
ORION

1
00:00:01,466 --> 00:00:07,466
[music playing]

2
00:00:17,200 --> 00:00:21,266
Welcome to the 2015
NASA Ames Summer Series.

3
00:00:23,466 --> 00:00:25,900
When you watch
science fiction movies,

4
00:00:25,900 --> 00:00:28,500
you watch vehicles
that go into space

5
00:00:28,500 --> 00:00:32,366
and return into planets
with ease,

6
00:00:32,366 --> 00:00:35,566
just like a plane.

7
00:00:35,566 --> 00:00:39,400
The reality is,
if you reenter any atmosphere,

8
00:00:39,400 --> 00:00:43,066
you need materials
that will protect your entry

9
00:00:43,066 --> 00:00:47,366
due to the friction that is
created by the atmosphere.

10
00:00:49,000 --> 00:00:50,733
NASA, as an agency,

11
00:00:50,733 --> 00:00:52,666
is the most experienced

in designing

12
00:00:52,666 --> 00:00:56,600
and developing reentry vehicles
into atmospheres,

13
00:00:56,600 --> 00:00:59,733
and we're currently working
on the next vehicle

14
00:00:59,733 --> 00:01:03,966
that will take us
beyond low Earth orbit.

15
00:01:03,966 --> 00:01:07,333
Today's seminar,
entitled "Burn to Shine:

16
00:01:07,333 --> 00:01:10,433
Experience and Lessons
from the Orion Heat Shield,"

17
00:01:10,433 --> 00:01:13,633
will be given
by Jeremy Vander Kam.

18
00:01:16,000 --> 00:01:19,133
Jeremy has
a Bachelor's of Science

19
00:01:19,133 --> 00:01:21,266
in Aerospace
and Mechanical Engineering

20
00:01:21,266 --> 00:01:24,400
from the University
of California at Davis.

21
00:01:24,400 --> 00:01:26,233
And then he went on to get

22
00:01:26,233 --> 00:01:28,933
a Master's in Science
and Engineering

23
00:01:28,933 --> 00:01:31,300
from the University
of California at Davis.

24
00:01:31,300 --> 00:01:34,133
After that, he has joined us
here at NASA Ames,

25
00:01:34,133 --> 00:01:37,966
first as a contractor
and now as part of the team.

26
00:01:37,966 --> 00:01:39,366
He is currently

27
00:01:39,366 --> 00:01:43,700
the deputy thermal protection
system manager for Orion.

28
00:01:43,700 --> 00:01:48,233
Please join me in welcoming
Jeremy Vander Kam.

29
00:01:48,233 --> 00:01:51,233
[applause]

30
00:01:54,100 --> 00:01:55,266
All right,
thank you very much.

31
00:01:55,266 --> 00:01:57,266
Thanks, everyone,
for coming today.

32

00:01:57,266 --> 00:02:00,866
As I was previously introduced,
I'm Jeremy Vander Kam.

33
00:02:00,866 --> 00:02:04,766
I'm the deputy manager for Orion
Thermal Protection Systems,

34
00:02:04,766 --> 00:02:08,066
and I wanted to give you
a four-part story today.

35
00:02:08,066 --> 00:02:10,166
I'm gonna give you a little bit
of background about Orion,

36
00:02:10,166 --> 00:02:12,533
the program,
then some overview

37
00:02:12,533 --> 00:02:14,600
of the manufacturing experience
for the heat shield

38
00:02:14,600 --> 00:02:17,000
that we had on the Exploration
Flight Test 1, EFT-1,

39
00:02:17,000 --> 00:02:18,666
that we just flew in December.

40
00:02:18,666 --> 00:02:20,266
I'll talk a little bit
about that flight test

41
00:02:20,266 --> 00:02:23,000
and the post-flight analysis
that we've been doing

42
00:02:23,000 --> 00:02:24,733

and then talk about
how we're advancing forward

43
00:02:24,733 --> 00:02:26,666
into the exploration missions,
or the EM missions,

44
00:02:26,666 --> 00:02:28,066
that come beyond that.

45
00:02:28,066 --> 00:02:30,166
And, you know,

46
00:02:30,166 --> 00:02:33,166
the picture there is of me
looking at the EFT-1 capsule

47
00:02:33,166 --> 00:02:34,800
just on the day of recovery.

48
00:02:34,800 --> 00:02:36,833
And in the same way that
I appear to be looking in awe

49
00:02:36,833 --> 00:02:38,966
at that capsule, sometimes
I look back at the whole journey

50
00:02:38,966 --> 00:02:40,466
to this point
with a little bit of awe.

51
00:02:40,466 --> 00:02:43,000
So I hope to share that
a little bit with you today.

52
00:02:43,000 --> 00:02:45,666
So the Orion program
and Ames' role.

53
00:02:45,666 --> 00:02:50,000
So Orion started,
or the program started, in 2006.

54
00:02:50,000 --> 00:02:51,966
Then, it was called
the Multi-Purpose Crew Vehicle,

55
00:02:51,966 --> 00:02:54,100
or MPCV.

56
00:02:54,100 --> 00:02:56,866
At the same time,
NASA recognized the need

57
00:02:56,866 --> 00:03:00,233
for a TPS Advanced Development
Project, or ADP.

58
00:03:00,233 --> 00:03:01,466
There's a couple of us
with the shirts on

59
00:03:01,466 --> 00:03:03,166
in the room today.

60
00:03:03,166 --> 00:03:05,266
That ran from 2006 to 2009,

61
00:03:05,266 --> 00:03:07,700
and its purpose was to get
started early

62
00:03:07,700 --> 00:03:10,066
on a large-scale
ablative heat shield,

63
00:03:10,066 --> 00:03:12,600
technology that NASA

had not pursued

64
00:03:12,600 --> 00:03:16,533
since the Apollo program ended
in the early '70s.

65
00:03:16,533 --> 00:03:18,600
That ADP was based here at Ames,

66
00:03:18,600 --> 00:03:20,533
and it provided
the early development work

67
00:03:20,533 --> 00:03:22,433
for the program.

68
00:03:22,433 --> 00:03:23,800
In 2009,

69
00:03:23,800 --> 00:03:25,700
the Orion contract itself
was awarded to Lockheed Martin,

70
00:03:25,700 --> 00:03:26,900
who then took on the work.

71
00:03:26,900 --> 00:03:28,666
And Ames has continued
to support that work

72
00:03:28,666 --> 00:03:31,733
with Arc Jet testing,
thermal and structural analysis,

73
00:03:31,733 --> 00:03:33,366
material development,
technical leadership,

74
00:03:33,366 --> 00:03:36,800

and continues to do that today.

75
00:03:36,800 --> 00:03:38,533
So the Orion spacecraft--

76
00:03:38,533 --> 00:03:40,766
we really consist
of three parts, three modules.

77
00:03:40,766 --> 00:03:43,266
We have a launch abort system,
a crew module,

78
00:03:43,266 --> 00:03:44,766
and a service module.

79
00:03:44,766 --> 00:03:47,366
The launch abort system
is only there in the case that,

80
00:03:47,366 --> 00:03:49,133
during ascent, there's a problem
with the booster,

81
00:03:49,133 --> 00:03:51,400
with the launcher,
and it pulls the crew module

82
00:03:51,400 --> 00:03:54,400
with the crew off
to perform a safe landing

83
00:03:54,400 --> 00:03:58,733
while the rocket is unsafely
doing something else.

84
00:03:58,733 --> 00:04:01,466
Once a nominal ascent happens,
though,

85
00:04:01,466 --> 00:04:03,133
we end up
in our on-orbit configuration.

86
00:04:03,133 --> 00:04:05,700
We've got the crew module
and the service module together,

87
00:04:05,700 --> 00:04:08,000
and you can see those modules
here on the right of the chart.

88
00:04:08,000 --> 00:04:09,900
Today, I'm going to be talking
about the heat shield,

89
00:04:09,900 --> 00:04:11,700
which is the base
of the crew module.

90
00:04:11,700 --> 00:04:13,733
So on the way up,
it's at the back,

91
00:04:13,733 --> 00:04:15,833
but on entry, that's the part
that comes in first,

92
00:04:15,833 --> 00:04:18,233
and that's the part
that really protects the vehicle

93
00:04:18,233 --> 00:04:22,066
from the heat of reentry.

94
00:04:22,066 --> 00:04:24,200
So, if you know any history,
even a little bit,

95

00:04:24,200 --> 00:04:28,433
you should notice that the Orion
architecture, the modules,

96
00:04:28,433 --> 00:04:30,133
they look
a lot like Apollo did.

97
00:04:30,133 --> 00:04:33,266
And so here's a brief comparison
of Apollo to Orion.

98
00:04:33,266 --> 00:04:35,900
So Orion is larger than Apollo.

99
00:04:35,900 --> 00:04:38,233
Apollo was, you know,
a little over 12 feet diameter,

100
00:04:38,233 --> 00:04:39,533
a little over 3 meters.

101
00:04:39,533 --> 00:04:43,433
Orion is 5 meters diameter,
16 1/2 feet.

102
00:04:43,433 --> 00:04:45,466
Apollo's designed
for three astronauts.

103
00:04:45,466 --> 00:04:47,600
Orion is designed for four.

104
00:04:47,600 --> 00:04:49,200
But one of the major differences

105
00:04:49,200 --> 00:04:51,133
between the two programs
is that, in the Apollo program,

106
00:04:51,133 --> 00:04:53,800
those missions were designed
for mission durations

107
00:04:53,800 --> 00:04:55,233
12 to 14 days or so.

108
00:04:55,233 --> 00:04:58,533
Orion is being designed for
upwards of 200 days in orbit.

109
00:04:58,533 --> 00:05:01,766
So even though the sizes
may look kind of similarly

110
00:05:01,766 --> 00:05:04,466
when placed in scale on paper
and you're only one more crew,

111
00:05:04,466 --> 00:05:05,933
there's a lot more going on
with Orion

112
00:05:05,933 --> 00:05:09,366
because of the focus on
the long-term mission duration,

113
00:05:09,366 --> 00:05:11,800
flexibility
to go to destinations

114
00:05:11,800 --> 00:05:14,466
and perform missions other--

115
00:05:14,466 --> 00:05:18,833
that are a little bit beyond
what the Apollo program did.

116
00:05:18,833 --> 00:05:21,200

So, before going too much
further into heat shields,

117
00:05:21,200 --> 00:05:24,600
we need one brief slide tutorial
on ablation

118
00:05:24,600 --> 00:05:26,133
and atmospheric entry.

119
00:05:26,133 --> 00:05:28,733
So it's really a power problem,
when you come to think of it.

120
00:05:28,733 --> 00:05:30,800
One of my colleagues
posed it very well that way.

121
00:05:30,800 --> 00:05:32,733
So an entering spacecraft,

122
00:05:32,733 --> 00:05:34,900
whether it's entering Earth's
atmosphere or anywhere else,

123
00:05:34,900 --> 00:05:37,033
is doing an energy exchange.

124
00:05:37,033 --> 00:05:39,166
You're exchanging
kinetic energy,

125
00:05:39,166 --> 00:05:42,300
or your orbital energy,
into heat, basically.

126
00:05:42,300 --> 00:05:45,133
You're changing it into heat
to slow yourself down.

127
00:05:45,133 --> 00:05:46,833
The faster that entry is,

128
00:05:46,833 --> 00:05:48,366
the more heat
that is generated,

129
00:05:48,366 --> 00:05:50,333
and the less time
you have to dissipate it,

130
00:05:50,333 --> 00:05:52,400
either by absorbing it
into the vehicle

131
00:05:52,400 --> 00:05:53,966
or ejecting it away
from the vehicle.

132
00:05:53,966 --> 00:05:57,633
Convective heating kind of goes
like the cube power of velocity.

133
00:05:57,633 --> 00:05:58,800
So as your velocities go up,

134
00:05:58,800 --> 00:06:01,966
your heating
goes up very, very quickly.

135
00:06:01,966 --> 00:06:04,200
Earth entries
from low Earth orbit

136
00:06:04,200 --> 00:06:07,600
are typically around the
7 kilometers per second range.

137
00:06:07,600 --> 00:06:09,066

That's where a space shuttle
would come in from,

138
00:06:09,066 --> 00:06:11,266
or other vehicles
from low Earth orbit.

139
00:06:11,266 --> 00:06:14,300
And today's materials that
we have, insulative materials,

140
00:06:14,300 --> 00:06:16,633
or materials
that might be reusable,

141
00:06:16,633 --> 00:06:20,433
simply cannot stand
the heat energy that results

142
00:06:20,433 --> 00:06:23,733
when you enter faster than
that 7 kilometers per second.

143
00:06:23,733 --> 00:06:24,966
So if you're gonna
do something like that,

144
00:06:24,966 --> 00:06:27,800
you need to get
into ablative systems.

145
00:06:27,800 --> 00:06:30,866
And so instead of simply
insulating a spacecraft

146
00:06:30,866 --> 00:06:33,033
from that heat,
what ablative systems do

147
00:06:33,033 --> 00:06:34,866

is actually consume
that heat energy

148
00:06:34,866 --> 00:06:37,633
through different
chemical processes:

149
00:06:37,633 --> 00:06:40,433
vaporization, sublimation,
pyrolization, et cetera.

