> 00:23:50,900
The Apollo astronauts were--
had to travel

577
00:23:50,900 --> 00:23:53,766
ten times the speed
of a rifle bullet to escape

578
00:23:53,766 --> 00:23:55,500
the gravitational pull of Earth,

579
00:23:55,500 --> 00:23:57,333
and that's because it takes
a lot of energy

580
00:23:57,333 --> 00:23:58,900
to get off of this planet,

581
00:23:58,900 --> 00:24:03,000
and that's why only about 2%
of a rocket is the thing

582
00:24:03,000 --> 00:24:05,333
we want in space
and the other 98% or so

583
00:24:05,333 --> 00:24:07,300
is the fuel and the rocket

584

00:24:07,300 --> 00:24:09,233
and the structure
and the engines and so on.

585

00:24:09,233 --> 00:24:12,766
So it's--there's not
a huge margin

586

00:24:12,766 --> 00:24:15,433
of the thing we want in space
compared to the rocket.

587

00:24:15,433 --> 00:24:19,100
So we look at it
as the supply chain problem.

588

00:24:19,100 --> 00:24:20,800
The supply chain to space
is broken,

589

00:24:20,800 --> 00:24:22,000
and it should be fixed.

590

00:24:22,000 --> 00:24:24,100
Today, the supply chain
looks like rockets

591

00:24:24,100 --> 00:24:26,366
that get put on barges
and shipped across oceans.

592

00:24:26,366 --> 00:24:27,700
Some rockets have to fit

593

00:24:27,700 --> 00:24:29,666
onto trains to move
to the launch pad,

594

00:24:29,666 --> 00:24:33,366
which means everything
that we put into space,

595
00:24:33,366 --> 00:24:35,700
first of all, is--
has to fit into a rocket.

596
00:24:35,700 --> 00:24:37,233
So the size of things in space

597
00:24:37,233 --> 00:24:39,400
are constrained by the size
of a rocket,

598
00:24:39,400 --> 00:24:41,233
and the size of a rocket,
in some cases,

599
00:24:41,233 --> 00:24:44,100
is constrained to the width
of a railroad track.

600
00:24:44,100 --> 00:24:46,966
So think about how funny
that is that the requirements

601
00:24:46,966 --> 00:24:50,000
on the width of a railroad track
dictate the requirements

602
00:24:50,000 --> 00:24:52,533
of the size of the things
we have in space,

603
00:24:52,533 --> 00:24:58,133
and that is a broken paradigm,
in our mind.

604
00:24:58,133 --> 00:25:01,433

It makes the costs of space extremely expensive.

605

00:25:01,433 --> 00:25:04,400

A liter of water is--
could be 10,000 kil--

606

00:25:04,400 --> 00:25:07,000

dollars in low Earth orbit.

607

00:25:07,000 --> 00:25:09,000

So while other people were looking

608

00:25:09,000 --> 00:25:12,966

at how to make a rocket better, more efficient, cheaper,

609

00:25:12,966 --> 00:25:15,400

reusable, we asked a different question.

610

00:25:15,400 --> 00:25:17,600

We asked, "What if things didn't have to be launched

611

00:25:17,600 --> 00:25:19,300

from Earth at all?"

612

00:25:19,300 --> 00:25:22,933

And what we're looking at is this idea of disruption,

613

00:25:22,933 --> 00:25:27,066

that if you could-- entire disruption from rockets,

614

00:25:27,066 --> 00:25:29,500

and I'll explain quickly what I mean by that.

615

00:25:29,500 --> 00:25:30,866

I--when I say disruption,

616

00:25:30,866 --> 00:25:35,166

I mean the definition

from Clayton Christensen,

617

00:25:35,166 --> 00:25:37,266

which I'll read out loud.

618

00:25:37,266 --> 00:25:39,566

It's "a process by which

a product or service

619

00:25:39,566 --> 00:25:41,966

takes root initially

in simple applications

620

00:25:41,966 --> 00:25:43,333

at the bottom of a market

621

00:25:43,333 --> 00:25:45,233

and then relentlessly

moves up market,

622

00:25:45,233 --> 00:25:48,266

eventually displacing

established competitors."

623

00:25:48,266 --> 00:25:52,200

So I'll give you an example

really fast what that means,

624

00:25:52,200 --> 00:25:55,833

but notice that

a disruptive innovation

625

00:25:55,833 --> 00:25:58,666

usually is very different
than the incumbent.

626

00:25:58,666 --> 00:26:01,800

So the example
is the spice trade.

627

00:26:01,800 --> 00:26:03,200

We all have heard
of the spice trade,

628

00:26:03,200 --> 00:26:06,933

but how many of you know why
wa--why did that exist?

629

00:26:06,933 --> 00:26:09,000

Why were we trading spices?

630

00:26:09,000 --> 00:26:10,400

Does anybody--just call it out

631

00:26:10,400 --> 00:26:13,600

if you know why
we traded spices.

632

00:26:13,600 --> 00:26:14,700

What's that?

633

00:26:14,700 --> 00:26:16,366

- Preservation of food.

- That's it.

634

00:26:16,366 --> 00:26:17,766

So most people don't know that.

635

00:26:17,766 --> 00:26:21,033

The--we were using spices
to preserve food.

636

00:26:21,033 --> 00:26:23,100
Spices were, in a way,

637
00:26:23,100 --> 00:26:26,266
a technology
of food preservation many,

638
00:26:26,266 --> 00:26:30,066
many years ago,
and the reason why was--

639
00:26:30,066 --> 00:26:33,533
well, we didn't have modern-day
technology to preserve food,

640
00:26:33,533 --> 00:26:37,066
but it's not like spices
made food last longer.

641
00:26:37,066 --> 00:26:38,900
It just made rotten food
taste better,

642
00:26:38,900 --> 00:26:41,666
but it was good enough to out--
for people to use it,

643
00:26:41,666 --> 00:26:43,466
and there was an entire industry
of shipping the spices

644
00:26:43,466 --> 00:26:44,800
around the world,

645
00:26:44,800 --> 00:26:48,333
until one day a gentleman
named Frederic Tudor,

646
00:26:48,333 --> 00:26:51,633
living in the Massachusetts

area, I believe,

647

00:26:51,633 --> 00:26:54,966

saw an--saw a new
business opportunity.

648

00:26:54,966 --> 00:26:59,266

You see, the lakes in that area
would freeze over in the winter,

649

00:26:59,266 --> 00:27:01,900

and they would--people would
cut the ice off of the lake

650

00:27:01,900 --> 00:27:05,033

and use it for a type
of food preservation,

651

00:27:05,033 --> 00:27:06,833

but it would melt very quickly.

652

00:27:06,833 --> 00:27:10,833

One day, Frederic Tudor
goes to the Caribbean,

653

00:27:10,833 --> 00:27:13,800

and he notices how hot it is,
and he thinks, "Wow.

654

00:27:13,800 --> 00:27:15,933

If they could have this ice
that I get in the winter,

655

00:27:15,933 --> 00:27:17,566

it would really
change things here."

656

00:27:17,566 --> 00:27:21,166

So he went back home,
and he designed--

657

00:27:21,166 --> 00:27:25,600

he designed a device
to keep ice cold.

658

00:27:25,600 --> 00:27:27,833

He became known
as the "Ice King," and he--

659

00:27:27,833 --> 00:27:29,766

what he invented was ice houses,

660

00:27:29,766 --> 00:27:31,433

these giant,
insulated buildings,

661

00:27:31,433 --> 00:27:33,133

and they would harvest the ice
in the winter,

662

00:27:33,133 --> 00:27:34,366

fill up the houses,

663

00:27:34,366 --> 00:27:36,533

and then sell it
all throughout the year

664

00:27:36,533 --> 00:27:38,200

and even ship it around
the world.

