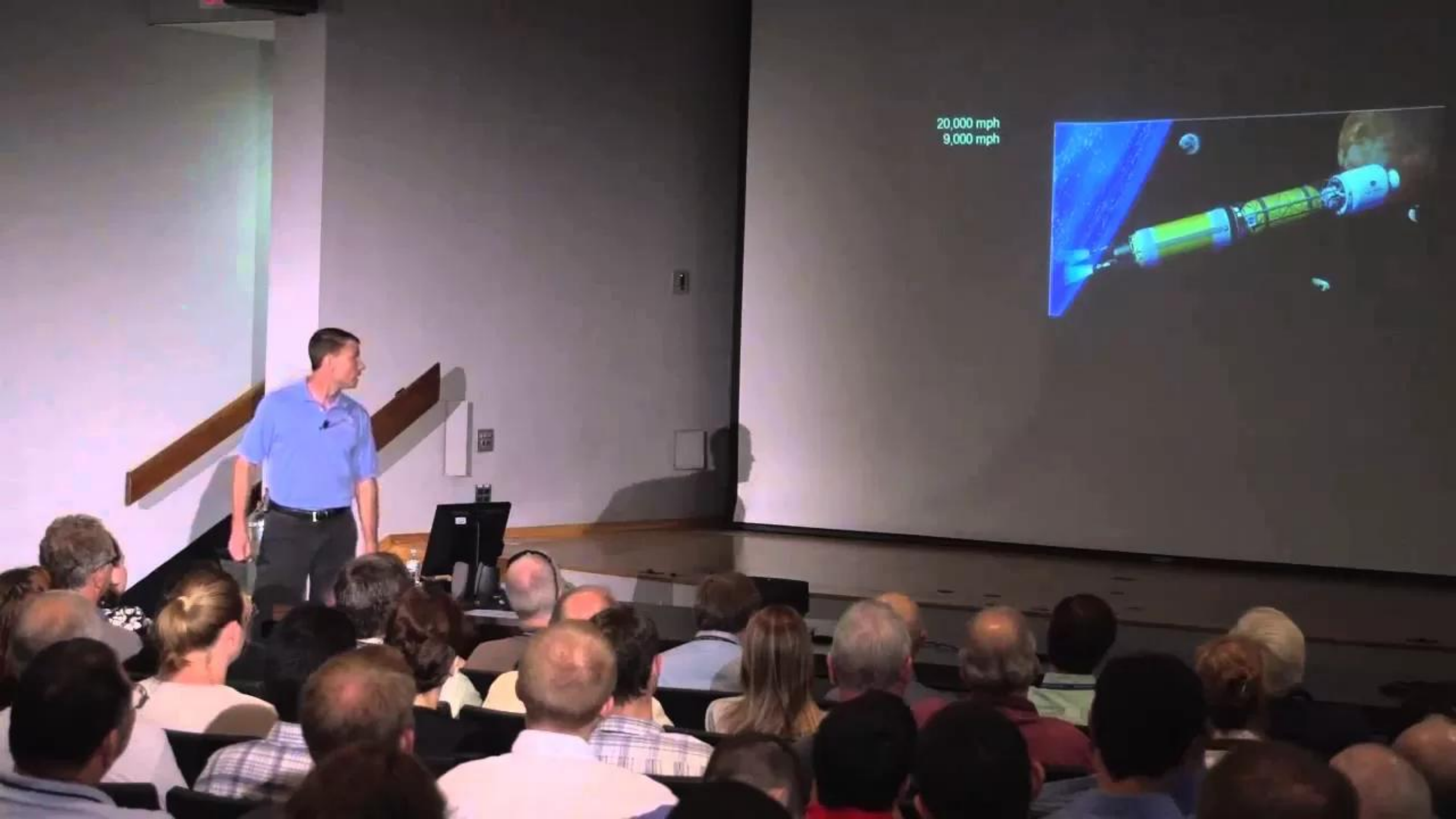
20,000 mph
9,000 mph

1
00:00:06,950 --> 00:00:04,309
so uh what i want to talk to you today

2
00:00:08,710 --> 00:00:06,960
about is why we're not here yet

3
00:00:10,390 --> 00:00:08,720
40 years after we've been to the moon we

4
00:00:12,310 --> 00:00:10,400
thought we'd be on mars like in the

5
00:00:14,070 --> 00:00:12,320
1980s or something like that and we're

6
00:00:14,910 --> 00:00:14,080
totally not on mars yet

7
00:00:17,990 --> 00:00:14,920
so

8
00:00:20,630 --> 00:00:18,000
um the short answer is we're not on mars

9
00:00:23,429 --> 00:00:20,640
because it's really expensive

10
00:00:26,950 --> 00:00:23,439
it's really expensive because it's hard

11
00:00:29,269 --> 00:00:26,960
and not only is flying to mars hard

12
00:00:31,429 --> 00:00:29,279
understanding why it's hard to fly to

13
00:00:33,510 --> 00:00:31,439

mars is hard

14
00:00:35,110 --> 00:00:33,520
it really does take a rocket scientist

15
00:00:37,990 --> 00:00:35,120
this is robert goddard

16
00:00:39,910 --> 00:00:38,000
so my goal in the next 40 minutes or so

17
00:00:41,830 --> 00:00:39,920
is to turn all of you who are not rocket

18
00:00:43,510 --> 00:00:41,840
scientists already into rocket

19
00:00:45,350 --> 00:00:43,520
scientists

20
00:00:46,869 --> 00:00:45,360
we're gonna do this in three easy steps

21
00:00:49,110 --> 00:00:46,879
we're gonna start with what we know and

22
00:00:51,029 --> 00:00:49,120
love well here at johnson space center

23
00:00:53,110 --> 00:00:51,039
uh low earth orbit talk about the moon

24
00:00:54,869 --> 00:00:53,120
which we did 40 years ago and then

25
00:00:56,630 --> 00:00:54,879
extend that to what it takes to go to

26
00:00:58,790 --> 00:00:56,640
mars

27
00:01:00,470 --> 00:00:58,800
so starting off in low earth orbit

28
00:01:01,670 --> 00:01:00,480
there's our favorite object in low earth

29
00:01:03,110 --> 00:01:01,680
orbit the international space station

30
00:01:05,509 --> 00:01:03,120
which they're busy operating over here

31
00:01:07,510 --> 00:01:05,519
just a couple yards to the south of us i

32
00:01:10,230 --> 00:01:07,520
also need to point out here the best

33
00:01:11,750 --> 00:01:10,240
module on the space station right there

34
00:01:13,510 --> 00:01:11,760
at the shiny one there that's the

35
00:01:16,950 --> 00:01:13,520
columbus lab that my crewmates and i put

36
00:01:18,469 --> 00:01:16,960
up totally unbiased uh

37
00:01:21,749 --> 00:01:18,479
remember that the space station orbits

38
00:01:23,429 --> 00:01:21,759

the earth only about 250 miles up

39
00:01:24,630 --> 00:01:23,439
and that's not very far into space

40
00:01:26,149 --> 00:01:24,640
especially when you compare it with the

41
00:01:29,190 --> 00:01:26,159
size of the earth the earth is a ball

42
00:01:32,630 --> 00:01:29,200
about 8 000 miles in diameter 250 miles

43
00:01:35,350 --> 00:01:32,640
up is just barely above the top of the

44
00:01:37,830 --> 00:01:35,360
atmosphere and that is the only place we

45
00:01:40,310 --> 00:01:37,840
could have put the space station

46