150
00:06:40,433 --> 00:06:43,400
So one of the other benefits
that they have is

151
00:06:43,400 --> 00:06:45,333
that when the materials do this,

152
00:06:45,333 --> 00:06:48,000
they tend to eject gases
out of the vehicle

153
00:06:48,000 --> 00:06:50,466
and push the boundary layer up,
away from the vehicle,

154
00:06:50,466 --> 00:06:53,566
sort of pushing the heat away,
if you will,

155
00:06:53,566 --> 00:06:55,100
to keep the spacecraft cool.

156
00:06:55,100 --> 00:06:56,266
What they're really doing,

157
00:06:56,266 --> 00:06:58,200
if you think about it
in a broader scale,

158
00:06:58,200 --> 00:07:01,200
is providing power out
of the spacecraft during entry,

159
00:07:01,200 --> 00:07:03,066
instead of taking
all that energy in

160
00:07:03,066 --> 00:07:06,233
and soaking it and, through
an insulative technique,

161
00:07:06,233 --> 00:07:08,466
they're actually
ejecting power out.

162
00:07:08,466 --> 00:07:10,533
So that's ablation
in a nutshell.

163
00:07:10,533 --> 00:07:13,266
So let's get into
the Orion system specifically.

164
00:07:13,266 --> 00:07:16,866
So for the EFT-1 flight test,

165
00:07:16,866 --> 00:07:18,233
this is a picture
of the heat shield

166
00:07:18,233 --> 00:07:22,166
right before the paint went on,
in the lower left there.

167
00:07:22,166 --> 00:07:24,433
It's the largest ablative
heat shield ever made,

168

00:07:24,433 --> 00:07:27,200
on this planet,
I like to say.

169
00:07:27,200 --> 00:07:29,700
It's made
of a material called Avcoat,

170
00:07:29,700 --> 00:07:33,900
and a specific formulation
of Avcoat, called HC/G,

171
00:07:33,900 --> 00:07:34,933
or honeycomb-gunned.

172
00:07:34,933 --> 00:07:36,566
So what Avcoat is,

173
00:07:36,566 --> 00:07:39,000
it's an epoxy novolac resin
that's injected

174
00:07:39,000 --> 00:07:41,733
into an open-cell fiberglass
honeycomb matrix

175
00:07:41,733 --> 00:07:43,833
on top of a carrier structure.

176
00:07:43,833 --> 00:07:45,566
And so, for our size,
for Orion,

177
00:07:45,566 --> 00:07:47,333
and this is the same system
that Apollo used--

178
00:07:47,333 --> 00:07:50,000
For our size, for Orion,
on our 5-meter heat shield,

179
00:07:50,000 --> 00:07:53,066
we have
over 300,000 individual cells

180
00:07:53,066 --> 00:07:56,166
within this honeycomb matrix
that were filled.

181
00:07:56,166 --> 00:07:57,300
When we were all done,

182
00:07:57,300 --> 00:08:00,233
the whole thing weighed
about 4,000 pounds,

183
00:08:00,233 --> 00:08:01,766
1,800 kilograms,

184
00:08:01,766 --> 00:08:05,233
and about 1/4 of that
was the Avcoat material itself.

185
00:08:05,233 --> 00:08:06,700
And you can see on the right,

186
00:08:06,700 --> 00:08:09,200
kind of get a sense of
what this looks like zoomed in.

187
00:08:09,200 --> 00:08:10,666
The upper picture is

188
00:08:10,666 --> 00:08:12,800
of one of our test articles
of this configuration.

189
00:08:12,800 --> 00:08:14,933
That's what it looks

like before entry.

190
00:08:14,933 --> 00:08:16,766
You can kind of see the
honeycomb structure in there,

191
00:08:16,766 --> 00:08:19,833
and then the brownish-purplish
ablator in each of those cells.

192
00:08:19,833 --> 00:08:23,200
And then after entry,
since it is an ablator,

193
00:08:23,200 --> 00:08:25,666
you can see the charred surface
on the lower right there.

194
00:08:25,666 --> 00:08:27,366
And that's the way
that the whole heat shield looks

195
00:08:27,366 --> 00:08:28,766
after it enters.

196
00:08:28,766 --> 00:08:33,533
And we'll talk about that
a little bit in a minute.

197
00:08:33,533 --> 00:08:35,166
So if you flip this thing over,

198
00:08:35,166 --> 00:08:36,700
the backside of the heat shield
looks like this.

199
00:08:36,700 --> 00:08:39,000
This is the carrier structure,
is what we call it.

200
00:08:39,000 --> 00:08:41,033
It's a carbon laminate skin.

201
00:08:41,033 --> 00:08:44,333
It's got a spider web of
titanium stringers on the back.

202
00:08:44,333 --> 00:08:48,266
And the reason it looks similar
to a bridge is because

203
00:08:48,266 --> 00:08:50,966
not only does this heat shield
have to protect the spacecraft

204
00:08:50,966 --> 00:08:52,666
during entry from entry heat,

205
00:08:52,666 --> 00:08:55,766
this is also how we splash down
in the ocean, right?

206
00:08:55,766 --> 00:08:59,433
The mission for Orion ends with
a splash down into the ocean,

207
00:08:59,433 --> 00:09:01,566
and the heat shield
is what you land on.

208
00:09:01,566 --> 00:09:03,400
So not only are
you protecting from entry,

209
00:09:03,400 --> 00:09:05,266
you also have
this other design constraint,

210
00:09:05,266 --> 00:09:07,866

that you have to take
all of that splashdown load,

211
00:09:07,866 --> 00:09:12,500
which is why it looks
as beefy as it does.

212
00:09:12,500 --> 00:09:14,033
So how do we make this stuff?

213
00:09:14,033 --> 00:09:17,266
The answer is exactly the way
we did before.

214
00:09:17,266 --> 00:09:19,966
So this is a photograph of
Apollo heat shield manufacture

215
00:09:19,966 --> 00:09:22,633
from the late 1960s,
and the way this works

216
00:09:22,633 --> 00:09:25,066
is you have
your carrier structure built,

217
00:09:25,066 --> 00:09:28,633
you come in, and you adhere
an open-cell honeycomb matrix

218
00:09:28,633 --> 00:09:30,200
down on that structure

219
00:09:30,200 --> 00:09:33,200
and then fill each
individual cell of that matrix

220
00:09:33,200 --> 00:09:35,100
with the Avcoat
ablative material,

221
00:09:35,100 --> 00:09:38,266
through what are essentially
glorified caulking guns.

222
00:09:38,266 --> 00:09:40,533
So this is how Apollo did it.

223
00:09:40,533 --> 00:09:43,366
And to get a feel
of how we did it,

224
00:09:43,366 --> 00:09:46,000
I have a little video here.

225
00:09:46,000 --> 00:09:47,000
Play.

226
00:09:47,000 --> 00:09:48,000
So we've got the heat shield

227
00:09:48,000 --> 00:09:50,033
sitting on a table there
in the back,

228
00:09:50,033 --> 00:09:52,100
and there's a crew
of technicians

229
00:09:52,100 --> 00:09:53,600
that stand around it.

230
00:09:53,600 --> 00:09:56,600
In this case, we used
a crew of six technicians,

231
00:09:56,600 --> 00:10:00,233
two shifts a day,
six days a week,

232
00:10:00,233 --> 00:10:03,133
and it took about 4 1/2 months
to get this done.

233
00:10:03,133 --> 00:10:05,966
And you just sit
and gun individual cells.

234
00:10:05,966 --> 00:10:09,300
You can see the guns
they're using there.

235
00:10:09,300 --> 00:10:12,066
They take a cartridge full
of the material in the back.

236
00:10:12,066 --> 00:10:13,733
They're pressurized and heated,

237
00:10:13,733 --> 00:10:15,533
which are the wires
hanging down,

238
00:10:15,533 --> 00:10:17,566
and you just pick out
your section,

239
00:10:17,566 --> 00:10:20,700
put your earphones on,
and go for it.

240
00:10:20,700 --> 00:10:21,866
So you can see, it's a very--

241
00:10:21,866 --> 00:10:24,766
you know,
this is a hand process.

242

00:10:24,766 --> 00:10:26,200
You can see fingers involved
and all that.

243
00:10:26,200 --> 00:10:27,600
And that's the way
Apollo did it,

244
00:10:27,600 --> 00:10:30,533
and that's the way
we did it for EFT-1 as well.

245
00:10:35,400 --> 00:10:38,633
All right, let that finish out.
So there you go.

246
00:10:38,633 --> 00:10:41,633
To kind of give you a sense
of the way that this progressed,

247
00:10:41,633 --> 00:10:44,500
this is a picture of the EFT-1
heat shield, the flight article,

248
00:10:44,500 --> 00:10:48,833
sort of about midway or so
through manufacturing.

249
00:10:48,833 --> 00:10:51,033
And you can kind of see
the three different stages here.

250
00:10:51,033 --> 00:10:54,033
Because the material has a--
we call it an out time--

251
00:10:54,033 --> 00:10:56,566
it's a shelf life, so it expires
some number of days

252

00:10:56,566 --> 00:10:57,966
after it's actually made,

253
00:10:57,966 --> 00:11:00,200
you have to use it by that time
and cure it by that time,

254
00:11:00,200 --> 00:11:02,166
otherwise it becomes bad.

255
00:11:02,166 --> 00:11:04,033
Our heat shield is big enough
that we can't do the whole thing

256
00:11:04,033 --> 00:11:07,166
in one go
with one batch of material,

257
00:11:07,166 --> 00:11:08,733
so we do it in sections.

258
00:11:08,733 --> 00:11:10,266
So we have, on the top there,

259
00:11:10,266 --> 00:11:11,900
you see a picture
of unfilled honeycomb.

260
00:11:11,900 --> 00:11:13,100
So that's the honeycomb matrix

261
00:11:13,100 --> 00:11:14,800
laid down
on the carrier structure.

262
00:11:14,800 --> 00:11:17,800
The purpler sections are areas
that have just been gunned

263

00:11:17,800 --> 00:11:19,533
and have not been cured yet,

264
00:11:19,533 --> 00:11:21,933
and then the more tan sections
have been cured.

265
00:11:21,933 --> 00:11:23,433
So you lay down your honeycomb,

266
00:11:23,433 --> 00:11:27,033
gun a section, cure,
gun the next section, cure,

267
00:11:27,033 --> 00:11:29,000
and move on like that.

268
00:11:29,000 --> 00:11:30,500
And then at the end of the day,

269
00:11:30,500 --> 00:11:32,400
there's one final cure
at a higher temperature

270
00:11:32,400 --> 00:11:35,400
to kind of lock
the whole thing together,

271
00:11:35,400 --> 00:11:38,533
which will become important
in just a minute.

272
00:11:38,533 --> 00:11:41,466
So we had some challenges
on the EFT-1 build.

273
00:11:41,466 --> 00:11:43,866
We had two major issues,
and, as we'll talk about,

274
00:11:43,866 --> 00:11:46,700
neither of them were actually
new to this system.

275
00:11:46,700 --> 00:11:48,800
The first issue we had

276
00:11:48,800 --> 00:11:51,133
is the flight heat shield
Avcoat cracked

277
00:11:51,133 --> 00:11:53,200
during the final cure.

278
00:11:53,200 --> 00:11:55,133
So this is the thing
we're supposed to fly in a year,

279
00:11:55,133 --> 00:11:57,433
comes out of the oven,
and it's got cracks in it.

280
00:11:59,866 --> 00:12:02,066
Primarily those cracks occurred

281
00:12:02,066 --> 00:12:03,566
in the seams between
those honeycomb sections,

282
00:12:03,566 --> 00:12:06,266
so the honeycomb
goes down in panels.

283
00:12:06,266 --> 00:12:08,400
We don't have one big
5-meter disc of honeycomb.

284
00:12:08,400 --> 00:12:10,366
It goes down in panels,

so there are seams,

285
00:12:10,366 --> 00:12:11,900
and that's where
our cracks occurred.

286
00:12:11,900 --> 00:12:14,200
The second problem we had
is that

287
00:12:14,200 --> 00:12:17,533
we started to show analytically
that the heat shield,

288
00:12:17,533 --> 00:12:20,466
the Avcoat on the heat shield
might crack during the mission,

289
00:12:20,466 --> 00:12:22,200
either by getting cold on orbit

290
00:12:22,200 --> 00:12:26,433
or due to the stresses
of entry itself.

291
00:12:26,433 --> 00:12:29,133
This was largely driven
by the strengths

292
00:12:29,133 --> 00:12:31,433
we were getting from what
we call witness panels,

293
00:12:31,433 --> 00:12:33,833
which is how we sort of verified
workmanship on the flight build.

294
00:12:33,833 --> 00:12:35,800
I'm gonna dig
into those two issues

295
00:12:35,800 --> 00:12:37,266
here in the next couple slides.

296
00:12:37,266 --> 00:12:38,900
Cracks are not good, right?

297
00:12:38,900 --> 00:12:40,533
If you have a crack
in your ablator,

298
00:12:40,533 --> 00:12:42,700
then you've opened up a pathway
for hot entry gases

299
00:12:42,700 --> 00:12:44,300
to get down into your structure,

300
00:12:44,300 --> 00:12:46,833
which is the very thing that
you have the heat shield for

301
00:12:46,833 --> 00:12:49,800
in the first place,
is not to allow that to happen.

302
00:12:49,800 --> 00:12:51,300
So let's talk
about the first problem first:

303
00:12:51,300 --> 00:12:53,033
manufacturing cracks.