665

00:27:38,200 --> 00:27:39,700

Some of the biggest ice houses

666

00:27:39,700 --> 00:27:42,200

ended up being built in India.

667

00:27:42,200 --> 00:27:45,066

So the spice trade

was 100% disrupted

668

00:27:45,066 --> 00:27:47,400

by the ice trade,
and what you--

669

00:27:47,400 --> 00:27:48,733

what's important to notice

670

00:27:48,733 --> 00:27:51,766

is that the people who were
working in spice trade

671

00:27:51,766 --> 00:27:53,133

probably were not the people

672

00:27:53,133 --> 00:27:55,600

who then transitioned
to ice harvesting.

673

00:27:55,600 --> 00:27:59,766

An entire industry of spices
got disrupted by something new,

674

00:27:59,766 --> 00:28:01,466

and that's not the end
of the story.

675

00:28:01,466 --> 00:28:02,733

Then there was the invention

676

00:28:02,733 --> 00:28:05,033

of what was called
artificial ice,

677

00:28:05,033 --> 00:28:07,733

and it took a long time
for artificial ice to catch on,

678

00:28:07,733 --> 00:28:09,700
because people didn't believe
it was as safe

679
00:28:09,700 --> 00:28:12,066
as natural ice from a lake,

680
00:28:12,066 --> 00:28:15,200
but eventually this technology
of creating ice

681
00:28:15,200 --> 00:28:17,033
became the new norm.

682
00:28:17,033 --> 00:28:18,666
And then there was ice delivery

683
00:28:18,666 --> 00:28:21,766
and these little boxes
that your grandparents had

684
00:28:21,766 --> 00:28:23,600
that you would--
ice would get delivered,

685
00:28:23,600 --> 00:28:25,066
and you'd put it
in this little box,

686
00:28:25,066 --> 00:28:28,133
and it's about the size
of a mini-fridge today,

687
00:28:28,133 --> 00:28:29,266
and that's not where it ended.

688
00:28:29,266 --> 00:28:32,333
Then there was the invention
of refrigerators

689

00:28:32,333 --> 00:28:33,700

and being able to make ice

690

00:28:33,700 --> 00:28:36,700

or just have refrigeration

in your home.

691

00:28:36,700 --> 00:28:39,266

So, once again,

the delivery of ice

692

00:28:39,266 --> 00:28:41,633

gets disrupted by this,

693

00:28:41,633 --> 00:28:44,300

and now, today, you know,

refrigerators are real fancy.

694

00:28:44,300 --> 00:28:46,166

There's--I just saw

this one recently

695

00:28:46,166 --> 00:28:48,733

that has a touch screen on it,

696

00:28:48,733 --> 00:28:51,666

and you can--

you can send notes to people,

697

00:28:51,666 --> 00:28:53,966

and it looks like there's

Evernote on there,

698

00:28:53,966 --> 00:28:56,333

in case you want to write down

a good idea

699

00:28:56,333 --> 00:28:57,700

while you're cooking.

700

00:28:57,700 --> 00:29:00,500

So the question to ask,

701

00:29:00,500 --> 00:29:02,566

if you're--if you're in
the refrigerator business is,

702

00:29:02,566 --> 00:29:05,000

"Is this really where it ends?

703

00:29:05,000 --> 00:29:08,533

Did we go from spices
all the way to this point

704

00:29:08,533 --> 00:29:11,133

where we could have the touch
screen on our refrigerator,

705

00:29:11,133 --> 00:29:12,866

or is there another
disruption coming?

706

00:29:12,866 --> 00:29:15,400

Does the refrigerator
get disrupted by something?"

707

00:29:15,400 --> 00:29:17,666

And the answer is probably yes.

708

00:29:17,666 --> 00:29:20,966

Now, to bring it back
to space, you know,

709

00:29:20,966 --> 00:29:23,966

if it weren't for refrigeration,
we wouldn't have--

710

00:29:23,966 --> 00:29:26,533

we wouldn't have liquid fuels
for our rockets.

711
00:29:26,533 --> 00:29:28,600
So, in a way,
maybe the spice trade

712
00:29:28,600 --> 00:29:30,566
is part of what helped us
get to the point

713
00:29:30,566 --> 00:29:32,366
where we could launch things
into space.

714
00:29:32,366 --> 00:29:33,966
So we asked
a different question.

715
00:29:33,966 --> 00:29:36,233
"What if you didn't have
to launch anything at all?"

716
00:29:36,233 --> 00:29:39,233
And our vision means that you
can build things in space

717
00:29:39,233 --> 00:29:41,366
that are far bigger
than a rocket.

718
00:29:41,366 --> 00:29:43,866
You could build antennas
the size of football fields

719
00:29:43,866 --> 00:29:46,166
that could provide
global broadband Internet

720
00:29:46,166 --> 00:29:48,833

anywhere on Earth,
and what matters, though,

721

00:29:48,833 --> 00:29:50,600

is what we build,
not how we build it.

722

00:29:50,600 --> 00:29:52,100

The machine is a machine,

723

00:29:52,100 --> 00:29:54,200

but what we build
is what's really important,

724

00:29:54,200 --> 00:29:56,066

and a little example there is,

725

00:29:56,066 --> 00:29:58,533

when New Horizons
was sent to Pluto,

726

00:29:58,533 --> 00:30:02,466

it captured award-winning photos
of Pluto

727

00:30:02,466 --> 00:30:04,066

that we'd never seen before.

728

00:30:04,066 --> 00:30:06,400

The--when it launched,
ten years ago,

729

00:30:06,400 --> 00:30:08,833

some of the software
didn't even exist

730

00:30:08,833 --> 00:30:11,966

to capture these images,
and the software team

731

00:30:11,966 --> 00:30:14,266

on New Horizons

actually worked

732

00:30:14,266 --> 00:30:15,833

on their software

for ten years,

733

00:30:15,833 --> 00:30:18,000

and as new advancements

in software came out,

734

00:30:18,000 --> 00:30:21,033

they updated and sent

the updates to the spacecraft,

735

00:30:21,033 --> 00:30:23,400

and that's how we got

these images.

736

00:30:23,400 --> 00:30:26,766

So they were able to send

the digital code of software

737

00:30:26,766 --> 00:30:29,266

to the spacecraft

years after it launched,

738

00:30:29,266 --> 00:30:31,033

and that's what we're doing

with hardware.

739

00:30:31,033 --> 00:30:33,166

We can send the machine

into space,

740

00:30:33,166 --> 00:30:36,133

not even have to know what it

will build for many years,

741

00:30:36,133 --> 00:30:39,166

and then send the digital
information when we need it.

742

00:30:39,166 --> 00:30:41,900

So now that we learned how to
do that with the first printer,

743

00:30:41,900 --> 00:30:43,833

we launched another printer
into space

744

00:30:43,833 --> 00:30:46,233

called the Additive
Manufacturing Facility.

745

00:30:46,233 --> 00:30:47,766

It's really a platform,

746

00:30:47,766 --> 00:30:50,066

and it's open for anybody
on the planet to use.

747

00:30:50,066 --> 00:30:51,200

So it's commercial.

748

00:30:51,200 --> 00:30:53,600

That means that anybody
in this room can use it.

749

00:30:53,600 --> 00:30:56,333

Anybody on the world can use it,
and they do.

750

00:30:56,333 --> 00:31:02,400

So we also open-sourced the code
that allows--

751

00:31:02,400 --> 00:31:04,000

or open-sourced the interfaces

752

00:31:04,000 --> 00:31:06,733

so that people can design
new hardware that goes on that.

753

00:31:06,733 --> 00:31:10,133

I'll play a quick video
of one of the--one of--

754

00:31:10,133 --> 00:31:12,666

one of the people using
the printer, which I enjoy.

755

00:31:12,666 --> 00:31:16,733

[piano music]

756

00:31:16,733 --> 00:31:19,500

So this is our partner
at Lowe's,

757

00:31:19,500 --> 00:31:21,133

the home improvement company.

