
NASA

1
00:00:01,000 --> 00:00:04,000
[music playing]

2
00:00:16,866 --> 00:00:21,833
- Welcome to the
2015 NASA Ames Summer Series.

3
00:00:23,266 --> 00:00:26,366
We're curious
about our surrounding.

4
00:00:26,366 --> 00:00:31,666
Curiosity is
an innate behavior that we have.

5
00:00:31,666 --> 00:00:34,966
That behavior drives exploration

6
00:00:34,966 --> 00:00:38,533
and our need to explore.

7
00:00:38,533 --> 00:00:42,833
Exploration of new places
on Earth, here,

8
00:00:42,833 --> 00:00:45,400
or far away places in space

9
00:00:45,400 --> 00:00:47,433
is important for our survival.

10
00:00:47,433 --> 00:00:50,666
It's the way
that we evolve.

11
00:00:50,666 --> 00:00:54,833
But an evolvable system
is what we need

12
00:00:54,833 --> 00:00:56,400
for space exploration.

13
00:00:56,400 --> 00:01:02,233
One that advances us,
to eventually get to Mars,

14
00:01:02,233 --> 00:01:04,233
and beyond.

15
00:01:04,233 --> 00:01:07,633
Today's talk entitled

16
00:01:07,633 --> 00:01:12,133
"Pioneering Space
Evolvable Mars Campaign:

17
00:01:12,133 --> 00:01:14,933
Architecture Studies
on Carrying Out

18
00:01:14,933 --> 00:01:17,000
the Journey To Mars"

19
00:01:17,000 --> 00:01:20,300
will be given by Jason Crusan.

20
00:01:20,300 --> 00:01:22,700
Jason is the director

21
00:01:22,700 --> 00:01:24,833
of Advanced Exploration
Systems Division

22
00:01:24,833 --> 00:01:28,033
at NASA headquarters.

23
00:01:28,033 --> 00:01:29,300

He has a bachelor's degree

24
00:01:29,300 --> 00:01:32,900
in electrical engineering
and physics

25
00:01:32,900 --> 00:01:37,566
and a master's degrees in
computers information systems.

26
00:01:37,566 --> 00:01:40,500
He is also currently
a PhD candidate

27
00:01:40,500 --> 00:01:44,800
in Engineering Management
at George Washington University.

28
00:01:44,800 --> 00:01:49,200
For those students realize that
while he is at headquarters,

29
00:01:49,200 --> 00:01:53,166
he's still continuing his
education to receive his PhD.

30
00:01:53,166 --> 00:01:56,533
Please join me
in welcoming Jason Crusan.

31
00:01:56,533 --> 00:01:59,533
[applause]

32
00:02:04,633 --> 00:02:05,900
- Thank you, guys.

33
00:02:05,900 --> 00:02:07,200
Glad this will be
probably easier than

34
00:02:07,200 --> 00:02:09,900
a dissertation defense
and those kind of things.

35
00:02:09,900 --> 00:02:12,966
So, I'm gonna talk to you
a little bit about today about

36
00:02:12,966 --> 00:02:15,500
what's been going on in
human spaceflight planning

37
00:02:15,500 --> 00:02:18,266
at NASA,
and you may hear a lot of terms

38
00:02:18,266 --> 00:02:21,166
like "Journey to Mars,"
"Pioneering Space,"

39
00:02:21,166 --> 00:02:23,066
"Evolvable Mars Campaign,"
and what I'm gonna try

40
00:02:23,066 --> 00:02:24,833
to attempt to do
is give you a little construct

41
00:02:24,833 --> 00:02:27,900
or con--uh--what--what do those
things mean and what's actually

42
00:02:27,900 --> 00:02:29,800
really going on
that we have.

43
00:02:29,800 --> 00:02:32,300
So, to start that off,

44

00:02:32,300 --> 00:02:35,700
we obviously use
in a lot of our talking points

45
00:02:35,700 --> 00:02:36,733
and visual graphics

46
00:02:36,733 --> 00:02:38,500
this graphic
that you see up here,

47
00:02:38,500 --> 00:02:39,733
the Journey to Mars graphic.

48
00:02:39,733 --> 00:02:42,500
And it's great for kinda
communicating

49
00:02:42,500 --> 00:02:44,700
to the general public
about our overall strategy,

50
00:02:44,700 --> 00:02:47,133
but it lacks kind of the detail
of what's really going on,

51
00:02:47,133 --> 00:02:50,366
and how we make
this transition,

52
00:02:50,366 --> 00:02:52,833
from where we're at today
to getting to Mars.

53
00:02:52,833 --> 00:02:54,166
So I actually draw
your attention

54
00:02:54,166 --> 00:02:55,333
to the very bottom

of the chart,

55
00:02:55,333 --> 00:02:56,866
which I think
is the most important piece

56
00:02:56,866 --> 00:02:59,933
and it talks about this
transition from Earth Reliant

57
00:02:59,933 --> 00:03:03,066
through a proving ground
period of time and space

58
00:03:03,066 --> 00:03:06,200
into, moving on to being
Earth Independent.

59
00:03:06,200 --> 00:03:07,500
So I'm gonna kinda
walk you through

60
00:03:07,500 --> 00:03:12,000
that thought process today,
and what that means.

61
00:03:12,000 --> 00:03:13,966
So, when people think about
human spaceflight,

62
00:03:13,966 --> 00:03:17,033
this is an iconic image
that comes to people's mind.

63
00:03:17,033 --> 00:03:20,033
There's a famous photographer
taking a picture

64
00:03:20,033 --> 00:03:21,800
of somebody coming down

the steps of the LEM,

65
00:03:21,800 --> 00:03:26,033
Buzz Aldrin stepping
onto the surface of the moon.

66
00:03:26,033 --> 00:03:28,000
People think about
this construct.

67
00:03:28,000 --> 00:03:30,133
It was Apollo.
"Get there first,

68
00:03:30,133 --> 00:03:32,133
plant the flag,
less than ten years."

69
00:03:32,133 --> 00:03:34,500
It was a very kind
of singular goal in nature.

70
00:03:34,500 --> 00:03:37,666
We ran that duration
of the Apollo program.

71
00:03:37,666 --> 00:03:39,466
The Apollo program stopped,

72
00:03:39,466 --> 00:03:41,066
not because we ran out
of hardware.

73
00:03:41,066 --> 00:03:42,766
There's some really good
museum pieces

74
00:03:42,766 --> 00:03:45,133
at three or four locations
around the country

75
00:03:45,133 --> 00:03:47,266
of actual flight hardware
that never did fly.

76
00:03:47,266 --> 00:03:48,900
We didn't run
out of hardware,

77
00:03:48,900 --> 00:03:51,366
we ran out of a will to go,
and much of that

78
00:03:51,366 --> 00:03:54,533
I would attribute to
a kind of a myopic view

79
00:03:54,533 --> 00:03:58,200
of a singular goal of
where we're at.

80
00:03:58,200 --> 00:03:59,866
So I'm gonna step into
where we're at today.

81
00:03:59,866 --> 00:04:01,866
Fast-forward
to the space station era

82
00:04:01,866 --> 00:04:03,166
that we live in today,

83
00:04:03,166 --> 00:04:06,700
and what also we term
as Earth Reliant.

84
00:04:06,700 --> 00:04:08,466
The space station
is fundamentally different

85
00:04:08,466 --> 00:04:10,500
than what we saw
during Apollo.

86
00:04:10,500 --> 00:04:11,866
It's not a singular goal.

87
00:04:11,866 --> 00:04:14,900
It's arguably four goals
in the way I lay it out.

88
00:04:14,900 --> 00:04:18,033
It's, obviously, advancing
the technology and systems

89
00:04:18,033 --> 00:04:19,833
to sustain human presence
off the planet,

90
00:04:19,833 --> 00:04:22,000
all the technology work
that's going on there.

91
00:04:22,000 --> 00:04:25,266
It's allowing us to understand
the fundamental biology

92
00:04:25,266 --> 00:04:27,400
of the human--
the human system

93
00:04:27,400 --> 00:04:29,100
living off the planet.
And what does that mean

94
00:04:29,100 --> 00:04:30,533
to actually live
off the planet?

95

00:04:30,533 --> 00:04:33,933
It's allowing us to do
fundamental research development

96
00:04:33,933 --> 00:04:37,100
of understanding effects
that the lack of gravity

97
00:04:37,100 --> 00:04:39,133
in the space environment
actually emphasize

98
00:04:39,133 --> 00:04:41,600
in order for us to understand
scientific fundamentals

99
00:04:41,600 --> 00:04:43,700
that are benefiting us
back here today.

100
00:04:43,700 --> 00:04:46,800
And the fourth goal is actually
another one that people

101
00:04:46,800 --> 00:04:50,300
kind of miss, but it's building
an off-world economy

102
00:04:50,300 --> 00:04:53,633
and how do we actually build
a low-Earth orbit economy

103
00:04:53,633 --> 00:04:57,033
or a true space economy
that's out there?

104
00:04:57,033 --> 00:04:59,500
So you see this
human spaceflight

105

00:04:59,500 --> 00:05:01,266
went from this kinda
singular goal:

106
00:05:01,266 --> 00:05:03,466
Plant a flag
in less than ten years.

107
00:05:03,466 --> 00:05:04,733
Fast-forward to today

108
00:05:04,733 --> 00:05:07,700
to a very complex
human spaceflight endeavor

109
00:05:07,700 --> 00:05:09,766
that we have with these
multidisciplinary,

110
00:05:09,766 --> 00:05:13,000
multi-economic goals
coupled with scientific goals

111
00:05:13,000 --> 00:05:15,100
of living off the planet.

112
00:05:15,100 --> 00:05:17,333
But we're very much
in this Earth Reliant phase.

113
00:05:17,333 --> 00:05:19,866
So 10-15%
of a global launch business

114
00:05:19,866 --> 00:05:22,766
goes to resupply the
space station on a yearly basis.

115
00:05:22,766 --> 00:05:25,466
We can get crews back

in less than 17 hours

116
00:05:25,466 --> 00:05:27,066
if there's a medical emergency.

117
00:05:27,066 --> 00:05:30,300
Cargo flights,
now it's relatively routine

118
00:05:30,300 --> 00:05:32,366
to see a launch,
and six hours later, docking.

119
00:05:32,366 --> 00:05:35,400
But there's that
high supply chain,

120
00:05:35,400 --> 00:05:37,533
a logistics chain
that's out there.

121
00:05:37,533 --> 00:05:40,366
So one of the things,
as we extend human presence

122
00:05:40,366 --> 00:05:42,966
out there, is it's
much more about the logistics

123
00:05:42,966 --> 00:05:45,233
than a lot of other things
that weigh on us.

124
00:05:45,233 --> 00:05:47,666
So keep that in mind.

125
00:05:47,666 --> 00:05:50,800
So you fast-forward again
to our current administration

126
00:05:50,800 --> 00:05:53,733
and a talk that he gave
down at Kennedy Space Center

127
00:05:53,733 --> 00:05:54,933
in April 2010.

128
00:05:54,933 --> 00:05:58,466
Most people talk about
asteroid by 2025s,

129
00:05:58,466 --> 00:06:01,666
and Mars vicinity
in the 2030s.

130
00:06:01,666 --> 00:06:04,366
Okay, let's not harp
on that piece,

131
00:06:04,366 --> 00:06:06,433
but let's actually pull back
what he said right before that,

132
00:06:06,433 --> 00:06:09,100
which most people didn't
pay attention to.

133
00:06:09,100 --> 00:06:12,133
And I'll paraphrase it
in my own words, which is,

134
00:06:12,133 --> 00:06:14,300
extended human presence
further and further

135
00:06:14,300 --> 00:06:17,133
and staying for
longer and longer in space.

136

00:06:17,133 --> 00:06:20,166
Those two kind of fundamentals,
"go farther" and "stay longer,"

137
00:06:20,166 --> 00:06:22,700
I think are in the air of how
we're actually designing

138
00:06:22,700 --> 00:06:25,133
our human spaceflight
exploration program today.

139
00:06:25,133 --> 00:06:27,000
And it's not just
exploration anymore,

140
00:06:27,000 --> 00:06:29,100
it's about that extended
human presence.

141
00:06:29,100 --> 00:06:31,733
And, in fact,
in the 2014 strategic plan,

142
00:06:31,733 --> 00:06:33,833
'cause NASA does
strategic plans--

143
00:06:33,833 --> 00:06:35,900
you may not have actually
looked at it,

144
00:06:35,900 --> 00:06:38,233
but in there was the first time
we actually wrote,

145
00:06:38,233 --> 00:06:40,533
"A human presence
into the solar system,"

146

00:06:40,533 --> 00:06:42,766
"the surface of Mars."
By the way,

147
00:06:42,766 --> 00:06:43,833
that's the first time
it's ever been written

148
00:06:43,833 --> 00:06:47,266
in our strategic plan
to my knowledge.

149
00:06:47,266 --> 00:06:49,733
And--and for this multiple
kind of focuses,

150
00:06:49,733 --> 00:06:52,100
"advancing exploration,
science, innovation,

151
00:06:52,100 --> 00:06:53,633
"international,
and the humanity--

152
00:06:53,633 --> 00:06:55,100
the benefits to humanity."

153
00:06:55,100 --> 00:06:58,900
So again, kind of a rephrase
of that kind of complex nature

154
00:06:58,900 --> 00:07:01,300
of what human spaceflight
is today.

155
00:07:01,300 --> 00:07:04,066
So how do we go
from this Earth Reliant phase

156
00:07:04,066 --> 00:07:05,866

to being Earth Independent?

157
00:07:05,866 --> 00:07:07,800
Well, we don't just
do that overnight.

158
00:07:07,800 --> 00:07:09,033
We don't build the systems.

159
00:07:09,033 --> 00:07:10,200
We're learning a lot
from space station,

160
00:07:10,200 --> 00:07:11,600
but we're gonna need
to figure out

161
00:07:11,600 --> 00:07:14,566
where to assemble things,
where to live off this planet

162
00:07:14,566 --> 00:07:15,866
for extended periods of time,

163
00:07:15,866 --> 00:07:18,166
and we call this the
Proving Ground period of time.

164
00:07:18,166 --> 00:07:20,800
Some people refer to it
as a space, physical--

165
00:07:20,800 --> 00:07:22,666
I mean an actual location
in space.

166
00:07:22,666 --> 00:07:24,833
In our nomenclature,
it's in cislunar

167
00:07:24,833 --> 00:07:27,266
or the lunar distant
retrograde orbit,

168
00:07:27,266 --> 00:07:30,800
L1, L2, whatever you want
to call it, in cislunar space.