00:01:41,990 --> 00:01:40,320
if we put it any lower the air would

47
00:01:43,670 --> 00:01:42,000
have been dense enough to bring it down

48
00:01:45,270 --> 00:01:43,680
through air drag

49
00:01:46,950 --> 00:01:45,280
if we tried to put it any higher the

50
00:01:49,190 --> 00:01:46,960
space shuttle wouldn't have been able to

51
00:01:50,789 --> 00:01:49,200
carry those heavy payloads

52
00:01:52,550 --> 00:01:50,799
up that high to build the space station

53
00:01:56,310 --> 00:01:52,560
there so that was our only option about

54
00:01:57,830 --> 00:01:56,320
250 miles up to put the space station

55
00:01:59,429 --> 00:01:57,840
now remember the space station is in

56
00:02:01,590 --> 00:01:59,439
orbit and i want to talk for just a

57
00:02:03,109 --> 00:02:01,600
minute about what that means because

58
00:02:05,109 --> 00:02:03,119
most people don't know i think in this

59
00:02:06,469 --> 00:02:05,119
room we're probably pretty safe but bear

60
00:02:08,630 --> 00:02:06,479
with me

61
00:02:10,790 --> 00:02:08,640
so this picture is actually from the

62
00:02:13,670 --> 00:02:10,800
principia by isaac newton

63
00:02:15,589 --> 00:02:13,680

in which he invented the concept

64
00:02:18,630 --> 00:02:15,599
uh and his thought experiment was to

65
00:02:20,070 --> 00:02:18,640
have a really tall mountain here that uh

66
00:02:22,150 --> 00:02:20,080
is higher than the atmosphere so you

67
00:02:24,470 --> 00:02:22,160
don't have to worry about air drag you

68
00:02:26,550 --> 00:02:24,480
put a cannon on top of the mountain and

69
00:02:28,630 --> 00:02:26,560
you fire cannon balls out of the cannon

70
00:02:29,830 --> 00:02:28,640
at various speeds and we all know what

71
00:02:31,190 --> 00:02:29,840
happens when you shoot a cannonball out

72
00:02:32,949 --> 00:02:31,200
of a cannon it flies a little ways and

73
00:02:34,550 --> 00:02:32,959
then its path curves under gravity until

74
00:02:37,030 --> 00:02:34,560
it comes down and hits the ground and

75
00:02:40,229 --> 00:02:37,040
that's uh illustrated here by this line

76
00:02:42,949 --> 00:02:41,589
so newton's thought was let's put a

77
00:02:44,550 --> 00:02:42,959
little bit more gunpowder in the cannon

78
00:02:46,550 --> 00:02:44,560
and fire the cannonball out at a higher

79
00:02:48,150 --> 00:02:46,560
speed and now maybe it will come flying

80
00:02:50,070 --> 00:02:48,160
around but it still curves down toward

81
00:02:52,150 --> 00:02:50,080
the ground but it goes further and maybe

82
00:02:53,509 --> 00:02:52,160
gets to point e

83
00:02:54,790 --> 00:02:53,519
and we'll load a little more gunpowder

84
00:02:57,270 --> 00:02:54,800
in and we'll fire the cannon again and

85
00:02:59,750 --> 00:02:57,280
this time we get a good head of speed

86
00:03:02,390 --> 00:02:59,760
cannonball flies a long way before it

87
00:03:04,149 --> 00:03:02,400
finally hits the ground there at point f

88
00:03:06,390 --> 00:03:04,159

but you can see what's happening as we

89
00:03:07,990 --> 00:03:06,400
increase the speed of that cannonball it

90
00:03:10,710 --> 00:03:08,000