758

00:31:21,133 --> 00:31:27,133

[piano music continues]

759

00:32:21,833 --> 00:32:25,266

- Three, two, one, zero.

760

00:32:25,266 --> 00:32:27,700

And we have liftoff.

761

00:32:27,700 --> 00:32:28,700

- Liftoff.

762

00:32:30,433 --> 00:32:33,100

- All right, so that's a--
that's one of our--

763

00:32:33,100 --> 00:32:35,133

one of the people who have used
and one of the groups

764

00:32:35,133 --> 00:32:37,933

who have used the printer
that's in space today.

765

00:32:37,933 --> 00:32:41,033

Lowe's printed this tool
for astronauts.

766

00:32:41,033 --> 00:32:44,133

It's one of their
branded wrenches,

767

00:32:44,133 --> 00:32:45,800

but it's specially designed

768

00:32:45,800 --> 00:32:48,133

for some applications
on the space station.

769

00:32:48,133 --> 00:32:50,600

So now we're--
now that the printer is there,

770

00:32:50,600 --> 00:32:52,333

we're doing all kinds
of interesting things,

771

00:32:52,333 --> 00:32:53,466

and interesting users

772

00:32:53,466 --> 00:32:55,600

are coming out to us
with their ideas.

773

00:32:55,600 --> 00:32:57,000

One of my favorites is,

774

00:32:57,000 --> 00:32:58,566

"How do you build satellites
in space?"

775

00:32:58,566 --> 00:33:00,700

This is, today,
how a satellite is built.

776

00:33:00,700 --> 00:33:02,333

They're big.
They involve clean rooms,

777

00:33:02,333 --> 00:33:05,133

lots of manual touch labor.

778

00:33:05,133 --> 00:33:07,366

Now we have, with CubeSats,

779

00:33:07,366 --> 00:33:10,400

the ability
to make really small,

780

00:33:10,400 --> 00:33:13,166

easy-to-build satellites,
and small teams can do it.

781

00:33:13,166 --> 00:33:15,400

We have university groups
coming to us

782

00:33:15,400 --> 00:33:17,866

with their designs of satellites

783

00:33:17,866 --> 00:33:20,633

that take some parts that are--

784

00:33:20,633 --> 00:33:23,466
that are built on the ground
and launched into space,

785
00:33:23,466 --> 00:33:25,566
and then other parts
that are 3-D-printed,

786
00:33:25,566 --> 00:33:28,333
and we can really quickly
assemble a satellite

787
00:33:28,333 --> 00:33:30,000
in space and deploy it.

788
00:33:30,000 --> 00:33:31,766
So imagine that--
you know, this is--

789
00:33:31,766 --> 00:33:34,533
this is right down the road
when we do this.

790
00:33:34,533 --> 00:33:37,166
Very soon, satellites
will have been built in space

791
00:33:37,166 --> 00:33:38,833
just like they've been done
on the ground,

792
00:33:38,833 --> 00:33:43,500
and what does that mean
for the future of satellites?

793
00:33:43,500 --> 00:33:44,800
Here they--here they look

794
00:33:44,800 --> 00:33:47,533
when a satellite

is launched from ISS.

795

00:33:47,533 --> 00:33:49,500

The other is exercise.

There's--

796

00:33:49,500 --> 00:33:51,700

today, exercise

is a very intensive part

797

00:33:51,700 --> 00:33:54,900

of astronauts living in space,

to keep up muscle tone

798

00:33:54,900 --> 00:33:57,100

and bone density and so on.

799

00:33:57,100 --> 00:34:00,933

One of our--one of our partners

is Dr. Yvonne Cagle.

800

00:34:00,933 --> 00:34:03,000

She's an astronaut,

and she's developed

801

00:34:03,000 --> 00:34:05,366

some really interesting

medical applications

802

00:34:05,366 --> 00:34:07,800

so that you can reduce

the amount of time needed

803

00:34:07,800 --> 00:34:11,100

to exercise in space

by using these tools,

804

00:34:11,100 --> 00:34:14,633

and it turns out that the tools

can be 3-D-printed,

805

00:34:14,633 --> 00:34:16,766

for the most part,
and everything else

806

00:34:16,766 --> 00:34:19,066

is a found item
on the space station.

807

00:34:19,066 --> 00:34:20,833

So there's no need
to launch anything.

808

00:34:20,833 --> 00:34:22,166

You 3-D print some,

809

00:34:22,166 --> 00:34:24,400

go get the rest
from found items.

810

00:34:24,400 --> 00:34:27,766

So I said earlier,

811

00:34:27,766 --> 00:34:30,300

"What matters is what we build
and not how we build it."

812

00:34:30,300 --> 00:34:32,866

The printer is a magic box.

813

00:34:32,866 --> 00:34:34,700

What matters
is what comes out of it,

814

00:34:34,700 --> 00:34:38,266

and there's a parallel
I'd love to explain.

815

00:34:38,266 --> 00:34:40,766

These are the women of Apollo.

816

00:34:40,766 --> 00:34:43,433
Most people don't know the story
of the women of Apollo,

817

00:34:43,433 --> 00:34:48,033
but they were--they were
really the ones driving

818

00:34:48,033 --> 00:34:50,033
from the back end,

819

00:34:50,033 --> 00:34:51,800
making sure we could
send people to the Moon

820

00:34:51,800 --> 00:34:53,333
and bring them back safely.

821

00:34:53,333 --> 00:34:56,666
It's people like
Katherine Johnson,

822

00:34:56,666 --> 00:35:01,333
Margaret Hamilton, who--
their job was computer.

823

00:35:01,333 --> 00:35:04,500
Like, their profession
was a human computer,

824

00:35:04,500 --> 00:35:06,500
and this was at a time
where computers

825

00:35:06,500 --> 00:35:07,833
were too big and too expensive

826

00:35:07,833 --> 00:35:09,433
for everyone to have one
on their desk,

827
00:35:09,433 --> 00:35:11,900
so people did the math.

828
00:35:11,900 --> 00:35:17,000
Katherine, a Medal of Honor
winner from the president,

829
00:35:17,000 --> 00:35:22,500
did the math to figure out how
to send astronauts to the Moon

830
00:35:22,500 --> 00:35:24,000
and bring them back safely,

831
00:35:24,000 --> 00:35:26,466
and then people like Margaret
were building--

832
00:35:26,466 --> 00:35:28,466
writing the software code out
from that math

833
00:35:28,466 --> 00:35:30,633
and putting it
on the spacecraft.

834
00:35:30,633 --> 00:35:34,266
So there was a time when
computers were a profession,

835
00:35:34,266 --> 00:35:36,033
when people were computers,

836
00:35:36,033 --> 00:35:38,900
and we obviously know
how that changed, right?

837

00:35:38,900 --> 00:35:41,533

Now we all have computers
in our pocket.

838

00:35:41,533 --> 00:35:43,766

It used to be
that an entire room of people

839

00:35:43,766 --> 00:35:47,633

did the computation
that is not even anywhere close

840

00:35:47,633 --> 00:35:51,066

to what the computer
in your pocket can do.

841

00:35:51,066 --> 00:35:53,400

Today, though,
the way we design satellites,

842

00:35:53,400 --> 00:35:56,300

it's very much a manual process.

843

00:35:56,300 --> 00:35:58,500

It takes entire rooms of people

844

00:35:58,500 --> 00:36:01,600

and huge cubicle farms
to do the design work

845

00:36:01,600 --> 00:36:05,100

and to create the satellite.

846

00:36:05,100 --> 00:36:06,866

What that means
is that everything

847

00:36:06,866 --> 00:36:09,033

we put into space
is limited by,

848

00:36:09,033 --> 00:36:10,533
first of all, the capacity

849

00:36:10,533 --> 00:36:13,333
of what our human brain
can imagine

850

00:36:13,333 --> 00:36:15,000
and the capacity
of what two hands--

851

00:36:15,000 --> 00:36:19,100
one on a keyboard, one a mouse--
can manipulate on the computer.