169
00:07:30,800 --> 00:07:33,500
It's a location by which
we can advance all the systems,

170
00:07:33,500 --> 00:07:35,133
but, more importantly,
it's a location that

171
00:07:35,133 --> 00:07:38,166
will actually build our
spaceships to take us to Mars

172
00:07:38,166 --> 00:07:41,033
and also return them
and park them on the way back

173
00:07:41,033 --> 00:07:42,966
for the next trip
going outbound.

174
00:07:42,966 --> 00:07:45,100
So this is
an artist rendition

175
00:07:45,100 --> 00:07:48,733
that's actually physics correct
of seeing ourselves

176
00:07:48,733 --> 00:07:50,500
out at a lunar distance
retrograde orbit

177
00:07:50,500 --> 00:07:52,500
with the moon there and
the Earth off in the distance

178
00:07:52,500 --> 00:07:55,933
working on one of those
habitation systems

179
00:07:55,933 --> 00:07:57,533
and transportation systems
that would take us

180
00:07:57,533 --> 00:08:00,533
to Mars and back.

181
00:08:00,533 --> 00:08:02,400
This is all
in a stepping stone

182
00:08:02,400 --> 00:08:04,800
kind of build out approach
that allows us then

183
00:08:04,800 --> 00:08:07,233
to move into that
Earth Independent phase.

184
00:08:07,233 --> 00:08:11,300
But we don't do that
through just guessing

185
00:08:11,300 --> 00:08:12,700
on what decisions
we need to make.

186
00:08:12,700 --> 00:08:15,366
We actually put together
a set of guiding principles

187

00:08:15,366 --> 00:08:19,033
on how do we make decisions
of what investments

188
00:08:19,033 --> 00:08:20,600
we need to make?
How do we--

189
00:08:20,600 --> 00:08:22,000
How do we
as a human spaceflight

190
00:08:22,000 --> 00:08:25,500
or a total space community

191
00:08:25,500 --> 00:08:26,733
make some of those decisions?

192
00:08:26,733 --> 00:08:28,433
So we put together
some strategic principles

193
00:08:28,433 --> 00:08:31,200
that we think are pretty robust
on what we think

194
00:08:31,200 --> 00:08:33,533
are the drivers
to make all these decisions.

195
00:08:33,533 --> 00:08:34,866
I'll walk
through these briefly

196
00:08:34,866 --> 00:08:36,933
'cause it's good
to spend some time with them.

197
00:08:36,933 --> 00:08:40,300
So one of them is the

budget reality that we live in.

198
00:08:40,300 --> 00:08:43,466
Let's not design
a human spaceflight endeavor,

199
00:08:43,466 --> 00:08:45,566
or pioneering space,
or exploration endeavor

200
00:08:45,566 --> 00:08:49,466
that counts on some
unrealistic budget allocation

201
00:08:49,466 --> 00:08:52,200
coming to NASA or the
global community and budgets.

202
00:08:52,200 --> 00:08:54,600
There's been a lot of people
over the years

203
00:08:54,600 --> 00:08:55,633
that have talked about,

204
00:08:55,633 --> 00:08:57,266
"Oh, if we just had
a better plan,

205
00:08:57,266 --> 00:08:58,566
somebody will give us
the money."

206
00:08:58,566 --> 00:09:00,466
There's been
a lot of smart people

207
00:09:00,466 --> 00:09:02,533
that have tried to do that
over the past decades,

208
00:09:02,533 --> 00:09:04,000
and that's not been
the reality.

209
00:09:04,000 --> 00:09:07,800
So instead of kinda quibbling
about building a better plan,

210
00:09:07,800 --> 00:09:09,466
let's actually start
doing things.

211
00:09:09,466 --> 00:09:10,733
And--but let's do them in a way

212
00:09:10,733 --> 00:09:12,133
that we can actually do it
without having to ask

213
00:09:12,133 --> 00:09:14,066
for the additional
budget authority today.

214
00:09:14,066 --> 00:09:15,633
And we believe
that we can actually do that

215
00:09:15,633 --> 00:09:17,166
with the budget we have.

216
00:09:17,166 --> 00:09:19,233
The next one is,
"exploration enables science,

217
00:09:19,233 --> 00:09:20,533
science enables exploration."

218
00:09:20,533 --> 00:09:23,900

This is a quote
from the late Mike Wargo,

219
00:09:23,900 --> 00:09:26,000
our past
chief exploration scientist.

220
00:09:26,000 --> 00:09:29,000
And he liked to point out
that science and exploration

221
00:09:29,000 --> 00:09:31,233
are not against each other,
but rather additive

222
00:09:31,233 --> 00:09:32,966
to each other.

223
00:09:32,966 --> 00:09:36,066
And by concentrating
on them working together,

224
00:09:36,066 --> 00:09:38,300
we'll do a lot more,
and this--this kinda harp--

225
00:09:38,300 --> 00:09:41,300
harps on that principle
that we have.

226
00:09:41,300 --> 00:09:43,233
Next is technology readiness.

227
00:09:43,233 --> 00:09:46,266
So we're the--obviously
gonna hi--apply technologies

228
00:09:46,266 --> 00:09:48,166
that are ready to actually
implement the missions today,

229
00:09:48,166 --> 00:09:49,500
but we're not gonna
cut our seed corn

230
00:09:49,500 --> 00:09:51,233
for the next generation
of technology that we need

231
00:09:51,233 --> 00:09:55,366
to keep on expanding that
horizon into the solar system.

232
00:09:55,366 --> 00:09:58,200
So how do we have
a balanced technology portfolio?

233
00:09:58,200 --> 00:10:01,433
Near-term mission cadence
that's also not designed

234
00:10:01,433 --> 00:10:03,800
an overall plan
for human spaceflight

235
00:10:03,800 --> 00:10:05,133
that has long periods of time

236
00:10:05,133 --> 00:10:07,166
where there's no flights
going on

237
00:10:07,166 --> 00:10:08,466
like we have today.

238
00:10:08,466 --> 00:10:11,100
We've made that mistake
several times.

239

00:10:11,100 --> 00:10:12,333
Let's not make it
once again.

240
00:10:12,333 --> 00:10:16,100
And how do a monch--uh,
kind of a marching cadence

241
00:10:16,100 --> 00:10:17,966
of missions
on a regular basis?

242
00:10:17,966 --> 00:10:19,933
'Cause there's nothing
more inspirational

243
00:10:19,933 --> 00:10:21,600
than actually
flying hardware,

244
00:10:21,600 --> 00:10:23,533
and flying our missions.

245
00:10:23,533 --> 00:10:25,433
So how do we--how do we
design that cadence

246
00:10:25,433 --> 00:10:27,300
to be engaging?

247
00:10:27,300 --> 00:10:29,000
Commercial business.

248
00:10:29,000 --> 00:10:30,700
Very much I talked about

249
00:10:30,700 --> 00:10:32,633
the building
the low-Earth orbit economy

250
00:10:32,633 --> 00:10:33,833
with the ISS.

251
00:10:33,833 --> 00:10:35,733
A lot of that
we got into after

252
00:10:35,733 --> 00:10:38,500
we had already completed
station completion and all that.

253
00:10:38,500 --> 00:10:40,533
Let's actually figure out
how to do

254
00:10:40,533 --> 00:10:42,433
this whole
pioneering endeavor

255
00:10:42,433 --> 00:10:45,200
by involving the commercial
sector from day one

256
00:10:45,200 --> 00:10:47,166
instead of the reverse

257
00:10:47,166 --> 00:10:49,200
where we traditionally do
at NASA.

258
00:10:49,200 --> 00:10:52,300
So how do we leverage the--
the actual space economy,

259
00:10:52,300 --> 00:10:53,933
the commercial business
that's out there,

260
00:10:53,933 --> 00:10:57,566

and actually baseline that
as part of our overall plans

261
00:10:57,566 --> 00:10:59,800
for all of our endeavors?

262
00:10:59,800 --> 00:11:03,533
The other piece is multi-use in
evolvable space infrastructure.

263
00:11:03,533 --> 00:11:05,000
This means two things.

264
00:11:05,000 --> 00:11:07,600
Let's not
throw away hardware,

265
00:11:07,600 --> 00:11:09,966
which we have a tendency to do
in the space program.

266
00:11:09,966 --> 00:11:12,266
Fly something,
throw away 80% of it,

267
00:11:12,266 --> 00:11:14,700
or if not, 100% of it
by the end of the mission.

268
00:11:14,700 --> 00:11:16,000
But rather,
let's build infrastructure

269
00:11:16,000 --> 00:11:17,400
that's reused over time.

270
00:11:17,400 --> 00:11:19,833
We've not demonstrated
in the habitation world,

271
00:11:19,833 --> 00:11:22,633
at least, that we can build
30-year habitation structures.

272
00:11:22,633 --> 00:11:23,966
The space station,
in it's lifetime,

273
00:11:23,966 --> 00:11:25,466
will be in there
over 30 years

274
00:11:25,466 --> 00:11:28,666
of actual certification
and flight.

275
00:11:28,666 --> 00:11:31,033
And most of the--
most of the components can be

276
00:11:31,033 --> 00:11:33,233
changed out and retrofitted
and upgraded over time.

277
00:11:33,233 --> 00:11:34,966
So let's keep
that kind of mantra,

278
00:11:34,966 --> 00:11:37,466
with whatever we're doing.

279
00:11:37,466 --> 00:11:40,366
The second aspect of this,
is if there is something

280
00:11:40,366 --> 00:11:42,300
that we need to throw away,
or something that needs

281

00:11:42,300 --> 00:11:45,100
repeatable design,
how do you do that once

282
00:11:45,100 --> 00:11:47,600
and kind of
the assembly line approach

283
00:11:47,600 --> 00:11:49,866
of re-flight of the same
hardware over and over?

284
00:11:49,866 --> 00:11:52,933
And modularize your designs
to a point that you can

285
00:11:52,933 --> 00:11:54,500
maximize reusability.

286
00:11:54,500 --> 00:11:56,833
The last is we're not
gonna do this alone.

287
00:11:56,833 --> 00:11:58,800
We're gonna do this
with our international partners.

288
00:11:58,800 --> 00:12:01,300
Leveraging the current
ISS partners,

289
00:12:01,300 --> 00:12:03,666
but then building
upon those partners

290
00:12:03,666 --> 00:12:06,366
and expanding to all
the emerging space organizations

291
00:12:06,366 --> 00:12:07,900

that are out there as well.

292
00:12:07,900 --> 00:12:10,633
And with that,
we've been

293
00:12:10,633 --> 00:12:12,233
a concerted effort
over the past couple years.

294
00:12:12,233 --> 00:12:13,566
We have what we call

295
00:12:13,566 --> 00:12:16,166
an International Space
Exploration Coordination Group.

296
00:12:16,166 --> 00:12:18,466
They've designed
and developed what we call

297
00:12:18,466 --> 00:12:19,966
our Global Exploration Roadmap.

298
00:12:19,966 --> 00:12:22,466
So what you see here
is the front cover of that.

299
00:12:22,466 --> 00:12:25,266
But more importantly,
you see the list of seven items

300
00:12:25,266 --> 00:12:28,166
on the left-hand side there,
and we actually have

301
00:12:28,166 --> 00:12:30,233
among the 14 countries
at the table

302
00:12:30,233 --> 00:12:32,566
a common understanding
of what the goals are

303
00:12:32,566 --> 00:12:34,633
for exploration
around the world.

304
00:12:34,633 --> 00:12:37,500
Not just at NASA, but all
of our international partners.

305
00:12:37,500 --> 00:12:39,166
And that's
a huge accomplishment

306
00:12:39,166 --> 00:12:41,600
to actually get
global space leadership

307
00:12:41,600 --> 00:12:45,533
to agree on what the commonality
of all that is.

308
00:12:45,533 --> 00:12:48,100
The other side of it is
we also got agreement

309
00:12:48,100 --> 00:12:51,700
on what we don't know related
to strategic knowledge gaps.

310
00:12:51,700 --> 00:12:53,833
So there's a bunch of things
that we need to know

311
00:12:53,833 --> 00:12:56,100
about places that we want to go
before we go there.

312
00:12:56,100 --> 00:12:58,500
That weighs into our
engineering knowledge,

313
00:12:58,500 --> 00:13:00,800
it weighs into our
overall architecture planning.

314
00:13:00,800 --> 00:13:03,066
Are there resources there
that we can gather

315
00:13:03,066 --> 00:13:05,433
and utilize on trips
in the future?

316
00:13:05,433 --> 00:13:09,700
Will the environment cause
hazards for our humans

317
00:13:09,700 --> 00:13:11,200
when we send them there?

318
00:13:11,200 --> 00:13:13,200
So we've actually developed
a whole set

319
00:13:13,200 --> 00:13:14,666
of strategic knowledge gaps,
worked with

320
00:13:14,666 --> 00:13:17,933
the three assessment bodies for
lunar, Mars, and small bodies,

321
00:13:17,933 --> 00:13:20,700
and got commonality there
and understanding,

322

00:13:20,700 --> 00:13:22,733
and then worked that with
the international community

323
00:13:22,733 --> 00:13:24,366
and came up
with a whole set of findings

324
00:13:24,366 --> 00:13:28,333
of where--where do we see
commonalities even across

325
00:13:28,333 --> 00:13:29,900
all the destinations
that are out there?

326
00:13:29,900 --> 00:13:32,500
And this is kind of a short list
of those kind of things.

327
00:13:32,500 --> 00:13:34,533
But all that
is public information

328
00:13:34,533 --> 00:13:37,100
and posted, actually, on all
three of the assessment groups.

329
00:13:37,100 --> 00:13:40,233
And we're constantly
revisiting that data as we get

330
00:13:40,233 --> 00:13:43,800
and close actual strategic
knowledge gaps as well.

331
00:13:43,800 --> 00:13:46,033
With industry,
I talked about the involvement

332

00:13:46,033 --> 00:13:47,366
of commercial industry.

333
00:13:47,366 --> 00:13:48,800
One of the things
that NASA's been doing

334
00:13:48,800 --> 00:13:50,900
a lot lately
is running a whole series

335
00:13:50,900 --> 00:13:54,266
of RFIs, BAAs, nontraditional
procurement things

336
00:13:54,266 --> 00:13:56,066
of how do you ask
commercial industry

337
00:13:56,066 --> 00:13:58,066
how they want
to participate with us?

338
00:13:58,066 --> 00:14:00,900
So the most kind of
visual things are things

339
00:14:00,900 --> 00:14:02,966
like commercial cargo
and commercial crew,

340
00:14:02,966 --> 00:14:06,266
and our CASIS organization
working on National Lab.