304
00:12:53,033 --> 00:12:54,900
So we pull the heat shield
out of the oven

305
00:12:54,900 --> 00:12:56,500
for its final cure,

306
00:12:56,500 --> 00:13:00,300
and we found 28 cracks
in various locations

307
00:13:00,300 --> 00:13:02,133
on the heat shield, and you see
the map of those cracks there

308
00:13:02,133 --> 00:13:04,900
on the lower left.

309
00:13:04,900 --> 00:13:07,533
We think those were likely
caused by thermal expansion,

310
00:13:07,533 --> 00:13:10,266
by stress concentrations
at the seams, and I'd also add,

311
00:13:10,266 --> 00:13:13,233
probably some material quality
problems along those seams.

312
00:13:13,233 --> 00:13:14,933
And you can get a sense
for what they look like.

313
00:13:14,933 --> 00:13:16,833
You know, we're not talking
about vast canyons here.

314
00:13:16,833 --> 00:13:19,033
We're talking
about little fractures.

315
00:13:19,033 --> 00:13:22,033
There on the right, if you
can see them at that resolution.

316
00:13:22,033 --> 00:13:25,233
Yeah, you can kind of get
a feel for it.

317
00:13:25,233 --> 00:13:27,133
So, needless to say,
there was consternation

318
00:13:27,133 --> 00:13:29,666
and gnashing of teeth
because of this,

319
00:13:29,666 --> 00:13:31,400
but we got through it.

320
00:13:31,400 --> 00:13:34,633
How did we do that?
Well, we fixed them, right?

321
00:13:34,633 --> 00:13:36,866
One of the things
that we got by using a system

322
00:13:36,866 --> 00:13:39,833
that had been done in Apollo was
a whole set of specifications

323
00:13:39,833 --> 00:13:41,833
for how to fix problems.

324
00:13:41,833 --> 00:13:45,033
So they actually had repairs
for this type of issue

325
00:13:45,033 --> 00:13:47,733
already specked out to use,
and we did--

326
00:13:47,733 --> 00:13:49,366

we implemented those repairs.

327
00:13:49,366 --> 00:13:50,966
Now, because things
were a little bit different

328
00:13:50,966 --> 00:13:52,633
and because you always check
somebody else's work,

329
00:13:52,633 --> 00:13:54,666
we went ahead and certified
those repairs

330
00:13:54,666 --> 00:13:56,333
for our own flight
in our own way.

331
00:13:56,333 --> 00:13:58,000
The way we did that is,

332
00:13:58,000 --> 00:14:00,100
you've got on the upper right
there what a crack

333
00:14:00,100 --> 00:14:03,366
on the heat shield
would actually look like.

334
00:14:03,366 --> 00:14:04,766
On the lower right,
you've got a repair.

335
00:14:04,766 --> 00:14:06,533
That same crack
has been repaired

336
00:14:06,533 --> 00:14:08,000
with these overlapping plugs.

337
00:14:08,000 --> 00:14:11,066
On the side, what we did is
we built up test articles

338
00:14:11,066 --> 00:14:12,133
with the repairs in them.

339
00:14:12,133 --> 00:14:13,866
In this case,
Arc Jet test articles

340
00:14:13,866 --> 00:14:15,133
with overlapping plug repairs,

341
00:14:15,133 --> 00:14:16,766
we tested them in the Arc Jets,

342
00:14:16,766 --> 00:14:18,500
took them out,
checked how they worked,

343
00:14:18,500 --> 00:14:20,366
checked all the temperature
data, and they were all fine.

344
00:14:20,366 --> 00:14:22,066
So we certified the repairs
for flight

345
00:14:22,066 --> 00:14:24,333
as well as the pristine system.

346
00:14:26,600 --> 00:14:28,400
So I mentioned that we got
some of these spec repairs

347
00:14:28,400 --> 00:14:30,033
from Apollo.

348
00:14:30,033 --> 00:14:33,900
When this happened,
one of the things we did is

349
00:14:33,900 --> 00:14:35,766
we actually commissioned
different folks

350
00:14:35,766 --> 00:14:38,933
around the country to go
and photo survey

351
00:14:38,933 --> 00:14:41,833
whatever crew modules we could
get to in the various museums.

352
00:14:41,833 --> 00:14:43,233
And it turns out,
they're basically all there

353
00:14:43,233 --> 00:14:47,200
to go look at and photo survey,
so we did that.

354
00:14:47,200 --> 00:14:48,566
And these kinds of repairs

355
00:14:48,566 --> 00:14:50,300
are on every single
Apollo crew module

356
00:14:50,300 --> 00:14:51,400
that you can go look at.

357
00:14:51,400 --> 00:14:54,400
They're all there.
Lots of them.

358
00:14:54,400 --> 00:14:56,166

So repairs of this nature

359
00:14:56,166 --> 00:14:59,666
are a standard part of the
honeycomb-gunned Avcoat system,

360
00:14:59,666 --> 00:15:03,066
as evidenced
by the Apollo capsules.

361
00:15:03,066 --> 00:15:04,766
It didn't make us
feel better at that time,

362
00:15:04,766 --> 00:15:06,666
but it is something
worth noting,

363
00:15:06,666 --> 00:15:10,333
and I'm gonna talk
a little bit about that too.

364
00:15:10,333 --> 00:15:11,933
So the second problem we had was

365
00:15:11,933 --> 00:15:13,566
we were actually predicting
that the ablator could crack,

366
00:15:13,566 --> 00:15:15,166
or we call it
negative stress margins,

367
00:15:15,166 --> 00:15:17,533
during the EFT-1 flight.

368
00:15:17,533 --> 00:15:20,800
But it was impossible to verify

369

00:15:20,800 --> 00:15:23,166
whether or not that was true on
the full flight article, right?

370
00:15:23,166 --> 00:15:25,333
If you think about a 5-meter
heat shield sitting there

371
00:15:25,333 --> 00:15:28,200
that you've basically built
in situ, or in place,

372
00:15:28,200 --> 00:15:31,266
put your honeycomb down,
gunned it, and it's done,

373
00:15:31,266 --> 00:15:33,700
we don't have a way
to test that, to bend it,

374
00:15:33,700 --> 00:15:35,833
pull on it, heat it up,
cool it down,

375
00:15:35,833 --> 00:15:37,800
in the same way
that we expect to happen

376
00:15:37,800 --> 00:15:38,833
during the flight itself.

377
00:15:38,833 --> 00:15:41,833
So we have to rely
on side methods,

378
00:15:41,833 --> 00:15:43,900
or coupon bench-level tests
to do that.

379
00:15:43,900 --> 00:15:45,166

The way
we did this on the flight build

380
00:15:45,166 --> 00:15:47,500
is we used something
called a witness panel.

381
00:15:47,500 --> 00:15:50,400
A witness panel is a panel
that sits off on the side.

382
00:15:50,400 --> 00:15:53,066
You can see it here on the left,
in the green circle.

383
00:15:53,066 --> 00:15:54,833
Where'd my--I lost it.
There it is.

384
00:15:54,833 --> 00:15:56,200
The green circle
here on the left.

385
00:15:56,200 --> 00:15:58,200
So you'd have the technicians
gunning the ablator

386
00:15:58,200 --> 00:15:59,666
into the heat shield.

387
00:15:59,666 --> 00:16:01,666
After some time, they'd turn and
gun some into the witness panel,

388
00:16:01,666 --> 00:16:02,966
then they'd turn back
to the heat shield,

389
00:16:02,966 --> 00:16:04,266
then back to the witness panel,

back to the heat shield.

390
00:16:04,266 --> 00:16:05,766
And so the idea
is that this witness panel

391
00:16:05,766 --> 00:16:07,933
on the side is representative
of what's being done

392
00:16:07,933 --> 00:16:09,300
on the flight article.

393
00:16:09,300 --> 00:16:12,266
So we take that witness panel,
cure it, cut it up,

394
00:16:12,266 --> 00:16:13,633
and start testing it.

395
00:16:13,633 --> 00:16:14,933
We did pull tests,

396
00:16:14,933 --> 00:16:17,000
like you see in the upper right
there, tension tests.

397
00:16:17,000 --> 00:16:19,266
Measure the strength,
measure the density, et cetera.

398
00:16:19,266 --> 00:16:22,500
And the thing that happened was
is all of that data

399
00:16:22,500 --> 00:16:25,800
was coming back
with lower strength primarily,

400

00:16:25,800 --> 00:16:27,533
and density,
than what we expected

401
00:16:27,533 --> 00:16:28,866
or what was even required.

402
00:16:28,866 --> 00:16:30,166
The plot on the lower right

403
00:16:30,166 --> 00:16:33,600
is showing the region
that would be good, or in spec,

404
00:16:33,600 --> 00:16:37,866
is sort of this middle
upper square here,

405
00:16:37,866 --> 00:16:39,033
and then I plotted
the data points

406
00:16:39,033 --> 00:16:40,100
from those witness panels,

407
00:16:40,100 --> 00:16:41,200
and you can see
there's a large portion

408
00:16:41,200 --> 00:16:42,833
that are out of that box.

409
00:16:42,833 --> 00:16:45,466
So when you go
and fold those kind of results

410
00:16:45,466 --> 00:16:46,766
into the flight predictions--

411

00:16:46,766 --> 00:16:48,500
into the predictions
for the flight test,

412
00:16:48,500 --> 00:16:51,633
that's where we started seeing
the negative margins come up.

413
00:16:51,633 --> 00:16:53,233
So that left
the hanging question,

414
00:16:53,233 --> 00:16:55,133
"Well, are these witness panels
faithful witnesses," right?

415
00:16:55,133 --> 00:16:56,400
"Are they actually
what's on there?"

416
00:16:56,400 --> 00:16:58,100
But that's what we had
to deal with.

417
00:16:58,100 --> 00:17:01,600
That's what we had to work with.

418
00:17:01,600 --> 00:17:05,166
So it turns out that Apollo
fought through this as well.

419
00:17:05,166 --> 00:17:08,033
They had negative stress
predictions for their flight.

420
00:17:08,033 --> 00:17:10,466
So these are excerpts from
the final thermodynamics reports

421
00:17:10,466 --> 00:17:13,033

from the Apollo program
in the late '60s.

422
00:17:13,033 --> 00:17:15,333
You can see the highlighted area
on the top,

423
00:17:15,333 --> 00:17:16,466
"Structural analyses predict

424
00:17:16,466 --> 00:17:18,366
that cracking
of the ablator may occur."

425
00:17:18,366 --> 00:17:21,033
Wow.
And then at the bottom--

426
00:17:21,033 --> 00:17:22,366
so what did they do about it,
right?

427
00:17:22,366 --> 00:17:24,833
They went and decided
and found, "Are cracks okay?"

428
00:17:24,833 --> 00:17:26,333
And they did, right?

429
00:17:26,333 --> 00:17:27,800
Cracks predicted
for the crew compartment

430
00:17:27,800 --> 00:17:29,866
will not produce
structural overheating.

431
00:17:29,866 --> 00:17:33,200
So we think it might crack,
but it's okay if it does.

432
00:17:33,200 --> 00:17:35,800
So we went down that same path.

433
00:17:35,800 --> 00:17:38,833
We built test articles
with cracks, in this case,

434
00:17:38,833 --> 00:17:42,133
another Arc Jet test article
with a crack, tested them,

435
00:17:42,133 --> 00:17:44,533
measured how they performed,
looked at all the data,

436
00:17:44,533 --> 00:17:46,100
and said,
"You know what? Yeah."

437
00:17:46,100 --> 00:17:48,633
Apollo, we're coming to the same
conclusions that they did.

438
00:17:48,633 --> 00:17:53,533
If these cracks form, we'll be
okay for the EFT-1 flight.

439
00:17:53,533 --> 00:17:55,966
So I've talked a bit
about the problems of the EFT-1.

440
00:17:55,966 --> 00:18:00,066
We've shown that Apollo had
a lot of the similar problems.

441
00:18:00,066 --> 00:18:02,500
So this is
the first little anecdote

442
00:18:02,500 --> 00:18:04,566
that I've come up with here,
based on this experience.

443
00:18:04,566 --> 00:18:06,466
The Siren Song of Heritage.

444
00:18:06,466 --> 00:18:09,333
So Orion selected
the Avcoat heat shield,

445
00:18:09,333 --> 00:18:10,866
the honeycomb-gunned Avcoat
heat shield,

446
00:18:10,866 --> 00:18:12,733
primarily on
a heritage argument.

447
00:18:12,733 --> 00:18:14,500
And I'll quote myself
on the engineering definition

448
00:18:14,500 --> 00:18:15,900
of "heritage."

449
00:18:15,900 --> 00:18:17,733
So it's a previous system

450
00:18:17,733 --> 00:18:19,966
that has been designed,
fabricated,

451
00:18:19,966 --> 00:18:23,466
and operated very similarly
to a proposed system.

452
00:18:23,466 --> 00:18:24,766
So something

that's been done in the past

453
00:18:24,766 --> 00:18:26,500
that I'm gonna do the same way
in the future.

454
00:18:26,500 --> 00:18:29,000
And programs like this.
Organizations like this, right?

455
00:18:29,000 --> 00:18:30,433
Heritage systems
make us feel good,

456
00:18:30,433 --> 00:18:32,200
'cause it's
been done before,

457
00:18:32,200 --> 00:18:33,600
so we can do it too.