852

00:36:19,100 --> 00:36:22,666
The computer itself can do
far more than what we are able

853

00:36:22,666 --> 00:36:24,500
to manipulate the computer
to do.

854

00:36:24,500 --> 00:36:27,633
So where we're headed
is software

855

00:36:27,633 --> 00:36:29,933
that actually does design
for us,

856

00:36:29,933 --> 00:36:33,466
and we use the software
to have it give us

857

00:36:33,466 --> 00:36:35,233
the most optimal solution,

858

00:36:35,233 --> 00:36:39,733

and this is a--these are often
called optimization software,

859

00:36:39,733 --> 00:36:42,666

generative design,
evolutionary algorithms,

860

00:36:42,666 --> 00:36:44,366

but what we're working on
is the ability

861

00:36:44,366 --> 00:36:48,566

to give the computer
the operational environment.

862

00:36:48,566 --> 00:36:51,400

"I need--I need
two satellites connected

863

00:36:51,400 --> 00:36:52,900

by a very large truss,

864

00:36:52,900 --> 00:36:55,333

or I need an antenna the size
of a football field,

865

00:36:55,333 --> 00:36:56,733

and it's going to be
in low Earth orbit,

866

00:36:56,733 --> 00:36:59,200

and this is
the loading condition."

867

00:36:59,200 --> 00:37:00,666

You don't give it a design
and say,

868

00:37:00,666 --> 00:37:01,766

"Make this design better."

869

00:37:01,766 --> 00:37:03,466

You literally give it
the environment,

870

00:37:03,466 --> 00:37:07,066

and you ask it to give you
the most optimal design,

871

00:37:07,066 --> 00:37:08,900

and it runs through algorithms,

872

00:37:08,900 --> 00:37:11,566

and it comes back with maybe
thousands of options,

873

00:37:11,566 --> 00:37:13,200

and you narrow it down,
and you decide

874

00:37:13,200 --> 00:37:14,700

which one makes the most sense.

875

00:37:14,700 --> 00:37:18,766

So we're headed to a point
where the engineers--

876

00:37:18,766 --> 00:37:21,966

and I'm one too,
so I think a lot about this--

877

00:37:21,966 --> 00:37:24,633

become the mentors
to the machine.

878

00:37:24,633 --> 00:37:29,100

We use--we use these machines

to help us engineer better.

879

00:37:29,100 --> 00:37:31,866

What that means is that
we could be very close

880

00:37:31,866 --> 00:37:34,466

to a point in time where,
instead of a giant room

881

00:37:34,466 --> 00:37:37,600

of cubicles of people
designing things,

882

00:37:37,600 --> 00:37:39,433

any one of you,
with this software,

883

00:37:39,433 --> 00:37:42,966

can do what used to be done
by thousands of people.

884

00:37:42,966 --> 00:37:46,266

And that's an incredible power,
because imagine when everybody

885

00:37:46,266 --> 00:37:51,366

in that giant room of engineers
all has this power.

886

00:37:51,366 --> 00:37:53,333

What will we create next, right?

887

00:37:53,333 --> 00:37:55,600

So we're working on,
once again,

888

00:37:55,600 --> 00:37:57,433

the machine that can build
those things.

889

00:37:57,433 --> 00:38:00,400

It's called Archinaut,
architecture-astronaut,

890

00:38:00,400 --> 00:38:02,866

and it goes into space.
It's a spacecraft,

891

00:38:02,866 --> 00:38:04,900

and it builds really,
really big things.

892

00:38:04,900 --> 00:38:06,133

It uses 3-D printing.

893

00:38:06,133 --> 00:38:07,900

It uses robotic assembly,

894

00:38:07,900 --> 00:38:10,366

and it launches some things
that can't be built in space

895

00:38:10,366 --> 00:38:12,300

and assembles it
into the structure.

896

00:38:12,300 --> 00:38:16,233

So it allows us
to optimize designs in software

897

00:38:16,233 --> 00:38:18,300

that never have to exist
on Earth,

898

00:38:18,300 --> 00:38:20,200

send the information
to Archinaut,

899

00:38:20,200 --> 00:38:21,933
and have it build it there.

900
00:38:21,933 --> 00:38:23,433
And, to us,
that's really incredible

901
00:38:23,433 --> 00:38:26,766
because that means that maybe
a satellite, in the future,

902
00:38:26,766 --> 00:38:29,866
that today looks like something
that we can,

903
00:38:29,866 --> 00:38:31,366
you know, build by our own hands

904
00:38:31,366 --> 00:38:34,466
and put into a rocket,
one day will be far different.

905
00:38:34,466 --> 00:38:38,300
A ComSat may not look anything
like a ComSat in the future

906
00:38:38,300 --> 00:38:40,366
when Archinaut
can build it there.

907
00:38:40,366 --> 00:38:41,666
So what we've done as a company

908
00:38:41,666 --> 00:38:43,733
is we've taken something
from product--

909
00:38:43,733 --> 00:38:46,466
the first 3-D printer--
we built a platform.

910

00:38:46,466 --> 00:38:48,700

Now everybody can use it,
and that same technology

911

00:38:48,700 --> 00:38:51,866

builds new capabilities,
like Archinaut.

912

00:38:51,866 --> 00:38:53,200

But at the end of the day,

913

00:38:53,200 --> 00:38:56,400

what matters is not just
the idea of manufacturing

914

00:38:56,400 --> 00:38:59,766

but this concept of processing.

915

00:38:59,766 --> 00:39:01,566

Everything we're doing
with Made In Space

916

00:39:01,566 --> 00:39:04,266

with manufacturing in space

917

00:39:04,266 --> 00:39:07,433

is basically processing things
in a new way.

918

00:39:07,433 --> 00:39:09,533

We have this new environment
to process things.

919

00:39:09,533 --> 00:39:12,566

So I'd like to explain
how new processes

920

00:39:12,566 --> 00:39:14,200

unlock new industries.

921

00:39:14,200 --> 00:39:20,166

The first story
is the story of 19--

922

00:39:20,166 --> 00:39:22,966

or 17th-century England.

923

00:39:22,966 --> 00:39:25,400

Birchwood forests were being
completely decimated,

924

00:39:25,400 --> 00:39:26,766

and the reason why is the wood

925

00:39:26,766 --> 00:39:30,200

was being used
to burn for energy

926

00:39:30,200 --> 00:39:32,900

to support the industrialization
of England,

927

00:39:32,900 --> 00:39:34,433

but they were running out
of wood.

928

00:39:34,433 --> 00:39:37,166

They knew that in these
water-filled mines was coal,

929

00:39:37,166 --> 00:39:38,566

and if they could get the coal,

930

00:39:38,566 --> 00:39:40,700

they could--they could use that
for their energy,

931

00:39:40,700 --> 00:39:43,500
but there was no way to get
the water out of the mines,

932
00:39:43,500 --> 00:39:48,400
and then a gentleman
came along, Abraham Darby,

933
00:39:48,400 --> 00:39:49,800
and he invented a new process.

934
00:39:49,800 --> 00:39:52,500
He invented the coke oven,
and it was, essentially,

935
00:39:52,500 --> 00:39:54,666
an oven that got
to really high temperatures

936
00:39:54,666 --> 00:39:57,700
that allowed the formation
of coke to be created,

937
00:39:57,700 --> 00:39:59,966
and the coke was used
to make steel.

938
00:39:59,966 --> 00:40:01,766
Once you have steel,
you can make pumps,

939
00:40:01,766 --> 00:40:03,166
and once you have pumps,
you can get the water out

940
00:40:03,166 --> 00:40:04,700
of the mine and get the coal,

941
00:40:04,700 --> 00:40:06,666
and once you have the coal,

you can either burn it

942

00:40:06,666 --> 00:40:10,033

in the coke oven
and make more steel

943

00:40:10,033 --> 00:40:14,300

or you can do other things
with the coal.