341
00:14:06,266 --> 00:14:08,166
But then
you see emerging things

342
00:14:08,166 --> 00:14:10,266

like our
Asteroid Redirect Mission BAA,

343
00:14:10,266 --> 00:14:13,333
which was looking in
to optimize our design choices

344
00:14:13,333 --> 00:14:15,500
to maximize
commercial involvement

345
00:14:15,500 --> 00:14:17,600
in the
Asteroid Redirect Mission,

346
00:14:17,600 --> 00:14:19,066
to things like
Lunar CATALYST,

347
00:14:19,066 --> 00:14:22,166
where we're not building
lander capabilities ourselves

348
00:14:22,166 --> 00:14:24,433
but rather helping accelerate
the commercial industry--

349
00:14:24,433 --> 00:14:27,400
commercial industry's ability
to provide

350
00:14:27,400 --> 00:14:28,833
that capability
in the future,

351
00:14:28,833 --> 00:14:31,133
to things that are
farther reaching out

352
00:14:31,133 --> 00:14:33,833

like Mars telecom RFI,
where we're asking

353
00:14:33,833 --> 00:14:35,933
the public sector,
"How would you implement

354
00:14:35,933 --> 00:14:39,200
telecommunication services
commercially from Mars

355
00:14:39,200 --> 00:14:41,800
and along the way to Mars?"

356
00:14:41,800 --> 00:14:44,600
How do we evolve
the ISS?

357
00:14:44,600 --> 00:14:46,400
There's another ongoing
discussion of,

358
00:14:46,400 --> 00:14:47,733
"How do we evolve
from a government owned

359
00:14:47,733 --> 00:14:50,400
and operated space station
to commercially owned

360
00:14:50,400 --> 00:14:52,166
and operated space stations
over time?"

361
00:14:52,166 --> 00:14:53,533
That's an ongoing dialogue

362
00:14:53,533 --> 00:14:55,566
between us
and the commercial sector.

363
00:14:55,566 --> 00:14:57,866
And then lately we've been
moving into things like

364
00:14:57,866 --> 00:15:01,900
additional calls related
to Asteroid Redirect Mission

365
00:15:01,900 --> 00:15:05,033
on follow up with the commercial
strategy for that.

366
00:15:05,033 --> 00:15:07,866
And then most recently
our NextSTEP BAA,

367
00:15:07,866 --> 00:15:11,100
where we asked people
to give us synergies between

368
00:15:11,100 --> 00:15:12,966
advanced propulsion systems
that we want

369
00:15:12,966 --> 00:15:15,233
and commercial industry wants,
habitation systems,

370
00:15:15,233 --> 00:15:19,100
and even the small satellite
industry on that as well.

371
00:15:19,100 --> 00:15:21,400
And I'll actually touch base
on a few of those investments

372
00:15:21,400 --> 00:15:24,800
and selections we made
from that recent announcement.

373
00:15:24,800 --> 00:15:28,166
So if you think about
this big philosophy change

374
00:15:28,166 --> 00:15:30,800
of human spaceflight,
and the whole fact

375
00:15:30,800 --> 00:15:33,000
that you wanna actually analyze
against all those

376
00:15:33,000 --> 00:15:35,400
strategic principles,
we have an activity called

377
00:15:35,400 --> 00:15:37,766
The Evolvable Mars Campaign.

378
00:15:37,766 --> 00:15:40,966
What it is not--
it is not a plan to actually

379
00:15:40,966 --> 00:15:43,366
set out every mission
from here to Mars.

380
00:15:43,366 --> 00:15:45,900
We're not gonna do that
'cause the fact is,

381
00:15:45,900 --> 00:15:48,066
as soon as you publish it,
it will be wrong.

382
00:15:48,066 --> 00:15:50,333
We've done this
in the past.

383
00:15:50,333 --> 00:15:53,633
We call it Design Reference
Architecture 5.0.

384
00:15:53,633 --> 00:15:55,333
When it was written,

385
00:15:55,333 --> 00:15:57,300
we hadn't discovered
water on the moon.

386
00:15:57,300 --> 00:15:59,033
We hadn't discovered
water on Mars.

387
00:15:59,033 --> 00:16:02,466
There's a whole host and
series of other design trades

388
00:16:02,466 --> 00:16:05,300
that were in DRA 5.0,
and as soon as it was published,

389
00:16:05,300 --> 00:16:07,400
scientific and technology
advancement eclipsed

390
00:16:07,400 --> 00:16:08,933
its relevance.

391
00:16:08,933 --> 00:16:11,100
So rather,
what we're using

392
00:16:11,100 --> 00:16:14,333
in the Evolvable Mars Campaign
is a series of trade analyses

393
00:16:14,333 --> 00:16:16,833

to help us make really solid
near-term decisions

394
00:16:16,833 --> 00:16:18,400
in the next, say, five years--

395
00:16:18,400 --> 00:16:19,833
things that we actually
have the budget for--

396
00:16:19,833 --> 00:16:22,666
make the acquisition choices
and how we work with industry

397
00:16:22,666 --> 00:16:25,733
in the next five to ten years,
and actually explore that

398
00:16:25,733 --> 00:16:27,733
with the industrial
and international partners

399
00:16:27,733 --> 00:16:29,166
and get that kinda queued up
as the next things

400
00:16:29,166 --> 00:16:31,266
we need to do,
and then the kind of

401
00:16:31,266 --> 00:16:32,600
ten-year-and-out work.

402
00:16:32,600 --> 00:16:34,533
How do you then make sure
whatever decisions

403
00:16:34,533 --> 00:16:37,633
we're making today,
or in the next five to ten range

404
00:16:37,633 --> 00:16:38,900
with the industry folks--

405
00:16:38,900 --> 00:16:41,500
how do we make sure that
that doesn't get us

406
00:16:41,500 --> 00:16:43,466
to a point that we can't
continue on

407
00:16:43,466 --> 00:16:46,866
in our overall journey to Mars
and this whole pioneering space?

408
00:16:46,866 --> 00:16:48,633
So make sure
we don't have any dead ends

409
00:16:48,633 --> 00:16:50,433
and kinda
follow that through.

410
00:16:50,433 --> 00:16:52,366
So some things that we're
looking at are,

411
00:16:52,366 --> 00:16:54,700
how do you split apart
habitation capabilities?

412
00:16:54,700 --> 00:16:57,433
How do you optimize
for LEO commercialization,

413
00:16:57,433 --> 00:17:00,700
habit exploration, class
habitation at the same time?

414
00:17:00,700 --> 00:17:02,566
Where's the commonality
of those kind of systems?

415
00:17:02,566 --> 00:17:05,666
So split habs versus
large monolithic habs.

416
00:17:05,666 --> 00:17:09,333
Cargo pre-emplacement, so
how do you pre-emplace systems

417
00:17:09,333 --> 00:17:11,733
at Mars instead of having
a whole sequence of missions

418
00:17:11,733 --> 00:17:13,533
kinda clumped up together
that you have to do

419
00:17:13,533 --> 00:17:14,900
all your deployment?

420
00:17:14,900 --> 00:17:17,166
So things like that
we're analyzing.

421
00:17:17,166 --> 00:17:19,133
The Evolvable Mars Campaign
is made up of

422
00:17:19,133 --> 00:17:21,833
a whole series of NASA centers
including here at Ames

423
00:17:21,833 --> 00:17:24,633
and also the various
mission directorates

424

00:17:24,633 --> 00:17:27,600
both on our science side
and our technology side as well,

425
00:17:27,600 --> 00:17:29,766
our international partners
through what I said,

426
00:17:29,766 --> 00:17:31,666
the International Space
Exploration Coordination Group

427
00:17:31,666 --> 00:17:35,100
industry through
all these RFIs and such,

428
00:17:35,100 --> 00:17:37,166
and then strategic knowledge
gaps working with our

429
00:17:37,166 --> 00:17:39,066
assessment groups
and the--and the scientists

430
00:17:39,066 --> 00:17:41,300
and understanding
where we need to answer

431
00:17:41,300 --> 00:17:44,966
some key questions for these
overall architectures as well.

432
00:17:44,966 --> 00:17:48,433
So on the left-hand side
what you see here is

433
00:17:48,433 --> 00:17:49,600
what we've done in the past

434
00:17:49,600 --> 00:17:52,433

and what is continuing
to do--be done.

435
00:17:52,433 --> 00:17:54,366
There's a lot of
architecture studies out there.

436
00:17:54,366 --> 00:17:57,800
Design Reference Architecture
5.0 is one example.

437
00:17:57,800 --> 00:17:59,500
If somebody asks us
how we're gonna get to Mars,

438
00:17:59,500 --> 00:18:02,266
that's one example
of how you get to Mars.

439
00:18:02,266 --> 00:18:05,766
There are a whole host of other
ways to do that as well.

440
00:18:05,766 --> 00:18:08,166
And we have these
design reference architectures,

441
00:18:08,166 --> 00:18:09,266
and we're going to continue
to have them.

442
00:18:09,266 --> 00:18:11,233
Many of you are students
in the group.

443
00:18:11,233 --> 00:18:13,266
Many of your university
senior projects and all that

444
00:18:13,266 --> 00:18:15,900

are also going to be doing
design reference architectures.

445
00:18:15,900 --> 00:18:17,800
These are great.
We should encourage this.

446
00:18:17,800 --> 00:18:19,000
The more the merrier,

447
00:18:19,000 --> 00:18:21,833
looking at the entire
Tradespace of options

448
00:18:21,833 --> 00:18:23,200
that we have out there.

449
00:18:23,200 --> 00:18:26,233
What we then use
is the Evolvable Mars Campaign

450
00:18:26,233 --> 00:18:28,633
to actually analyze
that entire Tradespace

451
00:18:28,633 --> 00:18:30,733
to help us
make concrete decisions

452
00:18:30,733 --> 00:18:33,333
of real missions to fly
in the near-term,

453
00:18:33,333 --> 00:18:35,700
and then do that
overall long-range planning,

454
00:18:35,700 --> 00:18:38,033
not set every single step
from here

455
00:18:38,033 --> 00:18:39,866
for the next 30 years in stone.

456
00:18:39,866 --> 00:18:42,400
So this is
that kinda parallel

457
00:18:42,400 --> 00:18:44,566
of how these work together
and what we have going on.

458
00:18:44,566 --> 00:18:47,200
So I'm going to actually touch
on some of the results

459
00:18:47,200 --> 00:18:48,833
of some of these studies.

460
00:18:48,833 --> 00:18:52,633
So in FY 14,
we were actually catching up

461
00:18:52,633 --> 00:18:55,600
a lot of our knowledge,
related to destinations,

462
00:18:55,600 --> 00:18:57,533
in the Mars vicinity.

463
00:18:57,533 --> 00:19:00,333
So what do ConOps--uh,
concepts of operations

464
00:19:00,333 --> 00:19:01,600
look like at Mars?

465
00:19:01,600 --> 00:19:04,500
Things like even

Phobos operations?

466
00:19:04,500 --> 00:19:06,400
We didn't understand
what that would look like

467
00:19:06,400 --> 00:19:08,400
and hadn't done a lot of work
in that area.

468
00:19:08,400 --> 00:19:10,700
Transportation
and trajectory

469
00:19:10,700 --> 00:19:12,066
staging point analysis.

470
00:19:12,066 --> 00:19:15,166
How do we get to the
lunar distant retrograde orbit

471
00:19:15,166 --> 00:19:17,266
as the staging point
versus LEO,

472
00:19:17,266 --> 00:19:19,433
versus pick
your favorite orbit,

473
00:19:19,433 --> 00:19:21,133
L1 and L2,
all those kinds of things?

474
00:19:21,133 --> 00:19:24,400
How do we get
to where we're at with that?

475
00:19:24,400 --> 00:19:27,000
Looking at habitation
and our overall

476
00:19:27,000 --> 00:19:28,833
Mars habitation strategy.

477
00:19:28,833 --> 00:19:31,200
Looking at the Solar
Electric Propulsion system

478
00:19:31,200 --> 00:19:33,366
that is proposed
for the ARM mission,

479
00:19:33,366 --> 00:19:35,333
and how does
Solar Electric Propulsion

480
00:19:35,333 --> 00:19:38,900
fundamentally change the way
we do cargo pre-emplacement?

481
00:19:38,900 --> 00:19:40,466
Again, this is
another difference.

482
00:19:40,466 --> 00:19:44,066
When DRA 5.0 was written,
we had dreams of maybe

483
00:19:44,066 --> 00:19:45,700
5 kilowatt SEP systems.

484
00:19:45,700 --> 00:19:49,433
They have made
incredible advancements

485
00:19:49,433 --> 00:19:52,700
both within the government
and also within the industry,

486

00:19:52,700 --> 00:19:55,500
and now we can imagine
multi-tens of kilowatt

487
00:19:55,500 --> 00:19:56,800
Solar Electric
Propulsion systems

488
00:19:56,800 --> 00:19:59,900
that we couldn't imagine
back then being ready.

489
00:19:59,900 --> 00:20:02,833
Other things like--
we're building SLS.

490
00:20:02,833 --> 00:20:04,933
Wouldn't it be great
to actually send cargo along

491
00:20:04,933 --> 00:20:06,033
with the crew or have that

492
00:20:06,033 --> 00:20:08,566
excess capacity
of SLS be utilized

493
00:20:08,566 --> 00:20:10,466
to do some of that
cargo pre-emplacement?

494
00:20:10,466 --> 00:20:12,500
So what does
co-manifesting look like?

495
00:20:12,500 --> 00:20:15,733
And those sorts of things.

496
00:20:15,733 --> 00:20:19,000
So all this helps us

actually set up,

497
00:20:19,000 --> 00:20:20,900
what are some of our
proving ground objectives?

498
00:20:20,900 --> 00:20:23,666
What do we need to learn about
in this time period?

499
00:20:23,666 --> 00:20:25,500
What do we need to learn about
in cislunar space

500
00:20:25,500 --> 00:20:26,633
before we're ready to go?

501
00:20:26,633 --> 00:20:28,233
There's a list
of things up here.

502
00:20:28,233 --> 00:20:30,166
I won't read them to you,
but things like

503
00:20:30,166 --> 00:20:32,733
living in deep space
for a long duration,

504
00:20:32,733 --> 00:20:35,566
how to do some of these
semi-autonomous operations

505
00:20:35,566 --> 00:20:36,933
that we may have.
It's a slightly different

506
00:20:36,933 --> 00:20:38,600
operational model
that we have.

507
00:20:38,600 --> 00:20:41,033
Actually conducting EVAs
in deep space.

508
00:20:41,033 --> 00:20:43,466
We haven't done that
in a few--a few years

509
00:20:43,466 --> 00:20:47,366
and actually this whole
large scale robotics systems

510
00:20:47,366 --> 00:20:48,966
and human systems
working together

511
00:20:48,966 --> 00:20:52,033
and how to do
deep space trajectory flight

512
00:20:52,033 --> 00:20:54,533
is another challenge
that we have working on.

513
00:20:54,533 --> 00:20:58,133
People talk about, "Well,
when are we going to Mars?

514
00:20:58,133 --> 00:20:59,966
And where does
going to Mars mean?"