458
00:18:33,600 --> 00:18:36,600
The problem is,
is that heritage systems come

459
00:18:36,600 --> 00:18:39,700
with heritage policy and
somebody else's risk appetite.

460
00:18:39,700 --> 00:18:41,300
What I mean by that is,
the program

461
00:18:41,300 --> 00:18:43,866
that implemented
a certain solution in the past,

462
00:18:43,866 --> 00:18:45,566
you may build the same thing,

463
00:18:45,566 --> 00:18:47,866
but you may not have the same
design rules that they did.

464
00:18:47,866 --> 00:18:50,000
You may not be able to handle
the same level of risk

465
00:18:50,000 --> 00:18:51,366
that they did.

466
00:18:51,366 --> 00:18:52,733
So we, Orion,

467
00:18:52,733 --> 00:18:55,133
we recognize the value
of having a heritage system,

468
00:18:55,133 --> 00:18:58,733
but we didn't quite count
the cost of the challenges

469
00:18:58,733 --> 00:19:00,100
that Apollo saw

470
00:19:00,100 --> 00:19:02,666
and that we found
sort of in retrospect,

471
00:19:02,666 --> 00:19:04,866
going through all this.

472
00:19:04,866 --> 00:19:07,533
You know, Apollo documentation
shows that they had cracks

473
00:19:07,533 --> 00:19:10,700
in their fabricated heat shields
particularly early on.

474
00:19:10,700 --> 00:19:12,566
On the Orion program,

475
00:19:12,566 --> 00:19:15,000
we went straight
to the first full-scale article,

476
00:19:15,000 --> 00:19:16,900
was the first article
we were gonna fly.

477
00:19:16,900 --> 00:19:18,166
That was the EFT-1 heat shield.

478
00:19:18,166 --> 00:19:19,966
Everything else
to date, you know,

479
00:19:19,966 --> 00:19:21,366
up to that point was small.

480
00:19:21,366 --> 00:19:24,566
So, as Apollo
built large-scale things,

481
00:19:24,566 --> 00:19:26,033
found cracks,
worked around them,

482
00:19:26,033 --> 00:19:28,333
got them sorted out, and then
went onto the flight articles,

483
00:19:28,333 --> 00:19:29,466
we went straight to the end,

484
00:19:29,466 --> 00:19:32,300
because it was

a heritage system, right?

485
00:19:32,300 --> 00:19:34,700
On the stress analysis side
of the house, you know,

486
00:19:34,700 --> 00:19:37,133
Apollo used some design policies

487
00:19:37,133 --> 00:19:40,766
that Orion has not allowed
itself to use, frankly.

488
00:19:40,766 --> 00:19:42,666
And I'll talk about that
a little bit in the past too,

489
00:19:42,666 --> 00:19:44,000
and that kind of got us
into the pickle

490
00:19:44,000 --> 00:19:45,500
we were in
with the negative margins

491
00:19:45,500 --> 00:19:49,900
and having to show cracks good
in the same way that they did.

492
00:19:49,900 --> 00:19:50,966
But, needless to say,

493
00:19:50,966 --> 00:19:52,700
the EFT-1 flight test
was a success.

494
00:19:52,700 --> 00:19:55,933
So let's section to part two
of the story, or three,

495
00:19:55,933 --> 00:19:57,600
if you count the overview.

496
00:19:57,600 --> 00:20:01,133
So Exploration Flight Test 1,
December 5, 2014.

497
00:20:01,133 --> 00:20:04,266
Two orbits around the Earth,
about a four-hour duration.

498
00:20:04,266 --> 00:20:07,033
First orbit, a very low orbit.

499
00:20:07,033 --> 00:20:10,800
Second orbit kicks out
to almost 6,000 kilometers.

500
00:20:10,800 --> 00:20:12,300
To give you a sense of things,

501
00:20:12,300 --> 00:20:15,333
the International Space Station
orbits at about 400 kilometers.

502
00:20:15,333 --> 00:20:17,300
So we're out at six.

503
00:20:17,300 --> 00:20:19,400
The moon's
at 384,000 kilometers,

504
00:20:19,400 --> 00:20:20,933
so we're not quite there,

505
00:20:20,933 --> 00:20:23,466
but we're quite higher than
the typical low Earth orbits

506
00:20:23,466 --> 00:20:24,933
that you see.

507
00:20:24,933 --> 00:20:26,600
The reason
we did this was to test--

508
00:20:26,600 --> 00:20:28,700
one of the main reasons
we did this was to test

509
00:20:28,700 --> 00:20:31,166
the Thermal Protection System,
to test the heat shield.

510
00:20:31,166 --> 00:20:34,833
So we entered at about--
pushing 9 kilometers a second.

511
00:20:34,833 --> 00:20:36,966
Entries from LEO are
about 7 kilometers per second.

512
00:20:36,966 --> 00:20:39,500
Entries from the moon
may go a little north

513
00:20:39,500 --> 00:20:43,433
of 11 kilometers
per second, okay?

514
00:20:43,433 --> 00:20:45,766
So--and then the motivation
for the title.

515
00:20:45,766 --> 00:20:50,266
So this is a video
of the Orion capsule entering

516

00:20:50,266 --> 00:20:53,933
taken from a DoD asset
during the EFT-1 mission.

517
00:20:53,933 --> 00:20:55,433
So you've got the capsule there
in the upper left.

518
00:20:55,433 --> 00:20:57,000
- Camera track.
- Copy.

519
00:20:57,000 --> 00:21:00,666
Acquire at Mach 22,
160,000 feet.

520
00:21:00,666 --> 00:21:02,733
We actually get
good infrared imagery,

521
00:21:02,733 --> 00:21:04,233
and you can start to see

522
00:21:04,233 --> 00:21:06,133
features come out
in the infrared,

523
00:21:06,133 --> 00:21:07,533
because they're heating up
at different--

524
00:21:07,533 --> 00:21:08,566
to different temperatures,
because they're made

525
00:21:08,566 --> 00:21:10,000
of different materials.

526
00:21:10,000 --> 00:21:11,366
Those are the compression pads

or where the surface module

527
00:21:11,366 --> 00:21:15,766
and the crew module
are integrated together.

528
00:21:18,900 --> 00:21:20,300
And then we come down

529
00:21:20,300 --> 00:21:22,966
and splash down very nicely
into the Pacific.

530
00:21:22,966 --> 00:21:27,133
We're about 200 miles west
of the Baja Peninsula for this.

531
00:21:29,833 --> 00:21:31,333
So one of the important things
about EFT-1--

532
00:21:31,333 --> 00:21:32,600
I mean, remember,

533
00:21:32,600 --> 00:21:35,300
this is the first, you know,
ablative heat shield

534
00:21:35,300 --> 00:21:37,166
of this size
that anybody's ever built

535
00:21:37,166 --> 00:21:41,233
and certainly the first one that
NASA's built in a long time.

536
00:21:41,233 --> 00:21:43,800
As we worked very closely
with the recovery operations

537
00:21:43,800 --> 00:21:46,266
to make sure that the vehicle
we got back

538
00:21:46,266 --> 00:21:47,666
was as pristine as possible

539
00:21:47,666 --> 00:21:50,433
so that we could do
post-flight inspections,

540
00:21:50,433 --> 00:21:52,933
get all of our data off of it.

541
00:21:52,933 --> 00:21:56,733
So, for EFT-1, the U.S. Navy
accomplished this recovery,

542
00:21:56,733 --> 00:21:59,300
Mobile Diving
and Salvage Unit 11-7.

543
00:21:59,300 --> 00:22:01,366
So I worked with them
very closely to talk

544
00:22:01,366 --> 00:22:03,233
about what parts of the vehicles
are very important.

545
00:22:03,233 --> 00:22:04,833
"Please don't touch them.

546
00:22:04,833 --> 00:22:06,600
Please don't touch these parts
'cause it'll hurt you.

547
00:22:06,600 --> 00:22:07,666
You can touch these parts

548
00:22:07,666 --> 00:22:08,700
because they're not
as interesting."

549
00:22:08,700 --> 00:22:09,700
All of that kind of thing.

550
00:22:09,700 --> 00:22:12,166
And they did a great job.

551
00:22:12,166 --> 00:22:14,900
We recovered
onto the USS Anchorage,

552
00:22:14,900 --> 00:22:17,866
which is a landing assault ship
that the Navy has.

553
00:22:17,866 --> 00:22:20,066
And you can kind of get a feel
for how this worked

554
00:22:20,066 --> 00:22:21,800
from the picture
in the lower right.

555
00:22:21,800 --> 00:22:24,900
These ships have a giant garage
door, as it were, on the back.

556
00:22:24,900 --> 00:22:28,666
They can ballast down,
flood an interior volume,

557
00:22:28,666 --> 00:22:30,066
and you can float things
in and out

558

00:22:30,066 --> 00:22:31,566
and then
ballast the ship back up

559
00:22:31,566 --> 00:22:33,066
to pick up
what you've recovered.

560
00:22:33,066 --> 00:22:35,600
And that's what we did,
floated the vehicle in,

561
00:22:35,600 --> 00:22:37,666
and then ballasted the ship
up underneath it.

562
00:22:39,566 --> 00:22:41,200
And the heat shield did great.

563
00:22:41,200 --> 00:22:42,866
So this is one
of the first images we got

564
00:22:42,866 --> 00:22:44,666
once it came back
from a diver in the water

565
00:22:44,666 --> 00:22:46,500
before anyone else touched it.

566
00:22:46,500 --> 00:22:48,433
We've got, you know,
photo surveys

567
00:22:48,433 --> 00:22:50,533
that have happened
almost at every point now,

568
00:22:50,533 --> 00:22:52,333
since before flight

569
00:22:52,333 --> 00:22:54,033
to in the water,
to on the ship,

570
00:22:54,033 --> 00:22:57,200
to, you know, back at KSC,
and so on and so on,

571
00:22:57,200 --> 00:22:58,600
so we can compare
what's happening to it

572
00:22:58,600 --> 00:23:01,866
to make sure anything we see
is because of the flight

573
00:23:01,866 --> 00:23:05,333
and not because somebody dropped
a hammer on it afterwards

574
00:23:05,333 --> 00:23:06,400
or someone, you know, nudged it

575
00:23:06,400 --> 00:23:07,866
or from recovery damage
and all that.

576
00:23:07,866 --> 00:23:12,700
So we've been very careful
about delineating all of that.

577
00:23:12,700 --> 00:23:14,166
So here's what the heat shield
looks like,

578
00:23:14,166 --> 00:23:16,466
or looked like,
after the flight

579
00:23:16,466 --> 00:23:18,666
once we got it back,
took it off the vehicle.

580
00:23:18,666 --> 00:23:20,666
This is down
at Marshall Space Flight Center,

581
00:23:20,666 --> 00:23:24,166
where we did our post-flight
sample extractions.

582
00:23:24,166 --> 00:23:26,333
So there's a couple interesting
features to point out.

583
00:23:26,333 --> 00:23:28,133
The stagnation point there,

584
00:23:28,133 --> 00:23:31,633
or the point where the air
theoretically comes to a stop

585
00:23:31,633 --> 00:23:34,133
as the vehicle enters,
is over on the right.

586
00:23:34,133 --> 00:23:36,266
It's offset from the center
because we have a lifting entry,

587
00:23:36,266 --> 00:23:38,400
so the vehicle comes in
with an angle of attack.

588
00:23:38,400 --> 00:23:40,533
It's a lifting body.

589
00:23:40,533 --> 00:23:43,933

And so all the streamlines
emanate from that point.

590
00:23:43,933 --> 00:23:47,100
You can see features
like transition wakes here.

591
00:23:47,100 --> 00:23:50,366
So this is where the flow
would start laminar

592
00:23:50,366 --> 00:23:52,900
and then get tripped turbulent
because of some protuberance

593
00:23:52,900 --> 00:23:54,700
or because of the Reynolds
number getting high enough

594
00:23:54,700 --> 00:23:56,166
or what have you.

595
00:23:56,166 --> 00:23:59,166
In this case, protuberances,
right, because we have wedges.

596
00:23:59,166 --> 00:24:03,066
We have damage from the recovery
process here that we see.

597
00:24:03,066 --> 00:24:05,666
And then you can see
our repair plugs.

598
00:24:05,666 --> 00:24:09,766
These lines of the white circles
are all the repairs we made

599
00:24:09,766 --> 00:24:12,000
to those cracks

that we talked about before.

600
00:24:12,000 --> 00:24:16,366
So what we've done is,

601
00:24:16,366 --> 00:24:17,400
well, we're in the midst

602
00:24:17,400 --> 00:24:19,300
of an extensive
post-flight evaluation.

603
00:24:19,300 --> 00:24:20,800
And so a team from here,

604
00:24:20,800 --> 00:24:22,766
from NASA Ames, went down
to Marshall Space Flight Center,

605
00:24:22,766 --> 00:24:24,233
worked with the crews there.

606
00:24:24,233 --> 00:24:27,333
And the reason we were
at Marshall is because they have

607
00:24:27,333 --> 00:24:32,100
an extremely large,
seven-axis milling machine.

608
00:24:32,100 --> 00:24:35,733
And so what we did is
we identified squares

609
00:24:35,733 --> 00:24:38,533
or islands of material that
we wanted to take samples of,

610
00:24:38,533 --> 00:24:40,600

and the Marshall guys were able
to set up their machine

611
00:24:40,600 --> 00:24:45,333
to progressively machine down
the surface of the ablator

612
00:24:45,333 --> 00:24:47,100
to leave these islands
of samples,

613
00:24:47,100 --> 00:24:48,300
for us then to come off
at the end

614
00:24:48,300 --> 00:24:49,900
and just take off
with a hand tool.