keeps curving toward the earth so that

91
00:03:11,830 --> 00:03:10,720
it's going to hit the ground

92
00:03:13,670 --> 00:03:11,840
but

93
00:03:16,070 --> 00:03:13,680
when you get out to point f here the

94
00:03:18,149 --> 00:03:16,080
earth's surface has curved away from the

95
00:03:20,070 --> 00:03:18,159
cannonball quite a bit and it flies a

96
00:03:22,229 --> 00:03:20,080
lot farther finally

97
00:03:24,229 --> 00:03:22,239
we load enough gunpowder into the cannon

98
00:03:26,390 --> 00:03:24,239
and fire that cannonball

99
00:03:27,589 --> 00:03:26,400
it will come flying all the way around

100
00:03:30,789 --> 00:03:27,599
the world

101
00:03:32,470 --> 00:03:30,799
and it's still feeling plenty of gravity

102
00:03:33,670 --> 00:03:32,480
see all these pictures of the astronauts

103
00:03:35,430 --> 00:03:33,680
floating around in the space station

104
00:03:37,030 --> 00:03:35,440
looks like oh there's no gravity

105
00:03:39,270 --> 00:03:37,040
nonsense there's oodles of gravity up

106
00:03:41,030 --> 00:03:39,280
there if you built a tower 250 miles

107
00:03:42,470 --> 00:03:41,040
tall and stood on it of course you need

108
00:03:44,949 --> 00:03:42,480
a spacesuit because there's no air up

109
00:03:46,470 --> 00:03:44,959
there you'd feel something like 90

110
00:03:49,270 --> 00:03:46,480
percent of the gravity that you feel in

111
00:03:51,589 --> 00:03:49,280
this room you would be pulled down very

112
00:03:53,509 --> 00:03:51,599
solidly onto the top of that tower the

113
00:03:57,270 --> 00:03:53,519

reason the astronauts don't feel the

114
00:04:02,630 --> 00:03:59,589
and they can fall for weeks and months

115
00:04:04,710 --> 00:04:02,640
at a time because their forward speed is

116
00:04:06,470 --> 00:04:04,720
so great

117
00:04:08,550 --> 00:04:06,480
that even though their path is curving

118
00:04:10,390 --> 00:04:08,560
toward the earth's surface under gravity

119
00:04:12,149 --> 00:04:10,400
the surface of the earth is curving away

120
00:04:14,550 --> 00:04:12,159
from them at the same rate and they

121
00:04:16,789 --> 00:04:14,560
never hit the ground

122
00:04:19,110 --> 00:04:16,799
that is what it means to be in orbit

123
00:04:20,550 --> 00:04:19,120
you're going forward so fast that even

124
00:04:21,830 --> 00:04:20,560
though you're falling toward the ground

125
00:04:23,510 --> 00:04:21,840
the ground is

126
00:04:25,430 --> 00:04:23,520
curving away from you and you never hit

127
00:04:26,870 --> 00:04:25,440
it and that's also the hard part about

128
00:04:29,830 --> 00:04:26,880
getting into space

129
00:04:33,030 --> 00:04:29,840
getting up into space is not hard

130
00:04:35,030 --> 00:04:33,040
the germans were doing it in 1942

131
00:04:36,310 --> 00:04:35,040
sending things to antwerp and london

132
00:04:38,230 --> 00:04:36,320
okay

133
00:04:39,670 --> 00:04:38,240
up isn't the problem the problem is

134
00:04:43,990 --> 00:04:39,680
going forward fast enough so that when

135
00:04:47,430 --> 00:04:45,749
and that speed

136
00:04:49,830 --> 00:04:47,440