515
00:20:59,966 --> 00:21:03,533
If you notice that the talk,
when the--when the president

516
00:21:03,533 --> 00:21:05,733
announced it, he said,
"Mars vicinity," by the 2030s.

517
00:21:05,733 --> 00:21:07,266
So we get a lot of talk about,

518
00:21:07,266 --> 00:21:09,266
does that mean Mars' surface?
Mars' moons?

519
00:21:09,266 --> 00:21:11,466
Mars' orbit?

520
00:21:11,466 --> 00:21:12,866
Quite frankly,
it doesn't matter

521
00:21:12,866 --> 00:21:14,766
at the stage
that we're at today.

522
00:21:14,766 --> 00:21:16,800
We need to be able to figure out
the way to get

523
00:21:16,800 --> 00:21:19,766
from here to there
into the Mars system.

524
00:21:19,766 --> 00:21:22,700
There's a lot of commonality
that we can work on right now.

525
00:21:22,700 --> 00:21:24,333
And we can--we can
actually put off

526
00:21:24,333 --> 00:21:26,066
the final decision
of where we're going

527

00:21:26,066 --> 00:21:28,000
for some time,
and that's okay.

528
00:21:28,000 --> 00:21:30,800
We can concentrate on

529
00:21:30,800 --> 00:21:32,966
all the commonality
of those type systems.

530
00:21:32,966 --> 00:21:35,966
So, to give you an example,
in long duration habitation,

531
00:21:35,966 --> 00:21:39,633
we've been looking at transit
versus Phobos versus surface

532
00:21:39,633 --> 00:21:42,933
trying to find the common ground
in habitation systems.

533
00:21:42,933 --> 00:21:44,466
Yes, there's gravity
dependent components

534
00:21:44,466 --> 00:21:46,700
in some hab stuff,
but a lot of the components

535
00:21:46,700 --> 00:21:49,400
are actually--there's--
you don't need to

536
00:21:49,400 --> 00:21:50,733
actually figure out
where you wanna go,

537
00:21:50,733 --> 00:21:52,366

that a lot
of the transit systems,

538
00:21:52,366 --> 00:21:53,666
which is what you're
gonna need first,

539
00:21:53,666 --> 00:21:55,533
are actually extensible
to all the other areas.

540
00:21:55,533 --> 00:21:57,933
So how do you concentrate
on the common ground

541
00:21:57,933 --> 00:22:00,133
and then leave the small changes
for the future

542
00:22:00,133 --> 00:22:02,500
that you need to do
to make that change?

543
00:22:02,500 --> 00:22:05,733
So I talked about,
where do we do assembly?

544
00:22:05,733 --> 00:22:09,200
We have people talk about a
lunar distant retrograde orbit.

545
00:22:09,200 --> 00:22:11,766
This is a graphic
to kinda show you visually

546
00:22:11,766 --> 00:22:15,966
what gravity wells really mean
in a relatively simple way.

547
00:22:15,966 --> 00:22:17,933

So you've got Earth there,
at the center

548
00:22:17,933 --> 00:22:19,600
with its gravity well.

549
00:22:19,600 --> 00:22:21,233
You kinda come up
the circles there

550
00:22:21,233 --> 00:22:24,566
and you kinda see where ISS
is sitting in its orbit

551
00:22:24,566 --> 00:22:27,933
and you see the GEO belt
out there near L3

552
00:22:27,933 --> 00:22:31,100
and you kinda see
their relative gravity wells.

553
00:22:31,100 --> 00:22:33,866
You see moon out there.
You see the Lagrange Points.

554
00:22:33,866 --> 00:22:36,533
And you see the--
in yellow,

555
00:22:36,533 --> 00:22:38,566
the lunar distant
retrograde orbit.

556
00:22:38,566 --> 00:22:41,500
It's not "a" orbit.
It's a whole family of orbits.

557
00:22:41,500 --> 00:22:42,500
It's 70,000 kilometers,

558
00:22:42,500 --> 00:22:44,700
plus-or-minus
20 kilometers-ish

559
00:22:44,700 --> 00:22:46,933
and it's relatively stable.

560
00:22:46,933 --> 00:22:48,733
We actually
hadn't studied that orbit

561
00:22:48,733 --> 00:22:50,433
in a long period of time,
until, actually,

562
00:22:50,433 --> 00:22:51,933
the ARM mission came along.

563
00:22:51,933 --> 00:22:54,033
We were looking at a place
to park the asteroid

564
00:22:54,033 --> 00:22:56,133
that would take
very little Delta-v

565
00:22:56,133 --> 00:22:58,200
to keep it there,
and we went back to a lot of

566
00:22:58,200 --> 00:23:01,000
the trajectory analysis
we had done

567
00:23:01,000 --> 00:23:04,233
and went back
and rediscovered LDROs.

568

00:23:04,233 --> 00:23:05,666
It's a good staging point

569
00:23:05,666 --> 00:23:08,233
and what we found now is
actually staging out of an LDRO,

570
00:23:08,233 --> 00:23:09,800
because it takes
very little energy

571
00:23:09,800 --> 00:23:11,033
to keep something there.

572
00:23:11,033 --> 00:23:14,433
Again, that 70,000 mile--
70,000 kilometers--

573
00:23:14,433 --> 00:23:18,033
plus-or-minus 20,000 kilometers,

574
00:23:18,033 --> 00:23:19,566
it will stay there
for 80 years

575
00:23:19,566 --> 00:23:21,933
with no energy input.

576
00:23:21,933 --> 00:23:23,633
That's really great when
you're assembling something

577
00:23:23,633 --> 00:23:26,733
you wanna send
somewhere else.

578
00:23:26,733 --> 00:23:29,966
So this whole discussion about
Lagrange points versus LDRO

579
00:23:29,966 --> 00:23:32,200
and all that,
quite frankly it's kinda moot

580
00:23:32,200 --> 00:23:36,433
because physics kinda
tell us where we park things.

581
00:23:36,433 --> 00:23:38,900
And you see
the intersection of LDROs

582
00:23:38,900 --> 00:23:41,300
transferred from that
to L1, L2.

583
00:23:41,300 --> 00:23:43,966
These are all very minor
amounts of energy to do that.

584
00:23:43,966 --> 00:23:47,500
So we--we can agree
on a common area

585
00:23:47,500 --> 00:23:48,766
where we do assembly,

586
00:23:48,766 --> 00:23:51,466
and kind of move on
to the next decisions.

587
00:23:51,466 --> 00:23:54,333
At the same thing
on the Mars system,

588
00:23:54,333 --> 00:23:56,500
we don't know where
to do staging out of.

589

00:23:56,500 --> 00:23:58,966
And we've been doing a lot
of trajectory analysis for Mars.

590
00:23:58,966 --> 00:24:02,966
So what you see here is Mars'
equivalent gravity well,

591
00:24:02,966 --> 00:24:04,366
and you see Phobos and Deimos.

592
00:24:04,366 --> 00:24:07,533
What you also notice
is Phobos and Deimos

593
00:24:07,533 --> 00:24:08,966
almost have no effect.

594
00:24:08,966 --> 00:24:10,400
They're kinda little blips
on the r--

595
00:24:10,400 --> 00:24:12,666
in the Mars gravity forces.

596
00:24:12,666 --> 00:24:15,366
And in fact, any kind of
missions to Phobos or Deimos

597
00:24:15,366 --> 00:24:18,166
are actually more impacted
by the gravity of Mars

598
00:24:18,166 --> 00:24:20,433
than they are
by their own self, but how--

599
00:24:20,433 --> 00:24:21,600
where to stage things out?

600
00:24:21,600 --> 00:24:22,866
So you get
different approaches.

601
00:24:22,866 --> 00:24:25,533
Hyperbolic approach
and departure in the green line

602
00:24:25,533 --> 00:24:27,400
is one thing
that you could do.

603
00:24:27,400 --> 00:24:30,166
You also have
1-sol and 5-sol orbits,

604
00:24:30,166 --> 00:24:32,733
and these are a
function of what kind

605
00:24:32,733 --> 00:24:35,166
of in-space propulsion system
do you use.

606
00:24:35,166 --> 00:24:36,733
Do you use
a multi-stage approach,

607
00:24:36,733 --> 00:24:39,733
where you bring
multiple chemical stages,

608
00:24:39,733 --> 00:24:42,333
and/or multiple chemical
and SEP stages?

609
00:24:42,333 --> 00:24:45,600
And you could easily
get into kind of a 1-sol orbit

610
00:24:45,600 --> 00:24:48,733
with that kind of--
that kind of architecture.

611
00:24:48,733 --> 00:24:51,200
Or do you do a hybrid stage
where you actually combine

612
00:24:51,200 --> 00:24:54,266
the best of chemical and SEP
into a single stage

613
00:24:54,266 --> 00:24:57,400
in say a LOX methane
SEP stage?

614
00:24:57,400 --> 00:25:00,433
Then you can get into
something like a 5-sol orbit

615
00:25:00,433 --> 00:25:01,800
relatively easy.

616
00:25:01,800 --> 00:25:03,633
And then you're looking at 5--
5 sol orbits

617
00:25:03,633 --> 00:25:04,866
as your staging point.

618
00:25:04,866 --> 00:25:07,166
We haven't decided where
we stage at at Mars,

619
00:25:07,166 --> 00:25:09,333
but this is the type
of analysis that's going on

620
00:25:09,333 --> 00:25:12,333

by all the teams
internally and externally.

621
00:25:12,333 --> 00:25:14,900
So when we talked about
co-manifesting

622
00:25:14,900 --> 00:25:18,100
to give you a perspective
of what that looks like,

623
00:25:18,100 --> 00:25:19,700
we have
an expiration upper stage

624
00:25:19,700 --> 00:25:21,366
that's gonna be added to SLS.

625
00:25:21,366 --> 00:25:24,833
That increases
its overall launch capacity.

626
00:25:24,833 --> 00:25:27,366
We don't need that, obviously,
to throw just "Orion,"

627
00:25:27,366 --> 00:25:29,300
but we wanna be able
to put cargo with it.

628
00:25:29,300 --> 00:25:32,100
So here's a couple variants
of kind of

629
00:25:32,100 --> 00:25:34,466
what the fairings look like in
these different configurations.

630
00:25:34,466 --> 00:25:37,800
One of them's with Orion

with a habitation module

631
00:25:37,800 --> 00:25:39,533
sitting up underneath it.

632
00:25:39,533 --> 00:25:42,933
One's another with
a robotic lunar lander,

633
00:25:42,933 --> 00:25:45,666
say, and a short duration
hab module grouped together

634
00:25:45,666 --> 00:25:47,133
that could also fit in there.

635
00:25:47,133 --> 00:25:48,366
And they got a couple
blunt nose kind of

636
00:25:48,366 --> 00:25:49,500
fairing configurations.

637
00:25:49,500 --> 00:25:51,266
This is what it would look like
if you have

638
00:25:51,266 --> 00:25:53,833
a scientific mission going out
to an outer planet

639
00:25:53,833 --> 00:25:56,533
or something like
in the ARM mission as well.

640
00:25:56,533 --> 00:25:57,833
And then we're doing
further analysis

641

00:25:57,833 --> 00:26:00,900
on fairing optimization
for long duration,

642
00:26:00,900 --> 00:26:02,500
for things like
large telescopes

643
00:26:02,500 --> 00:26:04,400
and the habitation systems
we need for Mars,

644
00:26:04,400 --> 00:26:06,900
and trying to figure out,
"Is it an 8 meter, 10 meter?"

645
00:26:06,900 --> 00:26:09,533
Again, try to drive commonality
to get some cost

646
00:26:09,533 --> 00:26:11,100
out of the system
to figure that out.

647
00:26:11,100 --> 00:26:13,866
But you can imagine
that if you flew Orion

648
00:26:13,866 --> 00:26:15,766
with a habitation system
like this one here,

649
00:26:15,766 --> 00:26:19,866
over three to four launches
of this kind of configuration,

650
00:26:19,866 --> 00:26:22,666
you can aggregate the volume
you need for habitation

651

00:26:22,666 --> 00:26:24,533
for a transit to Mars

652
00:26:24,533 --> 00:26:26,533
in that kind of
launch configuration,

653
00:26:26,533 --> 00:26:28,000
where you don't have
a dedicated launch

654
00:26:28,000 --> 00:26:29,433
that's separate
just for a hab,

655
00:26:29,433 --> 00:26:30,833
but rather,
you aggregate it over time.

656
00:26:30,833 --> 00:26:33,600
So things like that
are being looked at.

657
00:26:33,600 --> 00:26:35,800
To give you
perspective on solar array

658
00:26:35,800 --> 00:26:39,100
and Solar Electric Propulsion,
ARM is kinda

659
00:26:39,100 --> 00:26:40,766
in the middle
of its class.

660
00:26:40,766 --> 00:26:42,166
"Deep Space 1" and "Dawn"
are over there

661
00:26:42,166 --> 00:26:43,633

as things that we've done
in the past

662
00:26:43,633 --> 00:26:45,066
and where ARM's gonna get us.

663
00:26:45,066 --> 00:26:47,266
And then what we need for
Solar Electric Propulsion

664
00:26:47,266 --> 00:26:51,166
for cargo and that hybrid stage
for Mars Crew.

665
00:26:51,166 --> 00:26:53,100
That's the power levels
that we're looking at

666
00:26:53,100 --> 00:26:54,666
that we need
for those class missions.

667
00:26:54,666 --> 00:26:56,366
Another simple way
to look at it,

668
00:26:56,366 --> 00:26:58,800
if you look at a comparison
with space shuttle main engine.

669
00:26:58,800 --> 00:26:59,900
There are three of those.

670
00:26:59,900 --> 00:27:02,566
First is a
300 kilowatt SEP system.

671
00:27:02,566 --> 00:27:06,266
There's Isp and thrust
up here that you have.

672
00:27:06,266 --> 00:27:09,800
If you have time on your side
the burn time there--

673
00:27:09,800 --> 00:27:11,833
if you have time in order
for the transit,

674
00:27:11,833 --> 00:27:13,533
and you can actually use that
as your dial.

675
00:27:13,533 --> 00:27:16,233
You can actually get
the equivalent energy

676
00:27:16,233 --> 00:27:19,733
out of--out of that kind
of propulsion system

677
00:27:19,733 --> 00:27:22,000
as you would out of a
traditional chemical system,

678
00:27:22,000 --> 00:27:25,200
at a--at a fraction
of the propellant mass.

679
00:27:25,200 --> 00:27:28,033
So this is, in a very simple
term, is what it means.

680
00:27:28,033 --> 00:27:30,766
So the equivalent
of 32,000 kilograms

681
00:27:30,766 --> 00:27:33,666
of launched mass
will get us the same amount

682
00:27:33,666 --> 00:27:36,133
of total energy
if we have time

683
00:27:36,133 --> 00:27:37,866
to do the pre-emplacement
of the cargo.