615
00:24:49,900 --> 00:24:51,500
It worked out really well.

616
00:24:51,500 --> 00:24:53,933
It also worked out well

617
00:24:53,933 --> 00:24:56,666
because they were gonna machine
the Avcoat off anyway.

618
00:24:56,666 --> 00:24:58,200
One of the things
that the program's doing

619
00:24:58,200 --> 00:24:59,900
is actually reusing
the carrier structure

620
00:24:59,900 --> 00:25:03,600
from the EFT-1 flight test
in water drop tests,

621
00:25:03,600 --> 00:25:06,166
for development purposes
up at Langley,

622
00:25:06,166 --> 00:25:08,600
starting in the late fall,
I think.

623
00:25:08,600 --> 00:25:09,966
So the Avcoat
was coming off anyway,

624
00:25:09,966 --> 00:25:11,700
so we got as much of it
as we could.

625
00:25:11,700 --> 00:25:13,966
So we took 192 samples
of these squares.

626
00:25:13,966 --> 00:25:16,400
They're all here
at Ames now.

627
00:25:16,400 --> 00:25:18,266
We took
over 200 recession measurements,

628
00:25:18,266 --> 00:25:21,066
or a measurement of
how much material ablated away

629
00:25:21,066 --> 00:25:23,533
during the entry,
and these are gonna get--

630
00:25:23,533 --> 00:25:25,066
these are getting characterized
and cataloged

631
00:25:25,066 --> 00:25:26,933
and everything here now,
and then they're gonna ship off

632
00:25:26,933 --> 00:25:29,533
in batches to various places
across the country

633
00:25:29,533 --> 00:25:31,633
for further analysis,
mechanical properties,

634
00:25:31,633 --> 00:25:34,133
thermal testing,
what have you.

635
00:25:34,133 --> 00:25:35,633
And that'll go on for a while,

636
00:25:35,633 --> 00:25:37,900
so the flood of papers
is just beginning.

637
00:25:37,900 --> 00:25:39,966
I can feel it.

638
00:25:42,033 --> 00:25:45,066
Okay, so moving forward a bit
to Exploration Mission Design.

639
00:25:45,066 --> 00:25:46,533
That's what we're in right now.

640
00:25:46,533 --> 00:25:49,966
So the next steps in the program
are two flight tests,

641
00:25:49,966 --> 00:25:53,266

Exploration Missions 1 and 2.

642
00:25:53,266 --> 00:25:55,533
Exploration Mission 1,
or EM-1,

643
00:25:55,533 --> 00:25:58,200
is set to go off in 2018 or so.

644
00:25:58,200 --> 00:25:59,833
Right now,
it's being characterized

645
00:25:59,833 --> 00:26:02,433
as a Distant Retrograde Orbit,
or a DRO.

646
00:26:02,433 --> 00:26:04,566
This is an orbit
that actually takes apogee out

647
00:26:04,566 --> 00:26:06,833
past where the moon is,

648
00:26:06,833 --> 00:26:11,366
so past 380,000 kilometers
or so.

649
00:26:11,366 --> 00:26:13,133
There's a couple reasons
for doing this.

650
00:26:13,133 --> 00:26:15,433
One is to demonstrate
heat shield capability

651
00:26:15,433 --> 00:26:19,333
at entry speeds that are up
around 11 kilometers per second.

652
00:26:19,333 --> 00:26:22,566
There's test objectives
about radiation protection

653
00:26:22,566 --> 00:26:24,066
that far away from Earth,

654
00:26:24,066 --> 00:26:26,833
and you get to say
that it's the furthest out

655
00:26:26,833 --> 00:26:28,600
that any human-capable
spacecraft

656
00:26:28,600 --> 00:26:32,033
has ever been from Earth,

657
00:26:32,033 --> 00:26:33,300
so that's nice.

658
00:26:33,300 --> 00:26:34,900
Then we have EM-2,

659
00:26:34,900 --> 00:26:36,466
which will be the first
crewed mission of Orion,

660
00:26:36,466 --> 00:26:38,733
which is set
around the 2021 timeframe,

661
00:26:38,733 --> 00:26:40,100
and that'll be--

662
00:26:40,100 --> 00:26:42,333
you can think of it
as a refly of Apollo 8.

663
00:26:42,333 --> 00:26:45,300
So it's to the moon,
orbits around the moon

664
00:26:45,300 --> 00:26:46,666
and back, all right?

665
00:26:46,666 --> 00:26:49,666
And that'll demonstrate
crewed operations.

666
00:26:49,666 --> 00:26:50,766
So we have these two missions
coming up,

667
00:26:50,766 --> 00:26:51,900
we just had a flight test,

668
00:26:51,900 --> 00:26:54,866
we built a heat shield
a particular way,

669
00:26:54,866 --> 00:26:56,533
and we're gonna change it.

670
00:26:56,533 --> 00:26:58,233
So you may have noticed,

671
00:26:58,233 --> 00:27:01,100
seen some of the media
come out back in November

672
00:27:01,100 --> 00:27:03,700
about changes
to the heat shield architecture,

673
00:27:03,700 --> 00:27:05,933
changes to the way
that the Avcoat is put on.

674
00:27:05,933 --> 00:27:08,266
So why would we do this?

675
00:27:08,266 --> 00:27:09,600
Let's talk about it.

676
00:27:09,600 --> 00:27:13,300
So motivations for a new
architecture, in this case--

677
00:27:13,300 --> 00:27:14,800
and I'll outline it
a little bit--

678
00:27:14,800 --> 00:27:17,766
blocks of Avcoat instead of
this honeycomb-gunned system.

679
00:27:17,766 --> 00:27:20,100
There's two main motivations.
One is technical.

680
00:27:20,100 --> 00:27:22,666
We talked a little bit
about the challenges we had

681
00:27:22,666 --> 00:27:24,633
with the EFT-1 build.

682
00:27:24,633 --> 00:27:26,866
Can we improve
the manufacturing enough,

683
00:27:26,866 --> 00:27:28,100
not have cracks during cure?

684
00:27:28,100 --> 00:27:30,000
Can we improve the material

strength enough

685
00:27:30,000 --> 00:27:31,200
so that we're not predicting
these negative margins

686
00:27:31,200 --> 00:27:32,633
all the time?

687
00:27:32,633 --> 00:27:35,700
The EM flight loads are higher
than the EFT-1 flight loads.

688
00:27:35,700 --> 00:27:37,566
We have more of a challenge
to go there.

689
00:27:37,566 --> 00:27:40,266
The second motivation
is programmatic,

690
00:27:40,266 --> 00:27:41,766
particularly, schedule.

691
00:27:41,766 --> 00:27:44,366
So fitting the honeycomb-gunned
architecture

692
00:27:44,366 --> 00:27:48,166
into the program's schedule box
has proved problematic.

693
00:27:48,166 --> 00:27:49,566
And a lot of that is

694
00:27:49,566 --> 00:27:52,733
because the honeycomb-gunned
manufacturing process is serial.

695

00:27:52,733 --> 00:27:54,900
So you build
your carrier structure,

696
00:27:54,900 --> 00:27:56,766
you put your honeycomb down,

697
00:27:56,766 --> 00:27:58,933
then you gun all the ablator in,
and then you cure.

698
00:27:58,933 --> 00:28:00,666
And you can't do one step
before the other

699
00:28:00,666 --> 00:28:02,066
or in parallel with the other.

700
00:28:02,066 --> 00:28:05,266
They have to go serially because
of the way that it works.

701
00:28:05,266 --> 00:28:06,466
If you came up with a system

702
00:28:06,466 --> 00:28:07,966
where you could build things
in parallel,

703
00:28:07,966 --> 00:28:09,266
you would save time.

704
00:28:09,266 --> 00:28:10,933
So the thought is,
what if we made blocks

705
00:28:10,933 --> 00:28:14,466
of this Avcoat ablator,
don't put it in a honeycomb?

706
00:28:14,466 --> 00:28:16,466
We can make those in parallel
with the carrier structure.

707
00:28:16,466 --> 00:28:18,633
We have to install those blocks,

708
00:28:18,633 --> 00:28:21,300
but that'll take less time than
it does to install the Avcoat

709
00:28:21,300 --> 00:28:23,966
on a honeycomb-gunned system,
so we'll save time

710
00:28:23,966 --> 00:28:25,533
and fit ourselves
back into the schedule box

711
00:28:25,533 --> 00:28:27,466
we've been given
from the agency, and,

712
00:28:27,466 --> 00:28:30,666
at the end of the day,
from Congress, right?

713
00:28:30,666 --> 00:28:32,700
So what is this architecture?

714
00:28:32,700 --> 00:28:34,433
So we're not changing
the ablator, right?

715
00:28:34,433 --> 00:28:37,133
It's still Avcoat, the same
formulation of the ablator.

716
00:28:37,133 --> 00:28:39,900

But instead of gunning it
into individual honeycomb cells

717
00:28:39,900 --> 00:28:43,766
on a carrier structure,
we're molding it into blocks

718
00:28:43,766 --> 00:28:46,166
to do that in parallel
with the carrier structure.

719
00:28:46,166 --> 00:28:48,100
Same ablator molded into blocks
instead of gunned

720
00:28:48,100 --> 00:28:49,700
into a honeycomb.

721
00:28:49,700 --> 00:28:52,533
And then in between
those blocks, we're putting RTV,

722
00:28:52,533 --> 00:28:56,933
or room temperature vulcanizing
adhesive, in between.

723
00:28:56,933 --> 00:28:58,166
So you can see
how this might play out

724
00:28:58,166 --> 00:28:59,566
on the Orion heat shield

725
00:28:59,566 --> 00:29:03,133
on the lower left,
about 300 or so of these blocks.

726
00:29:03,133 --> 00:29:05,400
And there's some precedent
for this in the past, right?

727
00:29:05,400 --> 00:29:07,500
Tiled systems have flown,
certainly.

728
00:29:07,500 --> 00:29:11,300
SpaceX is flying an ablative
tiled system right now.

729
00:29:11,300 --> 00:29:13,633
We already talked about heritage
and the problems with that.

730
00:29:13,633 --> 00:29:15,233
Is that system
sufficient heritage

731
00:29:15,233 --> 00:29:16,933
to say this one will work?

732
00:29:16,933 --> 00:29:20,333
Time will tell, right?

733
00:29:20,333 --> 00:29:22,066
So what are some of the
advantages and disadvantages?

734
00:29:22,066 --> 00:29:24,200
Well, advantages
of a block system,

735
00:29:24,200 --> 00:29:27,000
and particularly this one,

736
00:29:27,000 --> 00:29:29,500
is that you've got what we'd
call true acceptance testing

737
00:29:29,500 --> 00:29:31,166

and verification of the ablator

738
00:29:31,166 --> 00:29:33,566
before you commit to putting it
on the carrier structure.

739
00:29:33,566 --> 00:29:35,133
So remember,
with the honeycomb--

740
00:29:35,133 --> 00:29:37,100
with the EFT-1 heat shield, the
honeycomb-gunned architecture,

741
00:29:37,100 --> 00:29:38,500
we had these witness panels

742
00:29:38,500 --> 00:29:41,433
that we had to presume
were faithful representatives

743
00:29:41,433 --> 00:29:43,300
of what was actually
on the flight vehicle.

744
00:29:43,300 --> 00:29:44,666
With a tiled system,

745
00:29:44,666 --> 00:29:48,400
you can make your flight tiles
or your flight blocks,

746
00:29:48,400 --> 00:29:49,966
pull on them, test them,
make sure that they're good,

747
00:29:49,966 --> 00:29:51,633
before you actually
put them down, right?

748
00:29:51,633 --> 00:29:53,633
So you know what you've got.
That's one advantage.

749
00:29:53,633 --> 00:29:56,100
Parallel manufacturing,
we talked about.

750
00:29:56,100 --> 00:29:58,333
Cheaper fabrication costs
because of the reduction

751
00:29:58,333 --> 00:30:00,766
in labor time is a motivator.

752
00:30:00,766 --> 00:30:03,700
Faster test article
production throughput, again,

753
00:30:03,700 --> 00:30:05,133
because you're molding things
instead of gunning things

754
00:30:05,133 --> 00:30:07,833
individually into cells.

755
00:30:07,833 --> 00:30:10,000
We've actually found
that the molded ablator

756
00:30:10,000 --> 00:30:13,033
is stronger
than the honeycomb system.

757
00:30:13,033 --> 00:30:15,400
In some ways,
the honeycomb matrix

758
00:30:15,400 --> 00:30:18,033

actually is introducing
little stress concentrations

759
00:30:18,033 --> 00:30:21,566
into an otherwise
homogeneous material.

760
00:30:21,566 --> 00:30:23,000
And there's
less density variations.

761
00:30:23,000 --> 00:30:25,333
You can control things
at the molded block level

762
00:30:25,333 --> 00:30:29,066
as opposed to each gunner's hand
that day, or week,

763
00:30:29,066 --> 00:30:30,800
into each individual cell.

764
00:30:30,800 --> 00:30:33,100
There are disadvantages.

765
00:30:33,100 --> 00:30:35,233
We've introduced
a new system element, right?