once you allow for the fact that your

137
00:04:51,830 --> 00:04:49,840
rocket has to go uphill

138
00:04:53,990 --> 00:04:51,840

and in a headwind to get up through the

139
00:04:57,030 --> 00:04:54,000
atmosphere and get into space

140
00:04:57,990 --> 00:04:57,040
is about 20 000 miles per hour

141
00:04:59,510 --> 00:04:58,000
um

142
00:05:01,350 --> 00:04:59,520
and let's see for this audience i should

143
00:05:03,110 --> 00:05:01,360
be using feet per second for general

144
00:05:05,350 --> 00:05:03,120
audiences though miles per hour and for

145
00:05:07,110 --> 00:05:05,360
all the scientists i apologize for not

146
00:05:09,029 --> 00:05:07,120
using metric but if i use metric

147
00:05:11,110 --> 00:05:09,039
everybody's eyes roll up and a message

148
00:05:15,029 --> 00:05:11,120
gets lost so we're gonna we're gonna

149
00:05:21,350 --> 00:05:16,870
uh in the interest of our folks with

150
00:05:27,510 --> 00:05:24,790
a reminder about the harsh reality of

151
00:05:31,270 --> 00:05:29,670
mother nature is an extremely tough

152
00:05:32,870 --> 00:05:31,280
grader

153
00:05:34,390 --> 00:05:32,880
so every time you push the button to

154
00:05:36,550 --> 00:05:34,400
launch a rocket

155
00:05:38,950 --> 00:05:36,560
you are signing up for a situation where

156
00:05:41,670 --> 00:05:38,960
if you get 99

157
00:05:43,990 --> 00:05:41,680
of the way there 99 percent of your 20

158
00:05:45,270 --> 00:05:44,000
000 miles per hour that's a launch

159
00:05:47,430 --> 00:05:45,280
failure

160
00:05:49,350 --> 00:05:47,440
that means debris coming down in places

161
00:05:53,350 --> 00:05:49,360
and possibly funerals

162
00:05:54,629 --> 00:05:53,360
okay so 99 out of 100 is a is a failure

163
00:05:56,950 --> 00:05:54,639

that's what we're signing up for every

164
00:06:02,710 --> 00:05:56,960
time we burn a rocket engine to go to

165
00:06:05,909 --> 00:06:04,550
all right uh we've all seen tv in the

166
00:06:07,830 --> 00:06:05,919
movies and they make spice travel look

167
00:06:11,590 --> 00:06:07,840
really easy

168
00:06:14,469 --> 00:06:11,600
you just say engage or make it so or

169
00:06:17,189 --> 00:06:14,479
you know ahead warp factor six mr sulu

170
00:06:19,590 --> 00:06:17,199
and it happens but unfortunately

171
00:06:21,270 --> 00:06:19,600
we are not quite there yet from a

172
00:06:22,870 --> 00:06:21,280
technical standpoint

173
00:06:24,150 --> 00:06:22,880
so instead of using things that look

174
00:06:25,670 --> 00:06:24,160
like this

175
00:06:27,590 --> 00:06:25,680
we have to use things that look like

176
00:06:32,230 --> 00:06:27,600
this

177
00:06:34,390 --> 00:06:32,240
it looks like when you see a picture of

178
00:06:36,710 --> 00:06:34,400
the shuttle stack you have this big

179
00:06:38,469 --> 00:06:36,720
airplane thing and then a big tank

180
00:06:40,629 --> 00:06:38,479
that's yeah kind of about the same size

181
00:06:41,909 --> 00:06:40,639
as the airplane and then two skinny

182
00:06:43,189 --> 00:06:41,919
rockets that are smaller than the

183
00:06:45,909 --> 00:06:43,199
airplane

184