684
00:27:37,866 --> 00:27:39,833
So this is where some of that

685
00:27:39,833 --> 00:27:44,366
comes into some of our
design analysis.

686
00:27:44,366 --> 00:27:47,333
So we--we do this EMC not as a
whole series of decisions,

687
00:27:47,333 --> 00:27:49,866
but rather a series of questions
that are kinda asked every year.

688
00:27:49,866 --> 00:27:51,733
And the questions that are
going through this year

689
00:27:51,733 --> 00:27:53,633
are things like,
"How do we do this

690
00:27:53,633 --> 00:27:55,533
overall pioneering
kind of approach?"

691
00:27:55,533 --> 00:27:57,233
And in ISRU,
"What is the role

692
00:27:57,233 --> 00:28:00,700
of in-situ resource utilization
on our overall architecture?"

693
00:28:00,700 --> 00:28:02,033
That's one of the pieces
we're looking at.

694
00:28:02,033 --> 00:28:04,800
What are the objectives,
engineering, and operational

695
00:28:04,800 --> 00:28:06,666
considerations
for a landing site?

696
00:28:06,666 --> 00:28:08,466
And, in fact, we have
a landing site activity

697
00:28:08,466 --> 00:28:10,366
that I'll talk about
going on.

698
00:28:10,366 --> 00:28:11,566
There's a whole other
sequence here.

699
00:28:11,566 --> 00:28:13,500
We talked about
the asteroid redirect vehicle

700
00:28:13,500 --> 00:28:15,566
and pre-emplacement of cargo,
and I'll show you that,

701
00:28:15,566 --> 00:28:17,400
how it scales up.

702

00:28:17,400 --> 00:28:20,133
And then, "How do we look at
commonality of habitation

703
00:28:20,133 --> 00:28:22,433
systems for short-duration hab?"
is another one.

704
00:28:22,433 --> 00:28:25,566
So if you think about coming off
the surface of Mars,

705
00:28:25,566 --> 00:28:28,766
versus a Mars-vicinity taxi,
if you're in that 5-sol orbit,

706
00:28:28,766 --> 00:28:30,300
how do you go
from a 5-sol orbit

707
00:28:30,300 --> 00:28:31,833
to actually going
to the surface?

708
00:28:31,833 --> 00:28:34,933
Those may be short-duration
habitation systems.

709
00:28:34,933 --> 00:28:37,366
So even our initial exploration
hab that we would need

710
00:28:37,366 --> 00:28:40,200
in deep space, where is
the commonality of that.

711
00:28:40,200 --> 00:28:41,333
And we're doing a lot
of commonality

712

00:28:41,333 --> 00:28:45,300
and modularity studies
as well.

713
00:28:45,300 --> 00:28:47,633
So there's a whole series
of questions we have going on

714
00:28:47,633 --> 00:28:50,033
and I'll touch on the ones
I just highlighted.

715
00:28:50,033 --> 00:28:51,500
In-situ resource utilization.

716
00:28:51,500 --> 00:28:54,433
How do we go from
what our baseline assumption,

717
00:28:54,433 --> 00:28:57,900
which was creating an oxidizer
from the atmosphere of Mars,

718
00:28:57,900 --> 00:29:01,066
to now knowing that there's
robust water sources on Mars

719
00:29:01,066 --> 00:29:03,566
and other bodies
like asteroids and the moon?

720
00:29:03,566 --> 00:29:05,200
And how do those actually
play into

721
00:29:05,200 --> 00:29:07,233
the logistics challenge
that we have?

722
00:29:07,233 --> 00:29:09,333

And how do we build that up
over time

723
00:29:09,333 --> 00:29:12,966
to be our sources of consumables
and propellants

724
00:29:12,966 --> 00:29:14,866
that we need
for overall architectures?

725
00:29:14,866 --> 00:29:16,833
And that's one of the key things
that we're looking at.

726
00:29:16,833 --> 00:29:18,766
Things like our
Resource Prospector Mission

727
00:29:18,766 --> 00:29:20,866
that's in formulation right now

728
00:29:20,866 --> 00:29:22,966
is a key measurement
that we're looking at.

729
00:29:22,966 --> 00:29:25,933
We know water exists
with pretty high confidence,

730
00:29:25,933 --> 00:29:27,466
but we don't know
how it's bound,

731
00:29:27,466 --> 00:29:30,133
we don't know its distribution
and all that on the surface,

732
00:29:30,133 --> 00:29:32,266
but how do we understand

that better

733
00:29:32,266 --> 00:29:35,433
so then we can start counting
on it for our architectures?

734
00:29:35,433 --> 00:29:36,766
Site selection.

735
00:29:36,766 --> 00:29:38,500
We're actually working with,
between us

736
00:29:38,500 --> 00:29:40,000
and our science mission
directorate colleagues,

737
00:29:40,000 --> 00:29:42,666
on actually determining which
sites are the most likely ones

738
00:29:42,666 --> 00:29:45,566
that we want to send humans to.

739
00:29:45,566 --> 00:29:47,466
So over the course
of this next year,

740
00:29:47,466 --> 00:29:49,133
we're gonna have a whole series
of workshops

741
00:29:49,133 --> 00:29:51,533
and public engagements
to actually determine

742
00:29:51,533 --> 00:29:54,266
which are
the high likelihood sites

743
00:29:54,266 --> 00:29:58,266
and downselect the sites that we
would want to actually target

744
00:29:58,266 --> 00:30:00,166
for every future science mission
going to Mars

745
00:30:00,166 --> 00:30:01,866
as our areas of interest
where we'll get

746
00:30:01,866 --> 00:30:04,400
the high resolution imagery,
get all the data that we want

747
00:30:04,400 --> 00:30:06,433
from a civil engineering
perspective

748
00:30:06,433 --> 00:30:08,466
along with
a scientific perspective

749
00:30:08,466 --> 00:30:11,733
to actually do that
pre-emplacement over time.

750
00:30:11,733 --> 00:30:14,066
But it's really key
that we narrow down

751
00:30:14,066 --> 00:30:16,833
where we're looking at Mars now
in order to concentrate

752
00:30:16,833 --> 00:30:20,166
our scientific assets
on that capability.

753
00:30:20,166 --> 00:30:22,300
So to show you a little bit
of how things scale up

754
00:30:22,300 --> 00:30:24,166
on the Solar Electric
Propulsion--

755
00:30:24,166 --> 00:30:26,100
on the left-hand side
is the size

756
00:30:26,100 --> 00:30:28,733
of the Solar Electric Propulsion
bus as it's currently

757
00:30:28,733 --> 00:30:31,566
being thought about
for the ARM mission.

758
00:30:31,566 --> 00:30:34,700
It's 50 kilowatts, 40-kilowatt
electric propulsion system,

759
00:30:34,700 --> 00:30:36,300
and then 10 tons of xenon.

760
00:30:36,300 --> 00:30:38,033
If you were to take that
and scale it up

761
00:30:38,033 --> 00:30:43,033
to a multi-stage approach where
you have a full chemical stage

762
00:30:43,033 --> 00:30:45,866
and you have a full Solar
Electric Propulsion stage.

763

00:30:45,866 --> 00:30:48,400
That Solar Electric Propulsion
stage would look like

764
00:30:48,400 --> 00:30:50,800
190-kilowatt solar arrays,

765
00:30:50,800 --> 00:30:53,333
150-kilowatt electric
propulsion system,

766
00:30:53,333 --> 00:30:55,400
and 16 tons of xenon.

767
00:30:55,400 --> 00:30:57,233
Now, instead of having
two stages,

768
00:30:57,233 --> 00:30:58,633
which is two development
efforts,

769
00:30:58,633 --> 00:31:01,533
how do you put those together
into like a hybrid stage?

770
00:31:01,533 --> 00:31:02,900
What does that look like?

771
00:31:02,900 --> 00:31:04,566
And then what does
its packaging look like?

772
00:31:04,566 --> 00:31:06,700
And how would
it be launched into space?

773
00:31:06,700 --> 00:31:08,600
And those are the specs
for the hybrid stage,

774
00:31:08,600 --> 00:31:09,900
and there's two concepts there.

775
00:31:09,900 --> 00:31:12,466
You can literally take
two of the ARM type buses

776
00:31:12,466 --> 00:31:15,400
and put them together
underneath a chemical stage,

777
00:31:15,400 --> 00:31:17,333
and you can get
a packing efficiency

778
00:31:17,333 --> 00:31:20,100
that fits in a 10-meter fairing
on an SLS.

779
00:31:20,100 --> 00:31:22,900
Or you could actually
repackage it

780
00:31:22,900 --> 00:31:24,766
and get a little more elegant
in the engineering

781
00:31:24,766 --> 00:31:28,400
and you can get down 8.4 meters
in a fairing size.

782
00:31:28,400 --> 00:31:32,300
So these are the trades that
we're actually doing with us

783
00:31:32,300 --> 00:31:34,900
and even industry right now
to figure out what that is--

784
00:31:34,900 --> 00:31:38,600
what does that in-space
propulsion stage look like?

785
00:31:38,600 --> 00:31:40,966
All this, though,
for in-space propulsion,

786
00:31:40,966 --> 00:31:43,700
landing site analysis,
all this comes together

787
00:31:43,700 --> 00:31:46,000
in figuring out,
how do we actually land?

788
00:31:46,000 --> 00:31:48,133
And you always hear the number--
we want to land

789
00:31:48,133 --> 00:31:51,166
40 metric tons on the surface
of Mars.

790
00:31:51,166 --> 00:31:53,000
Well, how do you get
the 40 metric tons?

791
00:31:53,000 --> 00:31:57,433
Well, it happens to be
we took the largest indivisible

792
00:31:57,433 --> 00:32:02,000
payload unit and--
which happens to be

793
00:32:02,000 --> 00:32:03,866
your ascent vehicle to get home.

794

00:32:03,866 --> 00:32:05,966
That's not something
you want to DIY

795
00:32:05,966 --> 00:32:08,400
on the surface of Mars
to get back home.

796
00:32:08,400 --> 00:32:11,300
Crew kind of frowns on that.

797
00:32:11,300 --> 00:32:14,200
If you take that
and with all the propellant

798
00:32:14,200 --> 00:32:18,266
that you need in it and such,
it's about 35.5 tons,

799
00:32:18,266 --> 00:32:21,733
and that's where
that 40-ton number came from.

800
00:32:21,733 --> 00:32:23,200
You combine that
with the payload elements

801
00:32:23,200 --> 00:32:25,233
and the crew,
you get to this 40-ton chunk

802
00:32:25,233 --> 00:32:27,133
that needs to get down
to the surface.

803
00:32:27,133 --> 00:32:29,966
But if you think about
in-situ resource utilization--

804
00:32:29,966 --> 00:32:34,000

either your LOX, just the LOX
side or your methane side,

805
00:32:34,000 --> 00:32:35,700
you can then get savings.

806
00:32:35,700 --> 00:32:38,600
So one of those things
is if you have an ISRU plant

807
00:32:38,600 --> 00:32:41,900
just for LOX only,
you can save yourself

808
00:32:41,900 --> 00:32:43,600
a significant amount of mass.

809
00:32:43,600 --> 00:32:47,100
So if your LOX is 19.2 tons
but it only takes you

810
00:32:47,100 --> 00:32:49,800
10 tons of plant
to produce that,

811
00:32:49,800 --> 00:32:52,133
now you can save yourself
9 tons of mass

812
00:32:52,133 --> 00:32:54,000
right there in a landed
kind of increment.

813
00:32:54,000 --> 00:32:55,733
And then you get down
to landers

814
00:32:55,733 --> 00:33:00,933
that are in the 27-ton
to 18-ton category.

815
00:33:00,933 --> 00:33:06,133
If we're also producing methane
from Mars once we get there,

816
00:33:06,133 --> 00:33:08,766
that will be
a further reduction,

817
00:33:08,766 --> 00:33:10,000
and that's actually one
of the pieces

818
00:33:10,000 --> 00:33:13,133
that folks are studying now
as well.

819
00:33:13,133 --> 00:33:15,633
The other part is, like,
surface propellant transfer.

820
00:33:15,633 --> 00:33:17,100
Could we just bring
propellant tanks

821
00:33:17,100 --> 00:33:18,700
and do transfers?

822
00:33:18,700 --> 00:33:20,100
And that's another strategy.

823
00:33:20,100 --> 00:33:22,166
And you can get down
to 15 tons or 18 tons

824
00:33:22,166 --> 00:33:23,433
in that scenario.

825
00:33:23,433 --> 00:33:27,133

So when people talk about,
"What size of things

826
00:33:27,133 --> 00:33:28,666
do you want to land
on the surface?"

827
00:33:28,666 --> 00:33:31,033
you have to do your homework
and analyze

828
00:33:31,033 --> 00:33:32,700
your launch capacity,
your fairings,

829
00:33:32,700 --> 00:33:34,833
your in-space propulsion stages,

830
00:33:34,833 --> 00:33:36,666
this in-situ resource
utilization.

831
00:33:36,666 --> 00:33:39,500
So what the Evolvable Mars
Campaign teams

832
00:33:39,500 --> 00:33:41,500
both internally
and externally do--

833
00:33:41,500 --> 00:33:44,033
look through
the entire trade set,

834
00:33:44,033 --> 00:33:46,200
all these architectures that
other people are publishing

835
00:33:46,200 --> 00:33:48,833
to find new ideas,

and then run through

836
00:33:48,833 --> 00:33:51,700
a lot of this trade analysis
that we have.

837
00:33:51,700 --> 00:33:53,100
At the same time,
we're looking at

838
00:33:53,100 --> 00:33:55,266
commonality
of habitation systems.

839
00:33:55,266 --> 00:33:57,033
So you have two kinds of habs--

840
00:33:57,033 --> 00:33:58,766
things that you need to live
for a short time,

841
00:33:58,766 --> 00:34:00,766
things that you want
to live in for a long time.

842
00:34:00,766 --> 00:34:02,733
And you can look at--
how do you get

843
00:34:02,733 --> 00:34:04,633
and drive common elements?

844
00:34:04,633 --> 00:34:06,500
So if you think
about an initial hab

845
00:34:06,500 --> 00:34:08,500
to allow you to live
30 to 60 days

846
00:34:08,500 --> 00:34:10,766
with an LDRO
combined with Orion,

847
00:34:10,766 --> 00:34:11,966
you might be able
to fit something like that

848
00:34:11,966 --> 00:34:14,533
in the SLS
co-manifested space.

849
00:34:14,533 --> 00:34:17,533
But that kind of habitable unit
could also be the basis

850
00:34:17,533 --> 00:34:19,166
of your logistics carrier.