944

00:40:14,300 --> 00:40:17,100

So this new process
of the coke oven, in fact,

945

00:40:17,100 --> 00:40:19,066

was the beginning
of what we call

946

00:40:19,066 --> 00:40:21,666

the Industrial Revolution,
the Machine Age.

947

00:40:21,666 --> 00:40:24,533

All of the things
that built the foundation

948

00:40:24,533 --> 00:40:26,766

for the fa--for all
the technology around us

949

00:40:26,766 --> 00:40:28,700

came from this one new process

950

00:40:28,700 --> 00:40:32,200

of unlocking
the abundance of steel.

951

00:40:32,200 --> 00:40:36,466

Another great example is--
comes to this picture.

952

00:40:36,466 --> 00:40:38,266

What do these--
just yell it out--

953

00:40:38,266 --> 00:40:40,333

what does one of the--all these
pictures have in common?

954

00:40:40,333 --> 00:40:42,100

- Aluminum.

- Exactly.

955

00:40:42,100 --> 00:40:43,700

So it's aluminum, right?

956

00:40:43,700 --> 00:40:45,966

Everything from
the space shuttle

957

00:40:45,966 --> 00:40:47,833

to something we can crumple up

958

00:40:47,833 --> 00:40:49,566

and throw in the trash exists

959

00:40:49,566 --> 00:40:52,333

because we have
abundant aluminum,

960

00:40:52,333 --> 00:40:54,000

and what's surprising

961

00:40:54,000 --> 00:40:55,533

is that aluminum
wasn't always like this.

962

00:40:55,533 --> 00:40:58,866

It used to be one of the most

precious metals on Earth.

963

00:40:58,866 --> 00:41:02,700

It was the--Napoleon III

964

00:41:02,700 --> 00:41:06,533

fed the King of Siam

on aluminum utensils

965

00:41:06,533 --> 00:41:11,433

and an aluminum platter while

his people ate off of gold.

966

00:41:11,433 --> 00:41:13,633

So aluminum was more expensive

than gold.

967

00:41:13,633 --> 00:41:15,266

The tip

of the Washington Monument

968

00:41:15,266 --> 00:41:17,866

is made of aluminum

to signify that.

969

00:41:17,866 --> 00:41:20,733

So how did aluminum go from

one of the most expensive,

970

00:41:20,733 --> 00:41:23,100

rare materials to something

we throw away?

971

00:41:23,100 --> 00:41:24,933

Well, once again,

it was a new process.

972

00:41:24,933 --> 00:41:27,766

There was--kind of invented

by several people at--

973

00:41:27,766 --> 00:41:29,233
around the same time,

974

00:41:29,233 --> 00:41:31,566
once of which was Charles Hall.

975

00:41:31,566 --> 00:41:33,600
He's a pretty young guy.

976

00:41:33,600 --> 00:41:35,533
He's at Oberlin College in Ohio,

977

00:41:35,533 --> 00:41:37,166
and his chemistry professor
says,

978

00:41:37,166 --> 00:41:39,000
"The first person to figure out
how to make cheap aluminum

979

00:41:39,000 --> 00:41:41,900
will be very wealthy,"
and he goes home.

980

00:41:41,900 --> 00:41:43,166
His sister is a chemist,

981

00:41:43,166 --> 00:41:46,033
and together they figure out
an electrolysis process

982

00:41:46,033 --> 00:41:48,666
to unlock aluminum
from fluoride salts,

983

00:41:48,666 --> 00:41:52,766
and electrolysis--that process
is what makes aluminum

984

00:41:52,766 --> 00:41:55,633

so abundantly available
for us today.

985

00:41:55,633 --> 00:41:57,166

So the question is,

986

00:41:57,166 --> 00:42:00,566

"What new processes
might we create in space?"

987

00:42:00,566 --> 00:42:05,766

How can the space environment
allow us to unlock new processes

988

00:42:05,766 --> 00:42:07,400

that don't exist on Earth?

989

00:42:07,400 --> 00:42:12,600

We have access to microgravity,

990

00:42:12,600 --> 00:42:13,966

also controllable gravity.

991

00:42:13,966 --> 00:42:16,000

You're in--

you can spin anything up,

992

00:42:16,000 --> 00:42:17,933

if you wanted to,

and have any gravity you want.

993

00:42:17,933 --> 00:42:20,533

You have

the radiation environment

994

00:42:20,533 --> 00:42:22,766

of black body facing away

from the Sun.

995

00:42:22,766 --> 00:42:24,566

You have the temperature
extremes you can get

996

00:42:24,566 --> 00:42:28,733

from being in and out
of the Sun--its range.

997

00:42:28,733 --> 00:42:30,466

There's all kinds
of interesting things.

998

00:42:30,466 --> 00:42:33,200

The resources
that are out there

999

00:42:33,200 --> 00:42:34,733

are so much more, obviously,

1000

00:42:34,733 --> 00:42:36,133

than what we have on Earth.

1001

00:42:36,133 --> 00:42:38,933

So there's a lot
of really interesting things

1002

00:42:38,933 --> 00:42:42,200

that space allows us to do
that we can't do on Earth,

1003

00:42:42,200 --> 00:42:46,033

and that really is
the future of why

1004

00:42:46,033 --> 00:42:48,800

we should be indu--
bringing industry into space.

1005

00:42:48,800 --> 00:42:50,966

So I'll give one example,
really fast,

1006

00:42:50,966 --> 00:42:53,866

of what Made In Space
is doing there.

1007

00:42:53,866 --> 00:42:56,100

So we think a lot about
how to make things in space,

1008

00:42:56,100 --> 00:42:59,566

like 3-D printers that are there
to build things and Archinaut,

1009

00:42:59,566 --> 00:43:03,066

that builds big things in space,
but we're also thinking about,

1010

00:43:03,066 --> 00:43:06,433

"How do we make things in space
that can't be made on Earth

1011

00:43:06,433 --> 00:43:08,600

and then bring them back
to Earth?"

1012

00:43:08,600 --> 00:43:10,966

We announced a project recently.

1013

00:43:10,966 --> 00:43:12,366

It's a flight mission

1014

00:43:12,366 --> 00:43:15,833

that will make optical fiber
in space,

1015

00:43:15,833 --> 00:43:17,700

and this is something that--

1016

00:43:17,700 --> 00:43:19,733

we have optical fiber on Earth.

1017

00:43:19,733 --> 00:43:22,200

This is a--this is

a specific type of fiber that,

1018

00:43:22,200 --> 00:43:26,900

if it's made in zero gravity,

can be 10 to 100 times better

1019

00:43:26,900 --> 00:43:28,866

than the fiber being used

on Earth,

1020

00:43:28,866 --> 00:43:30,333

and it's simply because,

1021

00:43:30,333 --> 00:43:32,933

in the pristine microgravity

environment,

1022

00:43:32,933 --> 00:43:36,600

we can make a better type

of fiber.

1023

00:43:36,600 --> 00:43:38,966

So what we believe

is that we need to start

1024

00:43:38,966 --> 00:43:41,633

to find products

that can be made in space

1025

00:43:41,633 --> 00:43:43,100

and brought back to Earth,

1026

00:43:43,100 --> 00:43:45,700
and in the beginning
it may be--they may serve,

1027
00:43:45,700 --> 00:43:46,900
like, niche markets.