00:06:48,230 --> 00:06:45,919
but size is deceiving

185
00:06:52,870 --> 00:06:48,240
when this critter's sitting on the pad

186
00:06:55,350 --> 00:06:52,880
the airplane weighs about 100 tons

187
00:06:58,870 --> 00:06:55,360
each of these white rocket boosters

188
00:07:00,150 --> 00:06:58,880

weighs about 630 tons six times as much

189
00:07:02,309 --> 00:07:00,160
as the airplane

190
00:07:04,950 --> 00:07:02,319
that tank full of propellant weighs some

191
00:07:08,150 --> 00:07:04,960
like 840 tons

192
00:07:11,110 --> 00:07:08,160
eight times the mass of the airplane

193
00:07:12,469 --> 00:07:11,120
this thing is an eggshell

194
00:07:16,550 --> 00:07:12,479
these things

195
00:07:18,150 --> 00:07:16,560
are heavy and full of propellant

196
00:07:21,670 --> 00:07:18,160
that is the only thing that makes it to

197
00:07:26,070 --> 00:07:23,909
so the heart and soul of this system

198
00:07:28,230 --> 00:07:26,080
is a space shuttle main engine

199
00:07:31,270 --> 00:07:28,240
this is one in the test stand back at

200
00:07:32,469 --> 00:07:31,280
stennis space center in mississippi

201
00:07:34,309 --> 00:07:32,479
and although

202
00:07:36,070 --> 00:07:34,319
it has been joked that prediction is

203
00:07:38,230 --> 00:07:36,080
hard particularly about the future i'm

204
00:07:40,230 --> 00:07:38,240
going to come out and say not only is

205
00:07:41,350 --> 00:07:40,240
this the best chemical rocket engine

206
00:07:42,550 --> 00:07:41,360
ever made

207
00:07:44,790 --> 00:07:42,560
it may be

208
00:07:46,950 --> 00:07:44,800
the best chemical rocket engine that

209
00:07:48,550 --> 00:07:46,960
ever will be made

210
00:07:50,950 --> 00:07:48,560
i want to take a moment to explain that

211
00:07:52,629 --> 00:07:50,960
statement

212
00:07:54,869 --> 00:07:52,639
the thing that determines

213
00:07:57,270 --> 00:07:54,879

how much boost you get out of a rocket

214
00:07:59,670 --> 00:07:57,280
engine per unit mass of fuel you put

215
00:08:01,029 --> 00:07:59,680
into it is a parameter called specific

216
00:08:05,189 --> 00:08:01,039
impulse

217
00:08:07,110 --> 00:08:05,199
measuring the exhaust speed of the gases

218
00:08:09,670 --> 00:08:07,120
coming out that nozzle

219
00:08:11,670 --> 00:08:09,680
so you want to get a long ways with a

220
00:08:13,749 --> 00:08:11,680
little bit of fuel you need a really

221
00:08:15,909 --> 00:08:13,759
good specific impulse

222
00:08:17,830 --> 00:08:15,919
in your engine

223
00:08:20,070 --> 00:08:17,840
specific impulse then

224
00:08:22,150 --> 00:08:20,080
just measuring the exhaust speed depends

225
00:08:24,710 --> 00:08:22,160
on two things

226
00:08:26,469 --> 00:08:24,720
it depends on the temperature of the gas

227
00:08:28,390 --> 00:08:26,479
coming out of that nozzle

228
00:08:30,230 --> 00:08:28,400
higher temperature means faster speeds

229
00:08:31,909 --> 00:08:30,240
and better specific impulse

230
00:08:33,829 --> 00:08:31,919
and it depends on the molecular weight

231
00:08:35,909 --> 00:08:33,839
of the gas

232
00:08:37,909 --> 00:08:35,919