851
00:34:19,166 --> 00:34:21,400
It could be the basis
of your pressurized volume

852
00:34:21,400 --> 00:34:25,000
for a taxi to go out of that
5-sol orbit to Phobos

853
00:34:25,000 --> 00:34:27,200
and do visits there.

854
00:34:27,200 --> 00:34:28,566
It could be
the same pressurized volume

855
00:34:28,566 --> 00:34:30,233
that you have
on a surface mobility unit

856
00:34:30,233 --> 00:34:33,000

once you get to Phobos
or the surface of Mars.

857
00:34:33,000 --> 00:34:34,600
And it could be
the same pressurized volume

858
00:34:34,600 --> 00:34:36,500
that you need
for your ascent vehicle.

859
00:34:36,500 --> 00:34:40,166
So where is that kind
of commonality approach there?

860
00:34:40,166 --> 00:34:42,800
The other side
is long-duration hab.

861
00:34:42,800 --> 00:34:44,833
So if we just think about
a very large hab

862
00:34:44,833 --> 00:34:48,100
that can actually support
500 days on the surface of Mars

863
00:34:48,100 --> 00:34:51,133
or a transit to Phobos
or just your in-space transit

864
00:34:51,133 --> 00:34:54,033
that you need,
where is a commonality

865
00:34:54,033 --> 00:34:55,633
from that perspective?

866
00:34:55,633 --> 00:34:58,133
Now, you don't have to pick

one or the other.

867
00:34:58,133 --> 00:35:01,766
You can look at it from a
modularity perspective as well.

868
00:35:01,766 --> 00:35:04,366
So you can look at it from--
do you build something up

869
00:35:04,366 --> 00:35:05,466
that's out of that large element

870
00:35:05,466 --> 00:35:07,000
that then follows
all the way through?

871
00:35:07,000 --> 00:35:09,000
But then you have to design this
very large habitation

872
00:35:09,000 --> 00:35:10,600
from day one.

873
00:35:10,600 --> 00:35:12,966
Or do you want to incrementally
build it up over time?

874
00:35:12,966 --> 00:35:16,333
But then you go back
to that landed mass chunk.

875
00:35:16,333 --> 00:35:17,900
Do you want to aggregate
your hab

876
00:35:17,900 --> 00:35:19,333
on the surface of Mars or not?

877

00:35:19,333 --> 00:35:23,833
So these are the types of trades
that are ongoing out there.

878
00:35:23,833 --> 00:35:27,433
So we bring back--
it's not just NASA.

879
00:35:27,433 --> 00:35:28,966
We talk about this ecosystem.

880
00:35:28,966 --> 00:35:30,200
It's more than just NASA.

881
00:35:30,200 --> 00:35:31,933
It's not just NASA
and its contractors.

882
00:35:31,933 --> 00:35:33,433
There's an entire
industrial base

883
00:35:33,433 --> 00:35:35,100
of the space economy out there.

884
00:35:35,100 --> 00:35:36,400
So how do we engage them?

885
00:35:36,400 --> 00:35:38,466
And I talked about these
commercial strategies

886
00:35:38,466 --> 00:35:40,666
and engagement strategies
that we have with them.

887
00:35:40,666 --> 00:35:42,900
We have--the most recent
announcement

888
00:35:42,900 --> 00:35:44,966
was our NextSTEP BAA.

889
00:35:44,966 --> 00:35:46,633
It's a broad
agency announcement.

890
00:35:46,633 --> 00:35:49,633
It's a way to engage
in funding mechanisms

891
00:35:49,633 --> 00:35:52,233
with the external sector
that we don't define

892
00:35:52,233 --> 00:35:53,866
set requirements.

893
00:35:53,866 --> 00:35:55,400
Like you'd normally do
a requirements definition

894
00:35:55,400 --> 00:35:57,966
but you'd rather just set
performance goals

895
00:35:57,966 --> 00:36:01,000
or objectives and you don't tell
people how to do it.

896
00:36:01,000 --> 00:36:05,066
So we asked the commercial
sector in academics and industry

897
00:36:05,066 --> 00:36:07,466
as a whole,
how would they approach

898
00:36:07,466 --> 00:36:09,433

advanced propulsion systems?

899
00:36:09,433 --> 00:36:12,100
So how do we do some of these
larger thrusters that we want?

900
00:36:12,100 --> 00:36:13,866
How would they
approach habitation,

901
00:36:13,866 --> 00:36:16,333
including the life-support
elements that we have?

902
00:36:16,333 --> 00:36:18,800
And then because we also have
a large number

903
00:36:18,800 --> 00:36:20,500
of strategic knowledge gaps
that we need to know

904
00:36:20,500 --> 00:36:23,700
about destinations,
there is also this whole surge

905
00:36:23,700 --> 00:36:25,400
of small satellites occurring.

906
00:36:25,400 --> 00:36:27,333
So how do we leverage
that advancement

907
00:36:27,333 --> 00:36:29,900
in small satellite technology
that they can leverage here

908
00:36:29,900 --> 00:36:31,833
in LEO and GEO
and then we can use it

909
00:36:31,833 --> 00:36:34,000
to send missions out
into deep space

910
00:36:34,000 --> 00:36:35,633
using CubeSats and such.

911
00:36:35,633 --> 00:36:38,800
So we put out a call,
and what was unique about this

912
00:36:38,800 --> 00:36:41,933
is these were
fixed price contracts.

913
00:36:41,933 --> 00:36:45,900
We actually required them
to put their own money,

914
00:36:45,900 --> 00:36:48,600
their own skin in the game
at half the price

915
00:36:48,600 --> 00:36:50,766
of what they were asking us
to pay for.

916
00:36:50,766 --> 00:36:53,766
So these weren't just your idle,
standby folks.

917
00:36:53,766 --> 00:36:56,733
They were actually putting just
as much money in it as NASA was.

918
00:36:56,733 --> 00:36:59,133
And we got a very,
very robust response.

919
00:36:59,133 --> 00:37:01,266
We ended up selecting
a couple CubeSat missions.

920
00:37:01,266 --> 00:37:04,700
These are 6U CubeSats
that will also fly on EM-1,

921
00:37:04,700 --> 00:37:06,466
along with the ones that we're
building here at NASA,

922
00:37:06,466 --> 00:37:09,300
including BioSentinel
that's being built here at Ames.

923
00:37:09,300 --> 00:37:11,466
One's by Morehead State
University

924
00:37:11,466 --> 00:37:14,366
in partnership with Busek
for their propulsion system,

925
00:37:14,366 --> 00:37:16,200
and another one
is Lockheed Martin,

926
00:37:16,200 --> 00:37:18,433
which has a whole cadre
of technologies

927
00:37:18,433 --> 00:37:19,800
that they're advancing.

928
00:37:19,800 --> 00:37:22,166
These are gonna help us get some
of the measurements

929

00:37:22,166 --> 00:37:24,566
that we need about resources,

930
00:37:24,566 --> 00:37:27,533
and lunar resources specifically
in this case,

931
00:37:27,533 --> 00:37:31,366
as they do and conduct
their missions.

932
00:37:31,366 --> 00:37:34,966
On the propulsion side,
we had three different companies

933
00:37:34,966 --> 00:37:37,433
we selected.
So I've talked about ARM.

934
00:37:37,433 --> 00:37:39,800
We talk about 10-kilowatt
per thruster

935
00:37:39,800 --> 00:37:44,000
kind of is what the performance
is of the ARM-class SEP system.

936
00:37:44,000 --> 00:37:46,733
I talked about scaling up
to 300 kilowatts.

937
00:37:46,733 --> 00:37:48,966
Well, you can do that
by just ganging together

938
00:37:48,966 --> 00:37:52,200
a whole 10-kilowatt
and have 30 of those

939
00:37:52,200 --> 00:37:53,933

on the back end
of your spacecraft,

940
00:37:53,933 --> 00:37:57,666
or you could go to larger scale
single thrusters.

941
00:37:57,666 --> 00:38:00,233
We believe there is probably an
optimization that at some point

942
00:38:00,233 --> 00:38:01,933
we want these
larger scale thrusters

943
00:38:01,933 --> 00:38:04,366
in the 50- to 300-kilowatt
range.

944
00:38:04,366 --> 00:38:06,300
And you notice
the companies here--

945
00:38:06,300 --> 00:38:09,366
Ad Astra, Aerojet, and MSNW--

946
00:38:09,366 --> 00:38:11,966
they've done a lot of work
on their thruster designs

947
00:38:11,966 --> 00:38:14,200
and power management systems
over the past couple years,

948
00:38:14,200 --> 00:38:17,966
but none of them have actually
demonstrated continuous thrust

949
00:38:17,966 --> 00:38:21,100
at a reasonable amount of time

that's useful.

950
00:38:21,100 --> 00:38:24,800
So what these awards were
for were three-year awards.

951
00:38:24,800 --> 00:38:26,500
They have to demonstrate
100 kilowatt

952
00:38:26,500 --> 00:38:28,466
for 100 hours continuous thrust

953
00:38:28,466 --> 00:38:31,400
with full thermal management
and control of their thruster.

954
00:38:31,400 --> 00:38:34,666
This will get 'em at a TRL-6--
5, 6 level--

955
00:38:34,666 --> 00:38:36,766
that is then
in the competition range

956
00:38:36,766 --> 00:38:38,700
for next upcoming
design trades we have.

957
00:38:38,700 --> 00:38:40,833
So how do we--
this is the seed corn

958
00:38:40,833 --> 00:38:42,633
kind of feeding some of that.

959
00:38:42,633 --> 00:38:46,200
And some of these are--
we know Nested Hall Thrusters

960
00:38:46,200 --> 00:38:47,333
have been around for a while.

961
00:38:47,333 --> 00:38:48,800
That's Aerojet's concept.

962
00:38:48,800 --> 00:38:50,233
Plasma thrusters--
Ad Astra's been doing

963
00:38:50,233 --> 00:38:52,833
quite a bit of advancement
with that as well.

964
00:38:52,833 --> 00:38:55,833
Now it's time to actually
not just talk about it

965
00:38:55,833 --> 00:38:57,400
and not do just the engineering,

966
00:38:57,400 --> 00:39:00,066
but actually do the test
and get the data for it.

967
00:39:00,066 --> 00:39:03,033
On the habitation side, we--
I'll split it

968
00:39:03,033 --> 00:39:04,533
into kind of two sections.

969
00:39:04,533 --> 00:39:07,300
We talk about habitation,
the module that you'll live in,

970
00:39:07,300 --> 00:39:09,533
and then the life support
that will keep you alive.

971
00:39:09,533 --> 00:39:11,666
So on the habitation side,
we awarded to Lockheed,

972
00:39:11,666 --> 00:39:13,800
Bigelow, Orbital, and Boeing.

973
00:39:13,800 --> 00:39:15,966
And what we're trying to do
is that commonality,

974
00:39:15,966 --> 00:39:18,166
modularity kind of discussion
I had.

975
00:39:18,166 --> 00:39:20,766
What is that low-Earth orbit
commercial strategy

976
00:39:20,766 --> 00:39:24,033
versus our habitation strategy
we need for deep space?

977
00:39:24,033 --> 00:39:28,433
Where's the Venn diagram overlap
with what industry wants

978
00:39:28,433 --> 00:39:30,366
and is capable of doing?

979
00:39:30,366 --> 00:39:31,833
So we're asking
all four companies

980
00:39:31,833 --> 00:39:33,833
to give us their
independent approaches

981

00:39:33,833 --> 00:39:36,966
to optimizing for what--
meeting our NASA need,

982
00:39:36,966 --> 00:39:39,200
the exploration need,
but at the same time,

983
00:39:39,200 --> 00:39:41,433
maximizing their potential
to use it for other things

984
00:39:41,433 --> 00:39:43,966
like low-Earth orbit
commercialization.

985
00:39:43,966 --> 00:39:45,766
And we're doing this right
from the get-go

986
00:39:45,766 --> 00:39:48,066
instead of kind of
after the fact,

987
00:39:48,066 --> 00:39:49,400
so we're trying to get
that industry participation

988
00:39:49,400 --> 00:39:50,966
from day one.

989
00:39:50,966 --> 00:39:53,133
So these are some of their
graphical mock-ups

990
00:39:53,133 --> 00:39:55,833
of what their ideas look like.

991
00:39:55,833 --> 00:39:58,833
On the life support side,

we did three awards.

992
00:39:58,833 --> 00:40:01,700
Two of 'em are related
to kind of architectures.

993
00:40:01,700 --> 00:40:05,066
"How do you put together
a modular habitation system?"

994
00:40:05,066 --> 00:40:08,366
was the basis of
Hamilton Sundstrand's proposal.

995
00:40:08,366 --> 00:40:09,966
Hamilton's got
a long track record

996
00:40:09,966 --> 00:40:13,266
of building life support systems
for ISS and also Orion,

997
00:40:13,266 --> 00:40:15,700
but they're not modular
in nature.

998
00:40:15,700 --> 00:40:17,933
So how do you actually readdress
the modularity

999
00:40:17,933 --> 00:40:19,766
of life support systems?

1000
00:40:19,766 --> 00:40:22,000
Orbitec.
Very interesting.

1001
00:40:22,000 --> 00:40:24,533
There's a lot of talk
about bio and chemical

1002
00:40:24,533 --> 00:40:25,700
and electrochemical systems

1003
00:40:25,700 --> 00:40:27,100
working together
in life support.

1004
00:40:27,100 --> 00:40:32,000
The last study we had on biology
based life support systems

1005
00:40:32,000 --> 00:40:36,266
was at a time when LED lights
were not invented yet.

1006
00:40:36,266 --> 00:40:39,766
So if you had to keep your
biology alive

1007
00:40:39,766 --> 00:40:41,933
with those heavy,
older ways of doing that,

1008
00:40:41,933 --> 00:40:44,300
it didn't trade well
on our overall architecture.

1009
00:40:44,300 --> 00:40:46,133
So this is a basis
of getting Orbitec

1010
00:40:46,133 --> 00:40:49,366
to actually update our
integrated system analysis

1011
00:40:49,366 --> 00:40:51,000
of what does it really mean
when you say,

1012
00:40:51,000 --> 00:40:54,133
"I'm taking a biology based
life support system"?

1013
00:40:54,133 --> 00:40:56,100
And then Dynetics.

1014
00:40:56,100 --> 00:40:59,366
One of our primary challenges
we have on the space station

1015
00:40:59,366 --> 00:41:01,600
is our CO2 removal.

1016
00:41:01,600 --> 00:41:03,700
It's one of our
most troublesome systems.

1017
00:41:03,700 --> 00:41:06,100
So Dynetics
actually proposed a new way

1018
00:41:06,100 --> 00:41:07,933
that actually separates the CO2

1019
00:41:07,933 --> 00:41:10,733
from the other
undesirable gases.

1020
00:41:10,733 --> 00:41:13,833
And this is--what you see there
is one rack of--

1021
00:41:13,833 --> 00:41:16,300
that would fit in one rack unit
of the space station.