1028
00:43:46,900 --> 00:43:49,566
They may be very expensive
to buy on Earth,

1029
00:43:49,566 --> 00:43:51,566
but there'll be markets
for those,

1030
00:43:51,566 --> 00:43:53,133
and the moment that happens,

1031
00:43:53,133 --> 00:43:55,666
the moment we bring things back
to Earth,

1032
00:43:55,666 --> 00:43:59,400
the more people will realize
the benefit of doing that,

1033
00:43:59,400 --> 00:44:01,200
and we'll start to see
new things happen,

1034
00:44:01,200 --> 00:44:03,600
transportation
coming back to Earth

1035
00:44:03,600 --> 00:44:07,133
as available as transportation
going into space.

1036
00:44:07,133 --> 00:44:10,600
So I come back to the spaceship

1037

00:44:10,600 --> 00:44:13,133

and to this thought
that we live--

1038

00:44:13,133 --> 00:44:15,366

we all live on a spaceship
as well

1039

00:44:15,366 --> 00:44:18,000

and as much as I believe,
personally,

1040

00:44:18,000 --> 00:44:22,533

that we will go on to go to Mars

1041

00:44:22,533 --> 00:44:24,600

and to build habitats
on the Moon

1042

00:44:24,600 --> 00:44:26,900

and, my favorite,
build giant colonies in space,

1043

00:44:26,900 --> 00:44:29,800

like Gerard O'Neill imagined,

1044

00:44:29,800 --> 00:44:33,833

I also recognize that we've got
it pretty good here on Earth.

1045

00:44:33,833 --> 00:44:36,500

Like, this spaceship's
treating us really well.

1046

00:44:36,500 --> 00:44:38,466

It's--it wants to keep us alive

1047

00:44:38,466 --> 00:44:41,000

much more than space wants
to keep us alive,

1048
00:44:41,000 --> 00:44:42,166
and we need to respect that.

1049
00:44:42,166 --> 00:44:43,366
We need to respect the fact

1050
00:44:43,366 --> 00:44:45,666
that this is a really
interesting place

1051
00:44:45,666 --> 00:44:47,733
in the universe as we know it.

1052
00:44:47,733 --> 00:44:52,000
So as we talk about--
talk about these things,

1053
00:44:52,000 --> 00:44:53,600
I think it's important
to have the discussion

1054
00:44:53,600 --> 00:44:55,133
about changing the world

1055
00:44:55,133 --> 00:44:56,700
and not just about
changing worlds

1056
00:44:56,700 --> 00:44:58,633
and going to other places
in space.

1057
00:44:58,633 --> 00:45:02,500
And we need to have
that discussion,

1058

00:45:02,500 --> 00:45:05,566

because we aren't currently
doing the best we can.

1059

00:45:05,566 --> 00:45:07,166

Like, we can admit that.

1060

00:45:07,166 --> 00:45:11,400

The industrialization
of our planet has a dark side.

1061

00:45:11,400 --> 00:45:13,566

Our--we have to, you know,

1062

00:45:13,566 --> 00:45:16,333

to abide by the second law
of thermodynamics.

1063

00:45:16,333 --> 00:45:20,433

We have to radiate our heat
from our processes

1064

00:45:20,433 --> 00:45:22,866

into the atmosphere
or into the oceans,

1065

00:45:22,866 --> 00:45:25,900

and as our bla--
as our heat sinks.

1066

00:45:25,900 --> 00:45:28,466

In space,
your heat sink is abundant,

1067

00:45:28,466 --> 00:45:31,166

and it's just the universe,
and you don't pollute that.

1068

00:45:31,166 --> 00:45:33,133

So we need to be thinking

about that.

1069

00:45:33,133 --> 00:45:35,600

We need to be thinking
about, today,

1070

00:45:35,600 --> 00:45:37,200

how we turn mountains into holes

1071

00:45:37,200 --> 00:45:38,700

in the ground
to get our resources,

1072

00:45:38,700 --> 00:45:40,666

and one day we will run out
of mountains

1073

00:45:40,666 --> 00:45:42,200

to turn into holes
in the ground,

1074

00:45:42,200 --> 00:45:44,566

and we will evidently transition

1075

00:45:44,566 --> 00:45:47,766

to getting those resources
in space.

1076

00:45:47,766 --> 00:45:50,433

So when I ask that question
that I asked earlier,

1077

00:45:50,433 --> 00:45:52,566

"Is a planetary surface
the best place

1078

00:45:52,566 --> 00:45:56,066

for our advancing
industrial needs?"

1079

00:45:56,066 --> 00:45:58,933

Perhaps, today, it is,
but in the future,

1080

00:45:58,933 --> 00:46:00,900

at some point, it won't be.

1081

00:46:00,900 --> 00:46:04,600

That's the belief I have,
is that, one day, it won't be,

1082

00:46:04,600 --> 00:46:05,766

and to get to that point,

1083

00:46:05,766 --> 00:46:07,500

there's no reason
we should delay.

1084

00:46:07,500 --> 00:46:09,200

There's no reason
we should say,

1085

00:46:09,200 --> 00:46:10,866

"We'll just wait until
we have to go there,

1086

00:46:10,866 --> 00:46:12,100

and then we'll go there."

1087

00:46:12,100 --> 00:46:14,766

Like, there are things
we can do today better

1088

00:46:14,766 --> 00:46:16,900

off of Planet Earth
than on Planet Earth,

1089

00:46:16,900 --> 00:46:20,466

and we should start

with those things.

1090

00:46:20,466 --> 00:46:24,200

So I love this quote,
and I'll leave on this.

1091

00:46:24,200 --> 00:46:26,333

Perhaps the original
"Pale Blue Dot" speech,

1092

00:46:26,333 --> 00:46:28,433

but that--remembering
that we all live

1093

00:46:28,433 --> 00:46:32,566

on this fragile rock
in the Solar System,

1094

00:46:32,566 --> 00:46:34,733

and we should do everything
we can to protect it

1095

00:46:34,733 --> 00:46:38,466

while exploring space
and finding new places to live.

1096

00:46:38,466 --> 00:46:40,033

Thank you.

1097

00:46:40,033 --> 00:46:43,566

[applause]

1098

00:46:43,566 --> 00:46:45,500

That was good.
- Thank you very much.

1099

00:46:45,500 --> 00:46:49,600

We should talk afterwards.

1100

00:46:49,600 --> 00:46:51,266

So we have time
for a few questions.

1101

00:46:51,266 --> 00:46:53,600

If you have a question,
please raise your hand.

1102

00:46:53,600 --> 00:46:55,133

Wait for the microphone
to come to you,

1103

00:46:55,133 --> 00:46:57,066

stand up, ask the question,

1104

00:46:57,066 --> 00:46:58,700

and you'll get an answer.

1105

00:47:10,900 --> 00:47:00,500

- Thank you.

1106

00:47:10,900 --> 00:47:12,966

Very interesting talk,

1107

00:47:12,966 --> 00:47:15,233

but one question
that you mentioned--

1108

00:47:15,233 --> 00:47:20,400

that you are planning to build
the big structures in space.

1109

00:47:20,400 --> 00:47:23,100

That--to do this,

1110

00:47:23,100 --> 00:47:28,133

you need on--
not only the technology,

1111

00:47:28,133 --> 00:47:30,833

but you also need
the raw materials,

1112

00:47:30,833 --> 00:47:32,966

and a lot of them.

1113

00:47:32,966 --> 00:47:35,833

So it's not a problem
with these small tools,

1114

00:47:35,833 --> 00:47:38,333

but if you're going
to build something--

1115

00:47:38,333 --> 00:47:40,500

to build something big,

1116

00:47:40,500 --> 00:47:42,600

where would you get
these raw materials?

1117

00:47:42,600 --> 00:47:43,933

- Yeah.

1118

00:47:43,933 --> 00:47:45,966

That's a wonderful,
wonderful question.

1119

00:47:45,966 --> 00:47:47,600

Where do we get
the raw materials

1120

00:47:47,600 --> 00:47:50,100

to build the things
that we want to build?

1121

00:47:50,100 --> 00:47:52,866

So there's a few parts
to that answer.