lighter gases give higher exhaust speed

233
00:08:39,350 --> 00:08:37,919
and better specific impulse

234
00:08:40,870 --> 00:08:39,360
so those are the two things we would

235
00:08:42,230 --> 00:08:40,880
need to mess with to get a better

236
00:08:43,509 --> 00:08:42,240
specific impulse out of a chemical

237
00:08:46,230 --> 00:08:43,519
rocket engine

238
00:08:47,190 --> 00:08:46,240

let's talk about temperature first

239
00:08:49,430 --> 00:08:47,200
um

240
00:08:51,190 --> 00:08:49,440
this is actually a flame

241
00:08:52,790 --> 00:08:51,200
it's transparent

242
00:08:53,990 --> 00:08:52,800
because it's so hot

243
00:08:56,790 --> 00:08:54,000
the temperature in that flame is

244
00:08:59,190 --> 00:08:56,800
something like 5000 degrees fahrenheit

245
00:09:00,710 --> 00:08:59,200
and there is nothing on earth that can

246
00:09:03,110 --> 00:09:00,720
withstand that temperature without

247
00:09:04,870 --> 00:09:03,120
melting period end of sentence

248
00:09:07,190 --> 00:09:04,880
this nozzle is made out of a high

249
00:09:09,910 --> 00:09:07,200
temperature alloy it would melt in a

250
00:09:12,310 --> 00:09:09,920
flash if it didn't also have

251
00:09:14,550 --> 00:09:12,320
about 1100 little tubes in the outer

252
00:09:16,150 --> 00:09:14,560
wall that are running the ultra cold

253
00:09:17,670 --> 00:09:16,160
liquid hydrogen propellant that's going

254
00:09:19,910 --> 00:09:17,680
to be burned in the engines through that

255
00:09:21,670 --> 00:09:19,920
wall that nozzle to cool it and then

256
00:09:24,230 --> 00:09:21,680
that gas gets sent off to the turbo

257
00:09:26,389 --> 00:09:24,240
pumps to get burned in the engine

258
00:09:28,150 --> 00:09:26,399
so we need an actively cryogenically

259
00:09:30,470 --> 00:09:28,160
cooled engine made out of the highest

260
00:09:33,670 --> 00:09:30,480
temperature materials that we have

261
00:09:35,670 --> 00:09:33,680
just to withstand the flame temperature

262
00:09:38,550 --> 00:09:35,680
in this engine

263
00:09:39,910 --> 00:09:38,560

we can't really make the exhaust any

264
00:09:42,630 --> 00:09:39,920
hotter

265
00:09:43,910 --> 00:09:42,640
because we'll slag the motor

266
00:09:45,670 --> 00:09:43,920
alright so then the other thing we can

267
00:09:49,030 --> 00:09:45,680
mess with to get better specific impulse

268
00:09:52,470 --> 00:09:49,040
is the molecular weight of the gas

269
00:09:54,150 --> 00:09:52,480
space shuttle main engine burns hydrogen

270
00:09:56,150 --> 00:09:54,160
to burn anything you need to combine it

271
00:09:56,949 --> 00:09:56,160
with oxygen so we're stuck with oxygen

272
00:09:58,870 --> 00:09:56,959
although

273
00:10:00,070 --> 00:09:58,880
asterisk fine print

274
00:10:02,870 --> 00:10:00,080
i have read

275
00:10:05,670 --> 00:10:02,880
that if you really don't care about your

276
00:10:08,790 --> 00:10:05,680
neighbors you can replace the oxygen in

277
00:10:10,470 --> 00:10:08,800
any rocket engine with fluorine

278
00:10:12,710 --> 00:10:10,480
and you can get a few more seconds of

279
00:10:14,550 --> 00:10:12,720