766
00:30:35,233 --> 00:30:38,400
So now, not only do
we have the ablator itself,

767
00:30:38,400 --> 00:30:40,500
we have these seams
between blocks,

768
00:30:40,500 --> 00:30:44,033
an often overlooked portion
but a very important portion.

769
00:30:44,033 --> 00:30:45,600
So we have to go
characterize that.

770
00:30:45,600 --> 00:30:46,666
Will these seams work?

771
00:30:46,666 --> 00:30:47,666
Will they hold the blocks
together?

772
00:30:47,666 --> 00:30:49,566
Will they ablate properly?

773
00:30:49,566 --> 00:30:51,766
The blocks have
a less capable attachment system

774
00:30:51,766 --> 00:30:54,066
than that honeycomb
architecture.

775
00:30:54,066 --> 00:30:56,033
They're less tolerant
to first failure modes,

776
00:30:56,033 --> 00:30:57,433
and I'll go into that
a little bit more.

777
00:30:57,433 --> 00:31:00,233
What I mean by that is,
while the blocks

778
00:31:00,233 --> 00:31:02,733
may be stronger than
the honeycomb-gunned system,

779

00:31:02,733 --> 00:31:04,300
when they do fail,

780
00:31:04,300 --> 00:31:06,866
they tend to fail
more energetically,

781
00:31:06,866 --> 00:31:08,166
shall we say,

782
00:31:08,166 --> 00:31:11,333
than the cracks we saw
on the honeycomb-gunned system.

783
00:31:11,333 --> 00:31:13,333
Then we also have to deal
with the differential recession

784
00:31:13,333 --> 00:31:14,833
between the blocks

785
00:31:14,833 --> 00:31:17,633
and the interfaces
that we've laid out.

786
00:31:17,633 --> 00:31:20,366
So let's dig into two of
those challenges in particular.

787
00:31:20,366 --> 00:31:23,100
So the first one, this
differential recession problem.

788
00:31:23,100 --> 00:31:26,566
Anywhere you have two different
materials on an ablative system,

789
00:31:26,566 --> 00:31:29,700
they're gonna recede and ablate
at their own rate, right?

790
00:31:29,700 --> 00:31:31,666
So one of the worries
we have is that these seams

791
00:31:31,666 --> 00:31:35,133
between the Avcoat blocks
will actually start to protrude,

792
00:31:35,133 --> 00:31:36,966
or gap,
below the surrounding Avcoat,

793
00:31:36,966 --> 00:31:39,066
causing local heating
augmentation, right?

794
00:31:39,066 --> 00:31:40,833
If you stick something
up into the flow,

795
00:31:40,833 --> 00:31:42,700
into the airflow during entry,

796
00:31:42,700 --> 00:31:44,966
it's gonna cause
local heating augmentation.

797
00:31:44,966 --> 00:31:47,333
If it does, it means
you need more Avcoat thickness

798
00:31:47,333 --> 00:31:48,566
behind your augmen--

799
00:31:48,566 --> 00:31:49,833
the thing
that's augmenting the heating,

800

00:31:49,833 --> 00:31:51,333
which means your mass goes up,

801
00:31:51,333 --> 00:31:52,700
and you can kind of get into
a little bit of a runaway thing

802
00:31:52,700 --> 00:31:54,233
with that.

803
00:31:54,233 --> 00:31:55,766
So one of the ways
we look at this

804
00:31:55,766 --> 00:31:58,200
is through progressive
Arc Jet testing here.

805
00:31:58,200 --> 00:31:59,833
So up on the upper top

806
00:31:59,833 --> 00:32:04,366
you've got a simulation
of the EM entry profile,

807
00:32:04,366 --> 00:32:05,700
it's actually a skipping entry,

808
00:32:05,700 --> 00:32:09,900
so you've got two spikes
of heating that occur.

809
00:32:09,900 --> 00:32:12,566
And what we've done is we took
four separate test articles--

810
00:32:12,566 --> 00:32:14,633
this is a pathfinder--we took
four separate test articles,

811
00:32:14,633 --> 00:32:17,266
all built exactly the same with
this RTV seam in the middle.

812
00:32:17,266 --> 00:32:19,733
Run the first one through the
first part of the trajectory,

813
00:32:19,733 --> 00:32:21,033
take it out, measure.

814
00:32:21,033 --> 00:32:22,366
Run the second one
through a little bit more

815
00:32:22,366 --> 00:32:23,933
of the trajectory,
take it out, measure,

816
00:32:23,933 --> 00:32:25,233
so on and so forth,

817
00:32:25,233 --> 00:32:27,300
to get a sense
of how this interface

818
00:32:27,300 --> 00:32:29,900
might perform over the time
of that trajectory.

819
00:32:29,900 --> 00:32:31,433
And so you can see,
we start to form

820
00:32:31,433 --> 00:32:33,933
a little bit of a fence there
at the end.

821
00:32:33,933 --> 00:32:35,733

So this is the pathfinder,
first time we did this.

822
00:32:35,733 --> 00:32:37,833
We're just
getting into this now,

823
00:32:37,833 --> 00:32:40,066
actually running currently,
in the Arc Jets,

824
00:32:40,066 --> 00:32:42,866
with a whole series
of different kind of profiles

825
00:32:42,866 --> 00:32:44,733
correlating to different kinds
of trajectories,

826
00:32:44,733 --> 00:32:45,933
different places
on the heat shield,

827
00:32:45,933 --> 00:32:47,666
to get a sense
of how this works.

828
00:32:47,666 --> 00:32:50,333
We're also, as an aside,
implementing a system

829
00:32:50,333 --> 00:32:52,366
that'll let us measure
that differential recession

830
00:32:52,366 --> 00:32:53,900
real time in test,

831
00:32:53,900 --> 00:32:55,233
instead of having

to test different articles

832
00:32:55,233 --> 00:32:57,333
for different lengths
of profile testings.

833
00:32:57,333 --> 00:32:59,333
That can get
quite expensive.

834
00:33:02,533 --> 00:33:04,633
Another challenge
with this system,

835
00:33:04,633 --> 00:33:05,966
and it's kind of a challenge
in general,

836
00:33:05,966 --> 00:33:08,533
it's more
of a design philosophy thing,

837
00:33:08,533 --> 00:33:10,833
it's a risk posture
kind of question.

838
00:33:10,833 --> 00:33:12,966
Likelihood and consequence
of failure.

839
00:33:12,966 --> 00:33:15,000
So, on any system, right,

840
00:33:15,000 --> 00:33:18,866
the consequence of a failure
ought to, or should,

841
00:33:18,866 --> 00:33:21,500
dictate what your design policy
is for that system.

842
00:33:21,500 --> 00:33:23,666
We talked a little bit
about Apollo.

843
00:33:23,666 --> 00:33:27,200
They designed to average
material properties, right?

844
00:33:27,200 --> 00:33:28,566
They still--
and they show that, well,

845
00:33:28,566 --> 00:33:30,566
"It might crack,
but if it does, it's okay."

846
00:33:30,566 --> 00:33:32,266
So what you might call that is,

847
00:33:32,266 --> 00:33:34,700
if you're talking
about the failure of a crack,

848
00:33:34,700 --> 00:33:36,733
you have a fairly high
likelihood that it'll happen,

849
00:33:36,733 --> 00:33:39,500
but the consequence is low,
right?

850
00:33:39,500 --> 00:33:41,533
It might happen,
but if it does, it's all right.

851
00:33:41,533 --> 00:33:43,800
What we found
with the blocks is,

852
00:33:43,800 --> 00:33:45,266
as I've already mentioned,

853
00:33:45,266 --> 00:33:47,233
the likelihood
of a failure happening,

854
00:33:47,233 --> 00:33:49,800
of a crack happening,
is much lower,

855
00:33:49,800 --> 00:33:51,866
but if it does,
it's a lot worse,

856
00:33:51,866 --> 00:33:54,133
or we expect it to be
a lot worse, right?

857
00:33:54,133 --> 00:33:55,933
So you have
a high consequence system

858
00:33:55,933 --> 00:33:58,966
which must have a very, very,
very low likelihood

859
00:33:58,966 --> 00:34:00,800
of that initial failure
occurring.

860
00:34:00,800 --> 00:34:02,233
And you approach
these two problems

861
00:34:02,233 --> 00:34:04,666
in very different ways, right?

862
00:34:04,666 --> 00:34:07,266

If you've got a bucket,
a population, if you will,

863
00:34:07,266 --> 00:34:10,200
of strength data, per se,
like the plot

864
00:34:10,200 --> 00:34:12,833
in the upper right,
and you lay it all out.

865
00:34:12,833 --> 00:34:14,533
Let's say
it's a nice, pretty Gaussian

866
00:34:14,533 --> 00:34:16,600
that comes
right out of a textbook.

867
00:34:16,600 --> 00:34:19,233
You know, you can design to
the average of those properties,

868
00:34:19,233 --> 00:34:20,900
like Apollo did.

869
00:34:20,900 --> 00:34:22,766
And that doesn't--that's not
very hard to do, right?

870
00:34:22,766 --> 00:34:24,200
You just look at your data,
you take the average,

871
00:34:24,200 --> 00:34:26,000
you design to that,
and if your system closes,

872
00:34:26,000 --> 00:34:27,166
you say, great,

because I know that,

873
00:34:27,166 --> 00:34:28,533
if it does fail,

874
00:34:28,533 --> 00:34:30,433
if I get, you know,
some material on the vehicle

875
00:34:30,433 --> 00:34:32,033
that has less strength
than that,

876
00:34:32,033 --> 00:34:33,733
I know it's not that big a deal.

877
00:34:33,733 --> 00:34:36,633
Well, it takes a lot of time
and effort and sweat

878
00:34:36,633 --> 00:34:39,033
to show that it's not
that big a deal, right?

879
00:34:39,033 --> 00:34:41,000
And you can think of that,
if you're familiar

880
00:34:41,000 --> 00:34:42,666
with a 5x5 risk chart,

881
00:34:42,666 --> 00:34:44,966
or some people call it
a temperature chart.

882
00:34:44,966 --> 00:34:48,866
If you're gonna move a risk
from the right to the left,

883

00:34:48,866 --> 00:34:51,466
so decreasing what you think
the consequence will be,

884
00:34:51,466 --> 00:34:53,233
that takes a lot of proof,
right?

885
00:34:53,233 --> 00:34:55,500
You have to show
that that's actually the case.

886
00:34:55,500 --> 00:34:58,333
So if you're gonna kind of take
the first road easily

887
00:34:58,333 --> 00:34:59,566
and allow something to happen,

888
00:34:59,566 --> 00:35:01,600
it takes a lot of work
to go then

889
00:35:01,600 --> 00:35:04,266
and show that it's okay
if it does, right?

890
00:35:04,266 --> 00:35:06,500
This is, you know,
fracture tolerance,

891
00:35:06,500 --> 00:35:08,100
or defect tolerance.

892
00:35:08,100 --> 00:35:09,333
That's a lot of work.

893
00:35:09,333 --> 00:35:10,766
if you flip it around
the other way,

894
00:35:10,766 --> 00:35:14,466
where we are with the blocks,
if either your design policy

895
00:35:14,466 --> 00:35:17,000
simply won't let you design
to mean or average properties,

896
00:35:17,000 --> 00:35:19,600
which is the case on Orion,
we use more--

897
00:35:19,600 --> 00:35:21,166
I don't know,
I wouldn't call them advanced,

898
00:35:21,166 --> 00:35:22,366
they're just different policies,

899
00:35:22,366 --> 00:35:24,500
designed to A basis,
B basis properties.

900
00:35:24,500 --> 00:35:25,833
So we have to design

901
00:35:25,833 --> 00:35:29,366
to the 99th percentile
low strength of our population

902
00:35:29,366 --> 00:35:32,900
or 95th percentile low
in the case of B.

903
00:35:32,900 --> 00:35:34,800
You're coming
at the problem a different way.

904

00:35:34,800 --> 00:35:38,000
You're investing your time
and money and sweat up front

905
00:35:38,000 --> 00:35:41,266
to show that your design closes
to a very conservative estimate

906
00:35:41,266 --> 00:35:43,133
of what your strength is, right?

907
00:35:43,133 --> 00:35:45,533
So you have, you say,
I've got this body of data,

908
00:35:45,533 --> 00:35:46,900
population of data,

909
00:35:46,900 --> 00:35:48,900
about strength of the ablator,
in this case.

910
00:35:48,900 --> 00:35:50,866
I'm only gonna pretend
that I'm gonna get

911
00:35:50,866 --> 00:35:54,133
the 1 percentile worst case
of all that data,

912
00:35:54,133 --> 00:35:55,333
and I got to make
my design close to that,

913
00:35:55,333 --> 00:35:57,066
and that's where you spend your,
you know,

914
00:35:57,066 --> 00:35:58,700
your blood, sweat, and tears,

as it were, right?

915
00:35:58,700 --> 00:36:01,233
That costs a lot,
to get the design that tight

916
00:36:01,233 --> 00:36:03,366
because you're saying
that I'm not willing

917
00:36:03,366 --> 00:36:06,700
to go down the path of showing
that this failure is okay,

918
00:36:06,700 --> 00:36:08,533
because I don't think it is
in the first place, and second,

919
00:36:08,533 --> 00:36:10,900
because I think it'll cost too
much time, effort, and money.