1122

00:47:52,866 --> 00:47:57,433

The first part is that, today,
we launch them from Earth.

1123

00:47:57,433 --> 00:47:59,000

If it's the printer
on the space station,

1124

00:47:59,000 --> 00:48:01,933

we launch the materials
from Earth.

1125

00:48:01,933 --> 00:48:04,233

And the benefit there is that,

1126

00:48:04,233 --> 00:48:08,200

if the thing that we're building
only has to survive in space,

1127

00:48:08,200 --> 00:48:12,100

in zero gravity--let's imagine
the structure of a satellite--

1128

00:48:12,100 --> 00:48:13,733

it doesn't have
to survive launch.

1129

00:48:13,733 --> 00:48:15,600

It doesn't have to even exist

1130

00:48:15,600 --> 00:48:17,500

in one gravity in a clean room.

1131

00:48:17,500 --> 00:48:21,466

So the amount of material needed
for that structure is--

1132

00:48:21,466 --> 00:48:24,366

it can be less than the amount
of material for the structure

1133

00:48:24,366 --> 00:48:26,566

if it were built on Earth,
then launched.

1134

00:48:26,566 --> 00:48:29,800

So that means that, if we launch
raw material into space

1135

00:48:29,800 --> 00:48:31,633

and then build the thing
we need,

1136

00:48:31,633 --> 00:48:34,300

we actually--that material
goes a longer way

1137

00:48:34,300 --> 00:48:37,166

than had we just built the thing
on Earth and launched it.

1138

00:48:37,166 --> 00:48:39,500

So that--we start there,
and there's just,

1139

00:48:39,500 --> 00:48:42,066

right off the bat, improvement.

1140

00:48:42,066 --> 00:48:44,933

Next step is what we--
what we call

1141

00:48:44,933 --> 00:48:47,866

in situ resource utilization,
ISRU,

1142

00:48:47,866 --> 00:48:50,566

using the resources

that you have in space.

1143

00:48:50,566 --> 00:48:52,666

Now, most people think
about the asteroids

1144

00:48:52,666 --> 00:48:55,933

or maybe the Moon
as the resources.

1145

00:48:55,933 --> 00:48:59,966

We think about other resources
that may exist near-term.

1146

00:48:59,966 --> 00:49:03,100

So I mentioned earlier
we're building a recycler.

1147

00:49:03,100 --> 00:49:04,366

It goes into the space station.

1148

00:49:04,366 --> 00:49:06,766

It takes plastic waste
that's already there

1149

00:49:06,766 --> 00:49:09,066

and turns it into material.

1150

00:49:09,066 --> 00:49:12,466

So there's actually already
a lot of material in space

1151

00:49:12,466 --> 00:49:15,133

that we can reconstitute
into raw material

1152

00:49:15,133 --> 00:49:17,100

for the printing process.

1153

00:49:17,100 --> 00:49:20,400

Now, when we get to the thing
I think you're asking about--

1154

00:49:20,400 --> 00:49:22,266

how do we build the very,
very big things,

1155

00:49:22,266 --> 00:49:25,100

the things that may require
so much material

1156

00:49:25,100 --> 00:49:26,400

that you wouldn't launch it

1157

00:49:26,400 --> 00:49:29,500

because it would still take
many launches?

1158

00:49:29,500 --> 00:49:33,133

Eventually, we will need
to get resources from space.

1159

00:49:33,133 --> 00:49:36,333

We think that is, you know,
many steps down the road,

1160

00:49:36,333 --> 00:49:38,466

and to build a business,
we start on the things

1161

00:49:38,466 --> 00:49:39,800

that there are markets for

1162

00:49:39,800 --> 00:49:41,933

but think about building
those markets

1163

00:49:41,933 --> 00:49:44,600

towards the time

when you need the resources.

1164

00:49:44,600 --> 00:49:48,766

If you're really interested
in it, we have a NASA NIAC,

1165

00:49:48,766 --> 00:49:52,333

which is an Innovative
Advanced Concept project,

1166

00:49:52,333 --> 00:49:53,900

looking at that problem,

1167

00:49:53,900 --> 00:49:55,266

and the--what we're
looking at is,

1168

00:49:55,266 --> 00:49:58,366

"How do you move
an asteroid resource from,

1169

00:49:58,366 --> 00:50:01,066

let's say, the asteroid belt

1170

00:50:01,066 --> 00:50:04,333

to a location of interest
where maybe mining happens?"

1171

00:50:04,333 --> 00:50:07,000

And we came at it from
a completely different angle,

1172

00:50:07,000 --> 00:50:09,933

where we turn the asteroid
into a spacecraft

1173

00:50:09,933 --> 00:50:13,200

and have the asteroid
fly itself to that location.

1174

00:50:13,200 --> 00:50:17,500

So you can look that up,
and it's pretty interesting.

1175

00:50:17,500 --> 00:50:20,333

- These are wonderful thoughts--
[inaudible]

1176

00:50:20,333 --> 00:50:23,766

They're wonderful thoughts,
but what is your timeline?

1177

00:50:23,766 --> 00:50:26,100

When is this gonna happen?

1178

00:50:26,100 --> 00:50:27,666

- Specifically what?

1179

00:50:27,666 --> 00:50:29,233

I mean, we have a printer
in space today.

1180

00:50:29,233 --> 00:50:30,433

- You have a printer,

1181

00:50:30,433 --> 00:50:31,766

but you're gonna build
large structures.

1182

00:50:31,766 --> 00:50:33,500

How soon do you think
that's going to happen?

1183

00:50:33,500 --> 00:50:35,600

- Yeah.

That's a good question.

1184

00:50:35,600 --> 00:50:40,066

So the program with NASA

to do Archinaut

1185

00:50:40,066 --> 00:50:45,300

is a public-private partnership
between Made In Space and NASA,

1186

00:50:45,300 --> 00:50:48,566

and it's through a new program
they have called Tipping Points,

1187

00:50:48,566 --> 00:50:51,700

and Tipping Points
is specifically looking

1188

00:50:51,700 --> 00:50:55,700

at programs that,
if NASA funds today,

1189

00:50:55,700 --> 00:50:58,400

in the span of two years or so,

1190

00:50:58,400 --> 00:51:00,566

can get beyond a tipping point

1191

00:51:00,566 --> 00:51:03,066

where no more
government funding is needed.

1192

00:51:03,066 --> 00:51:05,366

It can go straight
to commercial markets.

1193

00:51:05,366 --> 00:51:07,100

So the Archinaut program

1194

00:51:07,100 --> 00:51:09,866

was awarded that contract
under Tipping Points,

1195

00:51:09,866 --> 00:51:12,800

which means

that in the very near term,

1196

00:51:12,800 --> 00:51:14,166

let's say two to four years,

1197

00:51:14,166 --> 00:51:17,133

we are introducing

real products into,

1198

00:51:17,133 --> 00:51:20,800

like, the space market

of building big things in space.

1199

00:51:20,800 --> 00:51:23,266

So it's pretty quick for us.

1200

00:51:23,266 --> 00:51:25,300

Yeah.

1201

00:51:25,300 --> 00:51:26,700

- Yeah, I have a question.

1202

00:51:26,700 --> 00:51:29,500

You mentioned this issue

of cost.

1203

00:51:29,500 --> 00:51:31,400

There are a number of issues

that you bring up

1204

00:51:31,400 --> 00:51:33,000

that are really interesting,

one of which is,

1205

00:51:33,000 --> 00:51:34,900

"Where are the resources

coming from?"

1206

00:51:34,900 --> 00:51:36,566

But there are other issues,
as well.

1207

00:51:36,566 --> 00:51:38,400

We know, for example,
that the human body

1208

00:51:38,400 --> 00:51:41,233

is so poorly adapted to space,

1209

00:51:41,233 --> 00:51:44,000

that people don't survive
in space.