1022
00:41:16,300 --> 00:41:19,100
And the consumables for that

would be on the order

1023
00:41:19,100 --> 00:41:22,733
of something about 6 inches
by 6 inches by 6 inches

1024
00:41:22,733 --> 00:41:25,333
for an entire duration trip
to Mars.

1025
00:41:25,333 --> 00:41:28,833
This is drastically changing
the equation

1026
00:41:28,833 --> 00:41:31,366
on how to remove CO2.

1027
00:41:31,366 --> 00:41:34,266
And that's gonna be really
intriguing to see

1028
00:41:34,266 --> 00:41:35,400
their advancement they make

1029
00:41:35,400 --> 00:41:37,466
over the next couple of years
on that.

1030
00:41:37,466 --> 00:41:40,833
So my whole purpose of today

1031
00:41:40,833 --> 00:41:44,133
is to actually give you
a little more technical detail

1032
00:41:44,133 --> 00:41:45,800
behind what our real planning
that's going on

1033

00:41:45,800 --> 00:41:48,600
in human spaceflight and
actually to draw your attention

1034
00:41:48,600 --> 00:41:51,933
away from the squiggly lines
up there at the top

1035
00:41:51,933 --> 00:41:54,233
and actually think about
the bottom part.

1036
00:41:54,233 --> 00:41:56,333
What does it really mean
to go from Earth Reliant

1037
00:41:56,333 --> 00:41:57,833
to Earth Independent?

1038
00:41:57,833 --> 00:42:00,400
And how do we make decisions
and technology investments

1039
00:42:00,400 --> 00:42:03,233
and mission decisions
that maximize our ability

1040
00:42:03,233 --> 00:42:05,833
to live off the planet
for longer and longer?

1041
00:42:05,833 --> 00:42:07,866
'Cause I think that's
our fundamental challenge.

1042
00:42:07,866 --> 00:42:10,200
And then if we prove
that we do that,

1043
00:42:10,200 --> 00:42:12,533

then the destinations
are all open to us.

1044
00:42:12,533 --> 00:42:15,100
So with that, I'll turn it over
for questions.

1045
00:42:15,100 --> 00:42:18,100
[applause]

1046
00:42:23,566 --> 00:42:25,300
- So if you have questions,
please line up

1047
00:42:25,300 --> 00:42:27,366
on the microphone in the middle
of the aisle.

1048
00:42:27,366 --> 00:42:29,400
One question and be succinct,
please.

1049
00:42:29,400 --> 00:42:32,400
Thank you.

1050
00:42:41,433 --> 00:42:43,633
So let me ask a question
until we get

1051
00:42:43,633 --> 00:42:46,300
other questions coming in.

1052
00:42:46,300 --> 00:42:48,866
At one point, as you have
an evolvable system,

1053
00:42:48,866 --> 00:42:50,966
you have to make a decision
and say,

1054
00:42:50,966 --> 00:42:53,266
"Okay, now we stop
with our current technology

1055
00:42:53,266 --> 00:42:55,800
and we go to that location,"

1056
00:42:55,800 --> 00:43:00,100
whether it's Mars, ARM,
or any of those locations.

1057
00:43:00,100 --> 00:43:02,466
How are you planning
to determine that stage

1058
00:43:02,466 --> 00:43:06,633
in the evolvable design
scenario?

1059
00:43:06,633 --> 00:43:08,233
- The basic premise of that is,

1060
00:43:08,233 --> 00:43:11,133
make no decision
before you have to.

1061
00:43:11,133 --> 00:43:13,966
And that just basically means
that we do a lot

1062
00:43:13,966 --> 00:43:15,566
of technology roadmaps
and we have

1063
00:43:15,566 --> 00:43:17,966
pre-deceive kind of
decision points

1064
00:43:17,966 --> 00:43:19,766

of when we think we need
to make a decision.

1065
00:43:19,766 --> 00:43:22,066
But it's very important
that we actually make decisions

1066
00:43:22,066 --> 00:43:25,266
when we really have to
and not close the on-ramps

1067
00:43:25,266 --> 00:43:28,566
of other new solutions
too prematurely

1068
00:43:28,566 --> 00:43:30,300
and keep our investments.

1069
00:43:30,300 --> 00:43:32,233
Now we can't fund everything
either, so that--

1070
00:43:32,233 --> 00:43:36,133
there's a kind of a tug of war
on being able to fund everything

1071
00:43:36,133 --> 00:43:38,766
versus making some of those
downselect choices.

1072
00:43:38,766 --> 00:43:41,966
So through some of this
trade analysis that we have,

1073
00:43:41,966 --> 00:43:44,933
we will narrow down the areas,

1074
00:43:44,933 --> 00:43:48,700
but we won't narrow down
the specific implementation

1075
00:43:48,700 --> 00:43:50,766
or the technologies
that we actually choose,

1076
00:43:50,766 --> 00:43:52,533
and we'll allow
technology advancement

1077
00:43:52,533 --> 00:43:54,933
and scientific understanding
to advance

1078
00:43:54,933 --> 00:43:57,000
and still make future decisions
as well.

1079
00:43:57,000 --> 00:44:00,466
So we gotta fight against
laying out

1080
00:44:00,466 --> 00:44:03,400
every mission from here to Mars
and actually say,

1081
00:44:03,400 --> 00:44:05,133
"Well, we already decided
what the mission is

1082
00:44:05,133 --> 00:44:06,666
15 years from now."

1083
00:44:06,666 --> 00:44:08,533
Well, guess what.
It'll be wrong.

1084
00:44:08,533 --> 00:44:10,333
So let's not make
that decision now,

1085
00:44:10,333 --> 00:44:13,000
but rather put that off
as long as we can

1086
00:44:13,000 --> 00:44:15,500
in order to allow technology
to continue to advance.

1087
00:44:15,500 --> 00:44:17,466
So...

1088
00:44:17,466 --> 00:44:19,066
- Hi.
My name's Thomas Graham.

1089
00:44:19,066 --> 00:44:20,666
I'm an intern here
for the summer,

1090
00:44:20,666 --> 00:44:22,933
and I liked your presentation.

1091
00:44:22,933 --> 00:44:24,666
I'll say that.

1092
00:44:24,666 --> 00:44:29,600
But there's a lot of talk
about going to Mars with people,

1093
00:44:29,600 --> 00:44:32,900
sending a lot
of research equipment

1094
00:44:32,900 --> 00:44:36,000
and doing a lot of research
on Mars looking for life.

1095
00:44:36,000 --> 00:44:40,066
And with respect

to the proving ground idea,

1096
00:44:40,066 --> 00:44:45,466
where do you see
lunar missions in that regard?

1097
00:44:45,466 --> 00:44:48,166
And what is your opinion
on the importance

1098
00:44:48,166 --> 00:44:52,133
of going to the moon or using
the moon or lunar orbits

1099
00:44:52,133 --> 00:44:54,566
as this proving ground?

1100
00:44:54,566 --> 00:44:58,100
- Yeah, so, the basic premise
of the program is lunar orbit.

1101
00:44:58,100 --> 00:45:00,766
That is our
staging point there.

1102
00:45:00,766 --> 00:45:04,266
So, the lunar environment is
intriguing to us in many ways.

1103
00:45:04,266 --> 00:45:06,566
Not as a place to go back
and plant another flag

1104
00:45:06,566 --> 00:45:08,833
and footprint, but rather,
as a place that is a source

1105
00:45:08,833 --> 00:45:11,633
for resources
to implement this reduction

1106
00:45:11,633 --> 00:45:13,200
of logistics from Earth.

1107
00:45:13,200 --> 00:45:17,100
So if and when we can actually
capture resources--

1108
00:45:17,100 --> 00:45:19,633
be they lunar resources,
asteroid resources,

1109
00:45:19,633 --> 00:45:21,466
Mars,
Mars' moon's resources,

1110
00:45:21,466 --> 00:45:23,633
we should be going after
this kind of

1111
00:45:23,633 --> 00:45:26,100
resource analysis piece
and how that

1112
00:45:26,100 --> 00:45:27,966
trades into our architecture.

1113
00:45:27,966 --> 00:45:30,033
The preliminary--
all the scientific data that

1114
00:45:30,033 --> 00:45:33,966
we have today points to a
pretty robust water environment

1115
00:45:33,966 --> 00:45:36,233
that exists
on the lunar surface.

1116

00:45:36,233 --> 00:45:39,433
We don't know how it's bounded,
we don't know hard it is,

1117
00:45:39,433 --> 00:45:42,800
we don't know how
to extract that material,

1118
00:45:42,800 --> 00:45:44,466
what it'll cost to do that.

1119
00:45:44,466 --> 00:45:47,266
We do know that the dial
of impact on our

1120
00:45:47,266 --> 00:45:49,900
overall logistics chain
to Mars

1121
00:45:49,900 --> 00:45:51,900
could be
extremely significant.

1122
00:45:51,900 --> 00:45:54,000
So, it's not something
to abandon

1123
00:45:54,000 --> 00:45:56,700
at this point in any means
and that's actually why

1124
00:45:56,700 --> 00:46:00,400
we've been keeping things
like these two additional

1125
00:46:00,400 --> 00:46:02,100
CubeSats missions
that I just showed you,

1126
00:46:02,100 --> 00:46:03,800

but even more so,
going to the surface

1127
00:46:03,800 --> 00:46:05,433
in a mission like
Resource Prospector

1128
00:46:05,433 --> 00:46:08,500
to actually get the surface
validation of that measurement

1129
00:46:08,500 --> 00:46:10,533
and how is that
water distributed

1130
00:46:10,533 --> 00:46:12,533
and how hard will it be
to actually utilize

1131
00:46:12,533 --> 00:46:14,466
an overall architecture?

1132
00:46:14,466 --> 00:46:18,300
So, yeah, it's--
I think it's gonna be key--

1133
00:46:18,300 --> 00:46:20,500
resources will be key
no matter where we wanna go.

1134
00:46:20,500 --> 00:46:22,600
So...
- Thank you.

1135
00:46:24,033 --> 00:46:27,833
- Hi, Jason.
[laughs]

1136
00:46:27,833 --> 00:46:29,600
When you make a decision,

you have some notion

1137
00:46:29,600 --> 00:46:32,733
of better or worse

1138
00:46:32,733 --> 00:46:35,833
and you also have
some notion of technology

1139
00:46:35,833 --> 00:46:37,566
that you use to analyze
all the information

1140
00:46:37,566 --> 00:46:40,433
at your disposal and say,
"I can quantify some decision

1141
00:46:40,433 --> 00:46:43,033
as better or worse
or possibly incomparable."

1142
00:46:43,033 --> 00:46:46,133
So what is it
that people are doing

1143
00:46:46,133 --> 00:46:48,800
in order to take
all the analyses,

1144
00:46:48,800 --> 00:46:51,600
all the trades,
all the architectures,

1145
00:46:51,600 --> 00:46:53,533
and to put them into,
if you like,

1146
00:46:53,533 --> 00:46:57,066
one decision support system
that helps you understand

1147
00:46:57,066 --> 00:46:59,333
"Even if I can't say
'this is best,

1148
00:46:59,333 --> 00:47:00,966
what is better
and what is worse?'"

1149
00:47:00,966 --> 00:47:03,333
How do you
actually do that?

1150
00:47:03,333 --> 00:47:06,200
- Yeah, so, to me, it's--

1151
00:47:06,200 --> 00:47:09,333
you can boil down all the
capability areas that you need

1152
00:47:09,333 --> 00:47:11,666
to sustain human presence
and send them out there.

1153
00:47:11,666 --> 00:47:13,233
There's different ways
to slice it.

1154
00:47:13,233 --> 00:47:15,066
The National Research Council
does it one way,

1155
00:47:15,066 --> 00:47:17,533
and NASA has it's
roadmaps another way,

1156
00:47:17,533 --> 00:47:20,066
however many capability areas
that you have.

1157
00:47:20,066 --> 00:47:22,533
And you can actually analyze
those capability,

1158
00:47:22,533 --> 00:47:26,133
kind of, decisions through
almost like a Pareto Analysis--

1159
00:47:26,133 --> 00:47:29,466
finding the optimal points on
curves for the best or worst

1160
00:47:29,466 --> 00:47:32,700
from an engineering perspective
that you have out there.

1161
00:47:32,700 --> 00:47:35,466
So, it's good to have
sound good engineering analysis

1162
00:47:35,466 --> 00:47:38,133
of what from a technical
performance basis is best.

1163
00:47:38,133 --> 00:47:41,700
That, not necessarily,
will be the thing we do.

1164
00:47:41,700 --> 00:47:44,466
Because then you also then
bring in the alignment with

1165
00:47:44,466 --> 00:47:48,033
industry,
commercial use of that,

1166
00:47:48,033 --> 00:47:49,900
the application
of the technology beyond

1167
00:47:49,900 --> 00:47:52,000
just NASA's requirement
for it,

1168
00:47:52,000 --> 00:47:53,833
international contributions,

1169
00:47:53,833 --> 00:47:58,200
so, you have this very
multi-variable problem

1170
00:47:58,200 --> 00:48:01,433
that it's very difficult
actually to determine

1171
00:48:01,433 --> 00:48:03,733
"better or worse"
and it's--

1172
00:48:03,733 --> 00:48:06,766
I would argue it's impossible
to determine best

1173
00:48:06,766 --> 00:48:10,333
'cause it's an unbound problem

1174
00:48:10,333 --> 00:48:14,700
and, so, if you analyze
that by capability area

1175
00:48:14,700 --> 00:48:17,033
you can make
good enough decisions

1176
00:48:17,033 --> 00:48:19,433
that you at least
have a confidence level

1177
00:48:19,433 --> 00:48:21,700

that you've not made a decision
that will close off

1178
00:48:21,700 --> 00:48:25,900
some future architecture
down the pipe.

1179
00:48:25,900 --> 00:48:27,266
This is a delicate area,
though,

1180
00:48:27,266 --> 00:48:31,100
so this is an area kind of
ripe for all of you in the room

1181
00:48:31,100 --> 00:48:32,900
to actually help with.

1182
00:48:32,900 --> 00:48:35,866
I don't think we have
good decision logics

1183
00:48:35,866 --> 00:48:38,033
and decision trees
that do this kind of things.

1184
00:48:38,033 --> 00:48:39,600
We're really good
at systems engineering

1185
00:48:39,600 --> 00:48:41,300
when we have a bounded problem,

1186
00:48:41,300 --> 00:48:42,766
but how do you
do a systems engineering

1187
00:48:42,766 --> 00:48:45,133
when you have
an unbounded problem?

1188
00:48:45,133 --> 00:48:48,233
And that's what we're facing
and I don't think

1189
00:48:48,233 --> 00:48:49,666
we should try to bound it.