920
00:36:10,900 --> 00:36:12,766
So in that case,
if you want to think of it

921
00:36:12,766 --> 00:36:15,466
as a 5x5 again,
you're spending your dollars,

922
00:36:15,466 --> 00:36:18,600
your time,
to drop the likelihood down,

923
00:36:18,600 --> 00:36:21,033
or to show that the likelihood
of your failure

924
00:36:21,033 --> 00:36:23,266
is way down here at the bottom.

925
00:36:23,266 --> 00:36:25,200
Now I picked this chart
for a reason,

926
00:36:25,200 --> 00:36:27,700
because where do
those two triangles end up

927
00:36:27,700 --> 00:36:29,833
in terms of a qualitative risk?

928
00:36:29,833 --> 00:36:31,433
The same place, right?

929
00:36:31,433 --> 00:36:32,566
On this
particular scoring chart.

930
00:36:32,566 --> 00:36:34,133
Different programs
have different charts

931
00:36:34,133 --> 00:36:35,433
that score these differently.

932
00:36:35,433 --> 00:36:37,100
They could both be called
high-risk systems,

933
00:36:37,100 --> 00:36:38,900
but they're very different
in the way that they operate,

934
00:36:45,100 --> 00:36:40,466
right?

935
00:36:45,100 --> 00:36:46,666
The dragon behind the smoke.

936
00:36:46,666 --> 00:36:48,433
So the knowledge
of a mature system

937
00:36:48,433 --> 00:36:51,666
versus the uncertainty
of a promising new idea, right?

938
00:36:51,666 --> 00:36:55,166
So Orion, we built,
had challenges with,

939
00:36:55,166 --> 00:36:58,933
but still flew successfully
the EFT-1 heat shield, right?

940
00:36:58,933 --> 00:37:01,400
But it was enough
of a technical challenge,

941
00:37:01,400 --> 00:37:02,500
there were
enough program challenges

942
00:37:02,500 --> 00:37:03,933
that motivated a change.

943
00:37:03,933 --> 00:37:05,533
So we had this challenge
we knew,

944
00:37:05,533 --> 00:37:07,166
the dragon we knew, right?

945
00:37:07,166 --> 00:37:08,800
We don't want
to fight that dragon.

946

00:37:08,800 --> 00:37:10,866
We want to--
give me a different dragon.

947
00:37:10,866 --> 00:37:12,366
Well, we've got this other one
that we think might be good,

948
00:37:12,366 --> 00:37:14,366
but it's kind of clouded
by immature design, right?

949
00:37:14,366 --> 00:37:16,300
We're not sure
what we're gonna get into yet.

950
00:37:16,300 --> 00:37:18,733
And when you first start out,
that's always the case, right?

951
00:37:18,733 --> 00:37:20,200
A proposed system

952
00:37:20,200 --> 00:37:22,266
is always less known
than a known system, right?

953
00:37:22,266 --> 00:37:23,500
It's obvious.

954
00:37:23,500 --> 00:37:26,066
And when you start
to kind of brush away the smoke,

955
00:37:26,066 --> 00:37:27,500
you might find
a different dragon

956
00:37:27,500 --> 00:37:30,666
than the one you initially

thought you had, right?

957
00:37:30,666 --> 00:37:31,866
I'm not saying Orion is here,

958
00:37:31,866 --> 00:37:34,066
but this is something to,
you know,

959
00:37:34,066 --> 00:37:35,100
to keep in mind, as it were.

960
00:37:35,100 --> 00:37:36,333
Consider it a lesson, right?

961
00:37:36,333 --> 00:37:40,166
You can never bank
on a proposed future system

962
00:37:40,166 --> 00:37:43,966
being exactly
what it's sold to be.

963
00:37:43,966 --> 00:37:46,200
One of the other things
that I feel like is important

964
00:37:46,200 --> 00:37:50,266
to point out
that has been really driven home

965
00:37:50,266 --> 00:37:52,300
is this idea of separating

966
00:37:52,300 --> 00:37:54,166
technical and programmatic
constraints, right?

967
00:37:54,166 --> 00:37:56,100

It's kind of like trying
to get to Neverland

968
00:37:56,100 --> 00:37:58,966
because they're always coupled,
right?

969
00:37:58,966 --> 00:38:00,666
In the case of Orion,

970
00:38:00,666 --> 00:38:02,666
you know, changing
the heat shield architecture

971
00:38:02,666 --> 00:38:04,800
after a successful flight test

972
00:38:04,800 --> 00:38:07,366
is really trading one set
of technical challenges

973
00:38:07,366 --> 00:38:09,166
for another set
of technical challenges

974
00:38:09,166 --> 00:38:11,733
in pursuit of
programmatic advantage, right?

975
00:38:11,733 --> 00:38:14,666
I mean, that's kind of the end
of the day where we are.

976
00:38:14,666 --> 00:38:16,933
Orion the program is looking
for a workable balance

977
00:38:16,933 --> 00:38:18,966
at that program level.

978
00:38:18,966 --> 00:38:21,666
Workable balance
does not equal optimal

979
00:38:21,666 --> 00:38:24,433
in any one sort of,
you know, evaluation metric.

980
00:38:24,433 --> 00:38:25,966
It's not gonna be
the perfect technical solution.

981
00:38:25,966 --> 00:38:28,100
It's not gonna be the perfect
programmatic solution.

982
00:38:28,100 --> 00:38:29,266
It's a workable balance.

983
00:38:29,266 --> 00:38:31,400
And that's what projects
try and do.

984
00:38:31,400 --> 00:38:32,933
You know, each organization

985
00:38:32,933 --> 00:38:34,300
and the sub-teams
within each organization

986
00:38:34,300 --> 00:38:36,866
is gonna weight
different metrics differently.

987
00:38:36,866 --> 00:38:39,966
The program wants to be
sort of technically good enough

988
00:38:39,966 --> 00:38:41,933

or technically responsive
to what it's been asked to do

989
00:38:41,933 --> 00:38:44,066
within the budget
and cost constraints

990
00:38:44,066 --> 00:38:46,033
it's been given.

991
00:38:46,033 --> 00:38:48,466
You know, what's every other
hearing on Capitol Hill about?

992
00:38:48,466 --> 00:38:49,766
"Why are you costing so much?

993
00:38:49,766 --> 00:38:52,700
Why are you taking
so much time?" Right?

994
00:38:52,700 --> 00:38:54,300
You know,
if there's a contract involved

995
00:38:54,300 --> 00:38:55,700
or a contractor involved,

996
00:38:55,700 --> 00:38:58,466
all of those program desires
have to be translated

997
00:38:58,466 --> 00:39:00,133
into contract language,

998
00:39:00,133 --> 00:39:02,366
and that's what the contractor
has to deliver on.

999

00:39:02,366 --> 00:39:05,133
So the contractor does whatever
is in their contract, right?

1000
00:39:05,133 --> 00:39:07,333
It's difficult to get, you know,

1001
00:39:07,333 --> 00:39:11,400
a large contractor
to exceed requirements, right,

1002
00:39:11,400 --> 00:39:12,866
because that costs more money,

1003
00:39:12,866 --> 00:39:14,533
which is what the program was
trying to do in the first place,

1004
00:39:14,533 --> 00:39:17,466
is not spend that money.

1005
00:39:17,466 --> 00:39:19,933
You've got engineering
communities who, you know,

1006
00:39:19,933 --> 00:39:21,100
if they're trying to decouple

1007
00:39:21,100 --> 00:39:22,633
this technical,
programmatic thing,

1008
00:39:22,633 --> 00:39:24,966
will be proposing
the best technical solution

1009
00:39:24,966 --> 00:39:27,566
irregardless of the--
regardless?

1010
00:39:27,566 --> 00:39:30,566
Irregardless of the cost, right?

1011
00:39:30,566 --> 00:39:32,933
The best technical solution
no matter what it takes.

1012
00:39:32,933 --> 00:39:34,433
I would love
the best technical solution.

1013
00:39:34,433 --> 00:39:36,366
Everybody would love the best
technical solution, right?

1014
00:39:36,366 --> 00:39:38,566
It's a matter
of fitting that into the box

1015
00:39:38,566 --> 00:39:40,833
you've been given
as a program to operate with,

1016
00:39:40,833 --> 00:39:42,166
in both time and money.

1017
00:39:42,166 --> 00:39:44,066
And, as always,
whenever you've got, you know,

1018
00:39:44,066 --> 00:39:45,666
challenges, you know,

1019
00:39:45,666 --> 00:39:48,366
there's the "whatever my idea is
is the best idea," right?

1020
00:39:48,366 --> 00:39:49,733
And that's out there too.

1021
00:39:49,733 --> 00:39:51,366
So all of these things
kind of balance,

1022
00:39:51,366 --> 00:39:52,733
and it's been quite interesting
to see

1023
00:39:52,733 --> 00:39:55,133
how these have played out
through the Orion experience

1024
00:39:55,133 --> 00:39:59,400
to get to where we are today.

1025
00:39:59,400 --> 00:40:02,666
So, despite substantial
challenges, right,

1026
00:40:02,666 --> 00:40:05,100
Orion flew EFT-1
very successfully.

1027
00:40:05,100 --> 00:40:10,333
Those flight test objectives
were satisfied almost in total.

1028
00:40:10,333 --> 00:40:12,700
The evaluations
we're doing now of that vehicle,

1029
00:40:12,700 --> 00:40:14,333
particularly of the heat shield,

1030
00:40:14,333 --> 00:40:16,966
are gonna be the first
publicly available data set

1031

00:40:16,966 --> 00:40:19,900
on a human-capable ablative
system since Apollo, okay?

1032
00:40:19,900 --> 00:40:22,533
So there's other crewed
ablative systems flying now,

1033
00:40:22,533 --> 00:40:23,800
commercial crewed systems,
et cetera.

1034
00:40:23,800 --> 00:40:25,766
Those data sets
are not nearly as extensive,

1035
00:40:25,766 --> 00:40:27,533
and they are not gonna
be publicly available.

1036
00:40:27,533 --> 00:40:29,133
This will be
the first one since Apollo,

1037
00:40:29,133 --> 00:40:31,133
and it is going to be
an exciting data set.

1038
00:40:31,133 --> 00:40:33,700
Already kind of seeing and being
a part of developing it,

1039
00:40:33,700 --> 00:40:35,666
it's gonna be tremendous.

1040
00:40:35,666 --> 00:40:38,933
Send out
your PhD thesis plans now.

1041
00:40:38,933 --> 00:40:40,933

[laughter]

1042
00:40:40,933 --> 00:40:42,333
You know, the other thing,
you know, kind of to leave with

1043
00:40:42,333 --> 00:40:44,433
is every engineering effort
is very coupled, right?

1044
00:40:44,433 --> 00:40:46,100
You have the technical,
you have the programmatic,

1045
00:40:46,100 --> 00:40:47,533
and you have the risk.

1046
00:40:47,533 --> 00:40:50,366
And none of these things can be
treated separately, right?

1047
00:40:50,366 --> 00:40:52,200
You may attack them with
separate groups or whatever,

1048
00:40:52,200 --> 00:40:54,033
but at some point,
they all have to come together.

1049
00:40:54,033 --> 00:40:55,633
What works for one program

1050
00:40:55,633 --> 00:40:57,900
may not work for another program
in any of these things, right?

1051
00:40:57,900 --> 00:41:00,766
A technical solution
on one program may be great.

1052
00:41:00,766 --> 00:41:02,766
It may not work
in the programmatic constraints

1053
00:41:02,766 --> 00:41:04,000
of another
or in the risk appetite

1054
00:41:04,000 --> 00:41:06,300
or posture of another.

1055
00:41:06,300 --> 00:41:07,733
You know,
and it's very interesting

1056
00:41:07,733 --> 00:41:09,666
to observe how
all of these things interplay

1057
00:41:09,666 --> 00:41:11,400
and how all of
these organizations interplay,

1058
00:41:11,400 --> 00:41:14,100
and it has been interesting
on Orion.

1059
00:41:14,100 --> 00:41:16,866
So that picture of Earth there

1060
00:41:16,866 --> 00:41:19,233
is taken
during the EFT-1 mission.

1061
00:41:19,233 --> 00:41:20,966
I would like to point out
it's quite a bit smaller than

1062
00:41:20,966 --> 00:41:24,033

what you see on NASA TV going by
under the space station.

1063
00:41:24,033 --> 00:41:25,566
So it's an exciting time.

1064
00:41:25,566 --> 00:41:27,766
I think that we're gonna have
a great path forward on Orion.

1065
00:41:27,766 --> 00:41:29,400
I'm excited
to see where it goes.

1066
00:41:29,400 --> 00:41:31,366
So thank you very much.

1067
00:41:31,366 --> 00:41:34,366
[applause]

1068
00:41:38,733 --> 00:41:41,300
So now we would like
to take some questions.

1069
00:41:41,300 --> 00:41:43,766
Please make a file
in the microphone

1070
00:41:43,766 --> 00:41:45,966
in the center aisle
and ask one question.

1071
00:41:45,966 --> 00:41:48,400
Keep it short and succinct,
please.

1072
00:41:57,600 --> 00:41:59,666
One thing about the design

1073

00:41:59,666 --> 00:42:03,866
of the Avcoat honeycomb versus
the new block heat shield,

1074
00:42:03,866 --> 00:42:06,300
something that wasn't mentioned
in the talk was an issue

1075
00:42:06,300 --> 00:42:08,600
with when you're injecting it
into the honeycombs,

1076
00:42:08,600 --> 00:42:10,766
the occurrence of voids,

1077
00:42:10,766 --> 00:42:13,633
little gaps, and bubbles inside
those individual honeycombs,

1078
00:42:13,633 --> 00:42:18,333
and is that addressed
in the new block form design?