1210

00:51:44,000 --> 00:51:45,600

I mean, we can keep them alive,

1211

00:51:45,600 --> 00:51:47,800

but it takes
incredible amounts of money

1212

00:51:47,800 --> 00:51:49,666

and energy to do that,

1213

00:51:49,666 --> 00:51:51,433

and their bodies
are deteriorating

1214

00:51:51,433 --> 00:51:52,866

at incredible rates--

1215

00:51:52,866 --> 00:51:55,366

endocrine system,
bones reabsorb,

1216

00:51:55,366 --> 00:51:57,100

muscles go away--

1217

00:51:57,100 --> 00:51:59,333

and what you're describing
is something

1218

00:51:59,333 --> 00:52:02,566

that is sort of far-fetched

1219

00:52:02,566 --> 00:52:06,900

in terms of how are we going
to utilize this environment

1220

00:52:06,900 --> 00:52:10,200

in a way that's both economical
and reasonable.

1221

00:52:10,200 --> 00:52:13,300

So I'm curious,
in terms of your timeline

1222

00:52:13,300 --> 00:52:17,666

and in terms of your plans,
why you think this is better,

1223

00:52:17,666 --> 00:52:19,800

also given that spaceship Earth

1224

00:52:19,800 --> 00:52:22,066

is really in need
of the kinds of technologies

1225

00:52:22,066 --> 00:52:24,266

that you're talking about?

1226

00:52:24,266 --> 00:52:27,000

- Okay, I think there might've
been a couple questions there,

1227

00:52:27,000 --> 00:52:31,833

but the--so the explorer in me,

1228

00:52:31,833 --> 00:52:33,733
and I--that's part of, like,

1229

00:52:33,733 --> 00:52:35,533
the driving force
of why I do what I do,

1230

00:52:35,533 --> 00:52:36,800
is exploration.

1231

00:52:36,800 --> 00:52:39,200
The explorer in me
wants to be able to go,

1232

00:52:39,200 --> 00:52:41,700
and I know a lot of people do,
and they'll say, "I'll go,

1233

00:52:41,700 --> 00:52:44,166
and maybe my body
can't handle it for very long,

1234

00:52:44,166 --> 00:52:45,833
but at least I get to go,"
right?

1235

00:52:45,833 --> 00:52:48,266
And I think
that will always exist.

1236

00:52:48,266 --> 00:52:50,400
There will always be people
who want to go,

1237

00:52:50,400 --> 00:52:52,866
because it's this part
of our brain

1238

00:52:52,866 --> 00:52:55,333

that wants us to explore
and say,

1239

00:52:55,333 --> 00:52:56,700

"What's on the other side
of that mountain?"

1240

00:52:56,700 --> 00:52:59,066

What's on the other side
of that ocean?"

1241

00:52:59,066 --> 00:53:00,866

I think that will always happen,
but--

1242

00:53:00,866 --> 00:53:02,400

and that's an important--

1243

00:53:02,400 --> 00:53:04,933

that's a very important part
of why we do what we do,

1244

00:53:04,933 --> 00:53:07,700

so that, as people go,
they bring tools with them

1245

00:53:07,700 --> 00:53:09,333

that they can build the things
they need,

1246

00:53:09,333 --> 00:53:11,566

and it's safer, right?

1247

00:53:11,566 --> 00:53:13,600

Maybe we don't solve
all the challenges

1248

00:53:13,600 --> 00:53:15,133

of a human being alive in space,

1249

00:53:15,133 --> 00:53:17,233

but at least we make it
a little bit better.

1250

00:53:17,233 --> 00:53:20,833

The--but on the grand scale
of things,

1251

00:53:20,833 --> 00:53:23,400

much of what I just talked about
doesn't require humans.

1252

00:53:23,400 --> 00:53:25,000

Archinaut is a robot in space

1253

00:53:25,000 --> 00:53:27,366

that builds big things
for Earth.

1254

00:53:27,366 --> 00:53:31,100

Making things in space
that we bring back to Earth

1255

00:53:31,100 --> 00:53:34,033

don't necessarily need
an astronaut to do the making.

1256

00:53:34,033 --> 00:53:35,866

It could be done robotically.

1257

00:53:35,866 --> 00:53:38,933

The printers in space today
are mostly controlled

1258

00:53:38,933 --> 00:53:42,100

by Made In Space engineers,
who--

1259

00:53:42,100 --> 00:53:43,500
some of them are in this room.

1260
00:53:43,500 --> 00:53:45,800
So, like, the people actually
building things in space

1261
00:53:45,800 --> 00:53:47,966
are sitting in this room
right now,

1262
00:53:47,966 --> 00:53:50,166
and there--we tele-operate
the printer.

1263
00:53:50,166 --> 00:53:52,733
So we are already trying
to do things,

1264
00:53:52,733 --> 00:53:54,000
in a way, robotically,

1265
00:53:54,000 --> 00:53:56,966
because we believe that some
of the biggest benefits

1266
00:53:56,966 --> 00:54:00,433
that space give u--gives us
could just be the products,

1267
00:54:00,433 --> 00:54:03,400
and we need to just make them
there and bring them back

1268
00:54:03,400 --> 00:54:05,733
and do it in a way where,
instead of polluting Earth,

1269
00:54:05,733 --> 00:54:09,900
we can move our processes

off of Earth.

1270

00:54:09,900 --> 00:54:13,366

- It was a question of cost.

- Oh.

1271

00:54:13,366 --> 00:54:15,133

So the cost of--

the cost difference

1272

00:54:15,133 --> 00:54:17,400

between doing it in space and--

1273

00:54:17,400 --> 00:54:19,166

- Building out in space versus

building it on Earth.

1274

00:54:19,166 --> 00:54:20,400

- Oh, sure.

1275

00:54:20,400 --> 00:54:22,500

Well, I mean,

what we're looking at are things

1276

00:54:22,500 --> 00:54:23,900

that you just can't build

on Earth.

1277

00:54:23,900 --> 00:54:28,633

There's--to--the optical fiber,

for example,

1278

00:54:28,633 --> 00:54:31,033

it can't be made

to the efficiency

1279

00:54:31,033 --> 00:54:34,500

that it could be made in space

in a gravity field.

1280

00:54:34,500 --> 00:54:36,533

So when you find products

1281

00:54:36,533 --> 00:54:38,633

that just literally

can't exist anywhere

1282

00:54:38,633 --> 00:54:40,966

but if they were made off

of the planet,

1283

00:54:40,966 --> 00:54:42,166

that's the place to start,

1284

00:54:42,166 --> 00:54:44,766

because then cost

isn't even the issue.

1285

00:54:44,766 --> 00:54:48,200

Now, the cost to buy

that fiber is something

1286

00:54:48,200 --> 00:54:50,366

that actually already

has proven markets on Earth

1287

00:54:50,366 --> 00:54:52,400

at the numbers

that it can be sold at.

1288

00:54:52,400 --> 00:54:55,133

So it's not like

you're making something

1289

00:54:55,133 --> 00:54:57,466

that then you dangle over

everyone's head and say,

1290

00:54:57,466 --> 00:54:58,866

"Don't you wish
you could have this?"

1291
00:54:58,866 --> 00:55:00,566
It's too expensive," right?

1292
00:55:00,566 --> 00:55:03,866
It's--I mean, you have to--
to have a business model,

1293
00:55:03,866 --> 00:55:05,133
you have to address cost,

1294
00:55:05,133 --> 00:55:10,166
but we look at things
that are beyond just that.

1295
00:55:10,166 --> 00:55:13,333
- So with that,
please join me in thanking Jason

1296
00:55:13,333 --> 00:55:14,466
for an excellent talk.

1297
00:55:14,466 --> 00:55:15,600
[applause]

1298
00:55:15,600 --> 00:55:17,500
Thank you very much.
Great talk.