1190
00:48:49,666 --> 00:48:51,866
So, that means we have
to figure out the other part.

1191
00:48:51,866 --> 00:48:54,333
So, I don't know if that
answers your question, Jeremy,

1192
00:48:54,333 --> 00:48:57,100
but I think some of your
guy's algorithm development

1193
00:48:57,100 --> 00:49:01,000
and decision type things
are key to some of that too.

1194
00:49:01,000 --> 00:49:03,300
So...
Yes?

1195
00:49:03,300 --> 00:49:04,600
- Hi, Jason,
Ryan Vaughn.

1196
00:49:04,600 --> 00:49:06,200
I'm a system engineer
here at Ames.

1197
00:49:06,200 --> 00:49:09,100
I work on Resource Prospector.
[chuckles]

1198
00:49:09,100 --> 00:49:10,866
I have a question about
what kind of research

1199
00:49:10,866 --> 00:49:14,166
is in place for
long duration exposure

1200
00:49:14,166 --> 00:49:18,166
to radiation both
on transit and in habs on Mars

1201
00:49:18,166 --> 00:49:21,000
and what kind of
work can be done

1202
00:49:21,000 --> 00:49:25,833
between now and these proving
grounds that mature that?

1203
00:49:25,833 --> 00:49:28,266
- Yeah, so, for
the radiation environment piece

1204
00:49:28,266 --> 00:49:31,366
I boil it down to
kinda three categories.

1205
00:49:31,366 --> 00:49:34,166
First is we need to actually
know no doubt what

1206
00:49:34,166 --> 00:49:36,900
the radiation environment is,
so that's the measurement piece.

1207
00:49:36,900 --> 00:49:39,433
So, with that, we've actually
got a whole team

1208
00:49:39,433 --> 00:49:42,333
of radiation Dosimetry--
both internal to NASA

1209
00:49:42,333 --> 00:49:44,400
and outside of NASA,
working together

1210
00:49:44,400 --> 00:49:46,833
on everything from
the Mars "Curiosity" instrument

1211
00:49:46,833 --> 00:49:50,200
to the ISS instruments,
EFT-1 flight of Orion

1212
00:49:50,200 --> 00:49:53,166
had a radiation sensor on it,
and even things like

1213
00:49:53,166 --> 00:49:55,700
BioSentinel that's being built
here as a CubeSat.

1214
00:49:55,700 --> 00:49:58,566
There's commonality
in all those instruments

1215
00:49:58,566 --> 00:50:00,766
and there's definitely
commonality on the team

1216
00:50:00,766 --> 00:50:03,700
so that we're actually
getting the radiation,

1217
00:50:03,700 --> 00:50:06,166
no doubt, measurements of what
the environments are gonna be.

1218
00:50:06,166 --> 00:50:08,833
And, in fact, on "Curiosity"
we monitored the--

1219
00:50:08,833 --> 00:50:11,866
we had our radiation instrument
on the entire transit

1220
00:50:11,866 --> 00:50:15,833
to Mars and we've had operations
on the surface of Mars as well

1221
00:50:15,833 --> 00:50:18,000
and as we get
these next instruments

1222
00:50:18,000 --> 00:50:20,366
in orbit around Mars,

1223
00:50:20,366 --> 00:50:23,766
from there we're actually
gonna get now

1224
00:50:23,766 --> 00:50:25,900
orbital characterization
radiation

1225
00:50:25,900 --> 00:50:27,866
coupled with the ground
characterization

1226
00:50:27,866 --> 00:50:29,500
and now we can figure out
directionality

1227
00:50:29,500 --> 00:50:32,466
and atmospheric effects
and all that.

1228

00:50:32,466 --> 00:50:35,400
So, that's the Dosimetry piece
and I think well in hand

1229
00:50:35,400 --> 00:50:37,166
of really understanding
the environment.

1230
00:50:37,166 --> 00:50:39,433
The next is actually
modeling.

1231
00:50:39,433 --> 00:50:42,266
The actual entire
solar system effects

1232
00:50:42,266 --> 00:50:43,800
and the heliophysics
and all that.

1233
00:50:43,800 --> 00:50:46,100
And that's working closely
with our science folks

1234
00:50:46,100 --> 00:50:48,000
in heliophysics
and figuring out

1235
00:50:48,000 --> 00:50:49,966
when you have an event,
what does that event mean

1236
00:50:49,966 --> 00:50:51,933
and how does it propagate
and how do you do

1237
00:50:51,933 --> 00:50:54,400
real-time operational
warning systems?

1238

00:50:54,400 --> 00:50:58,133
And right now, our modeling
could be a lot better

1239
00:50:58,133 --> 00:51:01,966
and there's considerable effort
on taking that, kind of,

1240
00:51:01,966 --> 00:51:04,533
scientific operational data--
the measurement data they have,

1241
00:51:04,533 --> 00:51:07,133
and propagating that
into our models that then

1242
00:51:07,133 --> 00:51:09,566
carry it through
the solar system

1243
00:51:09,566 --> 00:51:13,133
and understand what--
even down to, say I was standing

1244
00:51:13,133 --> 00:51:14,966
in the middle of a hab,
what is the hab's effects

1245
00:51:14,966 --> 00:51:16,600
and actually translating that
all the way down.

1246
00:51:16,600 --> 00:51:18,433
There's error bars on every one
of those steps,

1247
00:51:18,433 --> 00:51:20,433
and the modeling
needs to improve.

1248

00:51:20,433 --> 00:51:23,333
And then there's the Human
Research Program side of this

1249
00:51:23,333 --> 00:51:26,666
of once you actually
do get the radiation effect

1250
00:51:26,666 --> 00:51:28,833
to that individual,
what does it mean to them

1251
00:51:28,833 --> 00:51:30,500
and how do you mitigate that?

1252
00:51:30,500 --> 00:51:33,566
There's a whole
cadre of research going on

1253
00:51:33,566 --> 00:51:35,866
in the Human Research Program

1254
00:51:35,866 --> 00:51:39,966
that I can't talk
about as much as they could,

1255
00:51:39,966 --> 00:51:42,466
but the levels that we're
seeing--even in a Mars transit,

1256
00:51:42,466 --> 00:51:45,266
are within reasonable limits.

1257
00:51:45,266 --> 00:51:47,766
These are not
hard achievable things.

1258
00:51:47,766 --> 00:51:51,166
The PI for Mars "Curiosity"
put the estimate

1259
00:51:51,166 --> 00:51:54,233
of the lifetime risk
at 5% if you would have been

1260
00:51:54,233 --> 00:51:56,100
on "Curiosity" yourself.

1261
00:51:56,100 --> 00:51:57,866
Our current limit is 3%

1262
00:51:57,866 --> 00:52:00,166
based on radiation workers
tolerances.

1263
00:52:00,166 --> 00:52:04,066
We have 5% of your total risk

1264
00:52:04,066 --> 00:52:05,533
of lifetime cancer.

1265
00:52:05,533 --> 00:52:07,933
So that puts it in perspective,

1266
00:52:07,933 --> 00:52:09,866
the risk levels
that we're talking about.

1267
00:52:09,866 --> 00:52:11,566
So...

1268
00:52:14,666 --> 00:52:16,900
- Would it be possible,
and/or better,

1269
00:52:16,900 --> 00:52:20,900
to use nuclear power sources
for these 100s of kilowatt

1270
00:52:20,900 --> 00:52:23,033
electrical supplies
that you need?

1271
00:52:23,033 --> 00:52:26,366
Would a small nuclear reactor
have a higher

1272
00:52:26,366 --> 00:52:29,200
power output to mass ratio?

1273
00:52:29,200 --> 00:52:31,366
What is your
thoughts on that?

1274
00:52:31,366 --> 00:52:32,766
- Yeah, so there's--

1275
00:52:32,766 --> 00:52:34,966
- Is there some other reason
you would not use nuclear power?

1276
00:52:34,966 --> 00:52:37,566
- Yeah, so, nuclear is still
in our tradespace.

1277
00:52:37,566 --> 00:52:39,900
It's in our tradespace
in three areas.

1278
00:52:39,900 --> 00:52:41,766
Nuclear Thermal Propulsion,

1279
00:52:41,766 --> 00:52:45,300
so anywhere you saw
chemical stage there is still

1280
00:52:45,300 --> 00:52:47,666
a potential of trading out

that chemical stage

1281
00:52:47,666 --> 00:52:50,033
for a Nuclear Thermal
Propulsion stage.

1282
00:52:50,033 --> 00:52:54,266
And, in fact, we're still
doing the research on fuels

1283
00:52:54,266 --> 00:52:56,900
within AES,
the program I run,

1284
00:52:56,900 --> 00:52:58,566
and we're advancing
the fuels technology

1285
00:52:58,566 --> 00:53:00,633
and recovering
what we lost from NERVA

1286
00:53:00,633 --> 00:53:02,500
and actually moving forward
in our understanding

1287
00:53:02,500 --> 00:53:05,433
of the fuels piece
for nuclear thermal rockets.

1288
00:53:05,433 --> 00:53:07,233
The rocket
is relatively simple.

1289
00:53:07,233 --> 00:53:09,100
Not to underestimate
the rocket folks,

1290
00:53:09,100 --> 00:53:10,933
but it's a heat exchanger.

1291
00:53:10,933 --> 00:53:12,766
It doesn't have the complexity
of a normal rocket,

1292
00:53:12,766 --> 00:53:15,633
so the fuels
are the hard piece there.

1293
00:53:15,633 --> 00:53:18,400
Surface power
is the other area.

1294
00:53:18,400 --> 00:53:20,600
If you're doing all this in situ
research utilization

1295
00:53:20,600 --> 00:53:21,833
you're probably gonna need
significant power

1296
00:53:21,833 --> 00:53:23,333
on the surface.

1297
00:53:23,333 --> 00:53:25,900
So surface power--
surface nuclear power

1298
00:53:25,900 --> 00:53:28,733
is an area that's still going on
and you have investments by our

1299
00:53:28,733 --> 00:53:30,066
Space Technology
Mission Directorates

1300
00:53:30,066 --> 00:53:32,233
in things like Kilopower
is their project.

1301
00:53:32,233 --> 00:53:34,366
They're looking
at a 400 kilogram,

1302
00:53:34,366 --> 00:53:37,766
one kilowatt
nuclear reactor

1303
00:53:37,766 --> 00:53:40,200
and how does--
one kilowatt doesn't scale.

1304
00:53:40,200 --> 00:53:43,900
I mean, that small of a size
isn't worth it at that mass,

1305
00:53:43,900 --> 00:53:45,833
but you need to figure out,
"Can we--

1306
00:53:45,833 --> 00:53:48,733
"we don't need 40 kilowatts
in a single chunk

1307
00:53:48,733 --> 00:53:50,966
of nuclear power, but, maybe,
a ten kilowatt."

1308
00:53:50,966 --> 00:53:53,133
And how does that scale and what
is the incremental cost?

1309
00:53:53,133 --> 00:53:54,933
And that's one of
the investments that's going on.

1310
00:53:54,933 --> 00:53:56,766
We may not need it
for the initial missions,

1311
00:53:56,766 --> 00:53:58,766
but we will need it over time.

1312
00:53:58,766 --> 00:54:01,033
Your last question
was nuclear reactors--

1313
00:54:01,033 --> 00:54:02,966
Nuclear Electric
Propulsion,

1314
00:54:02,966 --> 00:54:04,733
or nuclear power there.

1315
00:54:04,733 --> 00:54:08,366
If you look at
multi-megawatt reactors

1316
00:54:08,366 --> 00:54:09,900
on that kind of scale,

1317
00:54:09,900 --> 00:54:12,533
when you're getting several
hundreds of kilowatts and such,

1318
00:54:12,533 --> 00:54:14,300
that is a potential solution.

1319
00:54:14,300 --> 00:54:16,833
Most of those reactors,
though

1320
00:54:16,833 --> 00:54:18,266
the designs
for those reactors

1321
00:54:18,266 --> 00:54:20,800
run at temperatures that are--
even our ground based

1322
00:54:20,800 --> 00:54:23,233
nuclear folks have not seen

1323
00:54:23,233 --> 00:54:24,666
except in runaway conditions.

1324
00:54:24,666 --> 00:54:28,600
So you can look at reactors
as a function of heat and, so,

1325
00:54:28,600 --> 00:54:30,600
that's a new development
effort and that could be

1326
00:54:30,600 --> 00:54:32,633
a multi-billion dollar
development effort.

1327
00:54:32,633 --> 00:54:34,900
So we've been concentrating
on using

1328
00:54:34,900 --> 00:54:36,633
Solar Electrical Propulsion
and we believe,

1329
00:54:36,633 --> 00:54:38,966
in this scale,
300-400 kilowatt range,

1330
00:54:38,966 --> 00:54:42,766
is reasonably achieved
by Solar Electric Propulsion.

1331
00:54:42,766 --> 00:54:45,400
The state of the art today
of Solar Electric Propulsion--

1332

00:54:45,400 --> 00:54:46,933
if you look at
the space station arrays,

1333
00:54:46,933 --> 00:54:48,666
you could generate
the same amount of power

1334
00:54:48,666 --> 00:54:52,266
the station has with 20%
the acreage.

1335
00:54:52,266 --> 00:54:54,266
So the advancement
of solar array technology

1336
00:54:54,266 --> 00:54:56,200
has come a long way.

1337
00:54:56,200 --> 00:54:58,266
So if you think about
station,

1338
00:54:58,266 --> 00:55:01,433
what we need is acreage the size
of the space station,

1339
00:55:01,433 --> 00:55:04,300
but that same acreage
would produce five times

1340
00:55:04,300 --> 00:55:06,033
the amount of power
the space station has.

1341
00:55:06,033 --> 00:55:09,566
So it is something
technically achievable today.

1342
00:55:09,566 --> 00:55:12,066

Now, at what cost to launch
that kind of acreage

1343
00:55:12,066 --> 00:55:14,100
is the challenge,
so, right now, we've chose

1344
00:55:14,100 --> 00:55:16,766
not to do the investment
in the in space nuclear,

1345
00:55:16,766 --> 00:55:19,300
but rather concentrate
on the engines to get there,

1346
00:55:19,300 --> 00:55:21,200
if we want to trade out
Nuclear Thermal Propulsion

1347
00:55:21,200 --> 00:55:23,533
and the surface power
as our first steps

1348
00:55:23,533 --> 00:55:26,800
and then use solar electric
for the transit piece.

1349
00:55:26,800 --> 00:55:27,966
It doesn't mean that
it couldn't

1350
00:55:27,966 --> 00:55:30,500
come on board
at some point, though.

1351
00:55:30,500 --> 00:55:32,133
- So, please join me

1352
00:55:32,133 --> 00:55:34,733
in thanking Jason

for an excellent talk.

1353
00:55:34,733 --> 00:55:37,733
[applause]