1079
00:42:18,333 --> 00:42:21,133
Yeah, so what Jeff
is getting at is

1080
00:42:21,133 --> 00:42:24,700
when these gunners inject
the Avcoat in the honeycomb,

1081
00:42:24,700 --> 00:42:26,933
what we've seen can happen

1082
00:42:26,933 --> 00:42:29,500
and found some instances
on the flight build for EFT-1

1083
00:42:29,500 --> 00:42:33,133
is that you get these voids

within a cell, as it were.

1084
00:42:33,133 --> 00:42:36,633
On EFT-1, we attempted
to screen those out with X-ray.

1085
00:42:36,633 --> 00:42:39,966
So we used backscatter X-ray
across the entire flight build

1086
00:42:39,966 --> 00:42:42,233
and were trying to discern
where these voids were.

1087
00:42:42,233 --> 00:42:45,000
The problem was, we didn't have
a solid reference case, right,

1088
00:42:45,000 --> 00:42:47,000
for the X-rays,

1089
00:42:47,000 --> 00:42:48,600
'cause we got
the carrier structure behind it,

1090
00:42:48,600 --> 00:42:50,133
so they're kind of difficult
to find.

1091
00:42:50,133 --> 00:42:51,633
So you're kind of eyeballing,

1092
00:42:51,633 --> 00:42:53,166
where on an X-ray image,

1093
00:42:53,166 --> 00:42:54,733
things might not look
quite right.

1094

00:42:54,733 --> 00:42:58,366
With the blocks,
where we're going is to get--

1095
00:42:58,366 --> 00:43:00,833
first of all, we've seen
less occurrence of the voids.

1096
00:43:00,833 --> 00:43:02,466
I don't think we've actually
seen any voids so far

1097
00:43:02,466 --> 00:43:04,033
in the manufacturing,

1098
00:43:04,033 --> 00:43:06,000
but we're also going down the
path of X-raying those blocks

1099
00:43:06,000 --> 00:43:07,600
separately on a table,

1100
00:43:07,600 --> 00:43:10,266
and we're probably gonna end up
CT scanning them as well.

1101
00:43:10,266 --> 00:43:11,666
So I don't think--

1102
00:43:11,666 --> 00:43:14,266
the voids will be more readily
addressed in that system.

1103
00:43:14,266 --> 00:43:16,400
Is that...

1104
00:43:16,400 --> 00:43:18,900
Get what you wanted?

1105

00:43:20,900 --> 00:43:23,733
So, while we're waiting
for the next question,

1106
00:43:23,733 --> 00:43:25,700
I'd like to switch places
with you.

1107
00:43:25,700 --> 00:43:26,900
Okay.

1108
00:43:26,900 --> 00:43:30,733
I have a question
about the most technical--

1109
00:43:30,733 --> 00:43:33,166
the best technical solution.

1110
00:43:33,166 --> 00:43:36,933
Would you recommend,
for future missions,

1111
00:43:36,933 --> 00:43:39,633
is it possible for a commercial
industry to find these,

1112
00:43:39,633 --> 00:43:41,633
or do you recommend the path

1113
00:43:41,633 --> 00:43:44,466
that NASA has developed
through this space heritage,

1114
00:43:44,466 --> 00:43:49,166
and maybe can expand
on that topic?

1115
00:43:49,166 --> 00:43:51,933
Sure, yeah.

1116
00:43:51,933 --> 00:43:53,566
Yeah,
I think it's definitely possible

1117
00:43:53,566 --> 00:43:56,200
that commercial programs
could find solutions,

1118
00:43:56,200 --> 00:43:58,533
you know, that would enable
other missions.

1119
00:43:58,533 --> 00:43:59,700
Is that kind of
what you're getting at?

1120
00:43:59,700 --> 00:44:00,766
Yeah.

1121
00:44:00,766 --> 00:44:02,533
Yeah, that would enable
other missions.

1122
00:44:02,533 --> 00:44:04,233
That's not what they're required
to do right now, right?

1123
00:44:04,233 --> 00:44:06,966
Their contracts are
for space station resupplying

1124
00:44:06,966 --> 00:44:08,666
crew rotation, so that's
what they're working to,

1125
00:44:08,666 --> 00:44:10,500
and those are the solutions
that they've selected

1126

00:44:10,500 --> 00:44:12,733
are to answer those missions,

1127
00:44:12,733 --> 00:44:14,600
within their cost
and schedule boxes, right,

1128
00:44:14,600 --> 00:44:15,833
that they've been given.

1129
00:44:15,833 --> 00:44:19,500
There's nothing, you know,

1130
00:44:19,500 --> 00:44:21,166
I guess the way I'd say it is,

1131
00:44:21,166 --> 00:44:22,700
within the way

1132
00:44:22,700 --> 00:44:23,833
that the commercial crew
programs have been set up,

1133
00:44:23,833 --> 00:44:25,133
they get a lot of help
from NASA.

1134
00:44:25,133 --> 00:44:26,366
NASA provides
a lot of expertise,

1135
00:44:26,366 --> 00:44:28,133
particularly in the TPS area.

1136
00:44:28,133 --> 00:44:30,333
So in the same way that that
expertise has been given to them

1137
00:44:30,333 --> 00:44:33,033

to do the mission they've been
asked to do, you know,

1138
00:44:33,033 --> 00:44:35,033
if they were to set out
and do an exploration mission,

1139
00:44:35,033 --> 00:44:37,133
a more capable heat shield
or something like that,

1140
00:44:37,133 --> 00:44:38,333
they'd receive that same help,

1141
00:44:38,333 --> 00:44:42,400
and they could probably
go do it.

1142
00:44:42,400 --> 00:44:45,266
So, with the tiled solution,

1143
00:44:45,266 --> 00:44:47,433
is the material in the seams

1144
00:44:47,433 --> 00:44:50,033
necessarily expected
to also be ablative,

1145
00:44:50,033 --> 00:44:53,966
or is it merely--must it be
ablative for the system to work,

1146
00:44:53,966 --> 00:44:57,000
or I saw the--I mean,
we have the demonstrations,

1147
00:44:57,000 --> 00:45:01,533
but must those joints also--
is that required as part

1148
00:45:01,533 --> 00:45:06,100
of the whole heat transfer
of the system?

1149
00:45:06,100 --> 00:45:07,833
Pretty much, yes.
Yeah.

1150
00:45:07,833 --> 00:45:10,666
So, if, in the hypothetical case
where we had seams

1151
00:45:10,666 --> 00:45:12,733
between blocks
that didn't ablate at all,

1152
00:45:12,733 --> 00:45:14,300
then whatever heat
got into those

1153
00:45:14,300 --> 00:45:15,966
would conduct directly down
to the structure

1154
00:45:15,966 --> 00:45:17,700
instead of being consumed
to the ablation process,

1155
00:45:17,700 --> 00:45:20,066
so you'd call that
a "thermal short," as it were.

1156
00:45:20,066 --> 00:45:22,100
But then also, because we want
to keep the surface

1157
00:45:22,100 --> 00:45:24,366
as smooth as possible

1158

00:45:24,366 --> 00:45:26,466
so that we don't have
local heating augmentations,

1159
00:45:26,466 --> 00:45:27,633
if one part's ablated,

1160
00:45:27,633 --> 00:45:29,466
you kind of want
the whole thing to be that way

1161
00:45:29,466 --> 00:45:32,200
so that you kind of keep
the OML, the outer mold line,

1162
00:45:32,200 --> 00:45:34,200
as smooth as you can.

1163
00:45:36,433 --> 00:45:37,733
Jeremy, thank you very much.

1164
00:45:37,733 --> 00:45:39,900
That was an outstanding talk.

1165
00:45:39,900 --> 00:45:44,000
I'd like to know
how much extra mass margin

1166
00:45:44,000 --> 00:45:48,266
you think is on the heat shield
because of our inability

1167
00:45:48,266 --> 00:45:51,966
to exactly predict, model,
simulate, and ground test

1168
00:45:51,966 --> 00:45:54,733
the thermal and structural loads
on the system.

1169
00:45:54,733 --> 00:45:56,166
How much could we take off

1170
00:45:56,166 --> 00:45:59,066
if we had
a perfect predictive capability?

1171
00:45:59,066 --> 00:46:00,700
I'll be able to answer better
when we're done

1172
00:46:00,700 --> 00:46:04,800
with the EFT-1
post-flight analysis.

1173
00:46:04,800 --> 00:46:06,333
You know, to eyeball it,

1174
00:46:06,333 --> 00:46:08,033
just based
on the margin policy we have,

1175
00:46:08,033 --> 00:46:14,033
anywhere from 25% to 50%
in thickness,

1176
00:46:14,033 --> 00:46:17,400
for a lot of different reasons
but probably in that ballpark.

1177
00:46:28,333 --> 00:46:30,900
If there are no--oh, we have
another additional question?

1178
00:46:30,900 --> 00:46:32,066
Yeah, please.

1179
00:46:32,066 --> 00:46:34,266
I was just curious

if you could give, like,

1180
00:46:34,266 --> 00:46:37,033
a specific example
on how to, like,

1181
00:46:37,033 --> 00:46:40,433
mitigate the technical risk
of the new tile system?

1182
00:46:40,433 --> 00:46:43,133
Like, just a specific example

1183
00:46:43,133 --> 00:46:46,800
rather than just saying it costs
time, money, and sweat.

1184
00:46:46,800 --> 00:46:48,266
Sure.

1185
00:46:48,266 --> 00:46:49,666
Yeah, I mean, the biggest--

1186
00:46:49,666 --> 00:46:52,700
one of the biggest--
one of the top two issues

1187
00:46:52,700 --> 00:46:55,133
we have with the tiled system
is to verify

1188
00:46:55,133 --> 00:46:56,700
that when those blocks
are bonded

1189
00:46:56,700 --> 00:46:57,866
to that carrier structure,

1190
00:46:57,866 --> 00:46:59,600

that they do not come off,
right?

1191
00:46:59,600 --> 00:47:01,666
Because if a block
comes off in flight,

1192
00:47:01,666 --> 00:47:04,166
you're gonna lose that vehicle.

1193
00:47:04,166 --> 00:47:07,666
So that's probably
our biggest challenge.

1194
00:47:07,666 --> 00:47:09,966
You know, so some examples of
how we're getting around that is

1195
00:47:09,966 --> 00:47:12,700
working up
all the process controls

1196
00:47:12,700 --> 00:47:15,533
that are gonna be needed
to adhere these blocks down.

1197
00:47:15,533 --> 00:47:19,733
We're doing a lot of sort of
benchtop level bending tests,

1198
00:47:19,733 --> 00:47:23,666
cold soak tests of these blocks
bonded down to the carrier,

1199
00:47:23,666 --> 00:47:25,766
bonded to each other,
making sure that

1200
00:47:25,766 --> 00:47:29,066
we can test them well beyond

the mechanical deflections

1201
00:47:29,066 --> 00:47:32,200
or the temperature loads that
we expect them to see in flight,

1202
00:47:32,200 --> 00:47:36,100
because they can't come off.

1203
00:47:36,100 --> 00:47:38,033
Yeah.

1204
00:47:41,033 --> 00:47:45,200
So you mentioned
different speeds of reentry.

1205
00:47:45,200 --> 00:47:48,433
I think one was 9,
9 kilometers, one was 11.

1206
00:47:48,433 --> 00:47:50,833
As we theoretically venture

1207
00:47:50,833 --> 00:47:53,766
farther out into space
and return,

1208
00:47:53,766 --> 00:47:57,333
does that speed
go up exponentially,

1209
00:47:57,333 --> 00:47:59,866
and if so,
do we need to sort of build

1210
00:47:59,866 --> 00:48:02,433
thicker or different shields,

1211
00:48:02,433 --> 00:48:05,000

or is there sort of
a constant speed

1212
00:48:05,000 --> 00:48:07,633
that is reached
kind of the farther out you go

1213
00:48:07,633 --> 00:48:09,700
and come back
and things like that?

1214
00:48:09,700 --> 00:48:11,400
It keeps going up, right?

1215
00:48:11,400 --> 00:48:14,433
So the speed you return is
related to the speed of your--

1216
00:48:14,433 --> 00:48:16,300
you know, your orbital velocity,

1217
00:48:16,300 --> 00:48:18,133
which is related
to the apogee away from the body

1218
00:48:18,133 --> 00:48:19,800
you're orbiting.

1219
00:48:19,800 --> 00:48:22,033
So, you know, low Earth orbit,
7 kilometers a second,

1220
00:48:22,033 --> 00:48:23,666
the moon,
11 kilometers per second,

1221
00:48:23,666 --> 00:48:27,366
Mars, 13 kilometers a second,

1222

00:48:27,366 --> 00:48:29,633
and after that, I don't know
how to quote the numbers,

1223
00:48:29,633 --> 00:48:32,833
but it keeps going up, yeah.

1224
00:48:37,366 --> 00:48:40,966
So, if there are
no other questions,

1225
00:48:40,966 --> 00:48:45,966
then please have additional
conversations in the reception.

1226
00:48:45,966 --> 00:48:49,400
We'd like to please
thank our speaker one more time.

1227
00:48:49,400 --> 00:48:52,400
[applause]