isp out of that you know maybe a one or

280
00:10:16,470 --> 00:10:14,560
two percent boost in the in the fuel

281
00:10:19,190 --> 00:10:16,480
economy but then you leave this big

282
00:10:21,829 --> 00:10:19,200
trail instead of hydrogen oxide which is

283
00:10:23,590 --> 00:10:21,839
water you leave hydrogen fluoride which

284
00:10:25,509 --> 00:10:23,600
is hydrofluoric acid and that like

285
00:10:26,710 --> 00:10:25,519
etches glass and

286
00:10:28,630 --> 00:10:26,720
anyway the environmental impact

287
00:10:29,670 --> 00:10:28,640
statement is beyond what we wanted to do

288
00:10:31,110 --> 00:10:29,680

and the

289
00:10:33,590 --> 00:10:31,120
performance gain

290
00:10:35,509 --> 00:10:33,600
isn't that great so

291
00:10:38,150 --> 00:10:35,519
let's just say we're stuck with oxygen

292
00:10:40,870 --> 00:10:38,160
fluorine doesn't help you that much

293
00:10:42,630 --> 00:10:40,880
our fuel is hydrogen that's the lightest

294
00:10:44,069 --> 00:10:42,640
element in the periodic chart and we are

295
00:10:45,430 --> 00:10:44,079
quite confident that we have thoroughly

296
00:10:46,710 --> 00:10:45,440
explored the periodic table of the

297
00:10:48,630 --> 00:10:46,720
element and we are not going to find any

298
00:10:49,670 --> 00:10:48,640
elements lighter in hydrogen

299
00:10:52,150 --> 00:10:49,680
so

300
00:10:53,590 --> 00:10:52,160
our two parameters that we can mess with

301
00:10:55,990 --> 00:10:53,600
to get more performance out of this

302
00:10:59,430 --> 00:10:56,000
engine temperature molecular weight and

303
00:11:01,829 --> 00:10:59,440
we're stuck we're at the limits of what

304
00:11:03,590 --> 00:11:01,839
the materials available to us

305
00:11:05,509 --> 00:11:03,600
and all the clever engineering that we

306
00:11:06,949 --> 00:11:05,519
can do with those materials

307
00:11:07,829 --> 00:11:06,959
will provide

308
00:11:10,630 --> 00:11:07,839
so i don't think we're going to do

309
00:11:12,230 --> 00:11:10,640
better than this with chemical engines

310
00:11:13,990 --> 00:11:12,240
uh if you're not using chemical engines

311
00:11:16,389 --> 00:11:14,000
then we have a different story but we'll

312
00:11:18,550 --> 00:11:16,399
talk about that later

313
00:11:21,190 --> 00:11:18,560

so despite those limitations

314
00:11:24,230 --> 00:11:21,200
despite having to carry many times more

315
00:11:26,150 --> 00:11:24,240
fuel than your payload weighs we did use

316
00:11:27,430 --> 00:11:26,160
chemical engines 40 years ago to get to

317
00:11:28,870 --> 00:11:27,440
the moon

318
00:11:31,910 --> 00:11:28,880
so let's talk about that for a few

319
00:11:37,030 --> 00:11:34,230
so here's our earth 8 000 miles across

320
00:11:39,190 --> 00:11:37,040
now we're going to pull the camera back

321
00:11:42,949 --> 00:11:39,200
we're going to back up and back up and

322
00:11:45,670 --> 00:11:42,959
back up until you can see this little

323
00:11:47,829 --> 00:11:45,680
gray dot there and that's the moon and

324
00:11:49,590 --> 00:11:47,839
this picture is to scale

325
00:11:51,750 --> 00:11:49,600
so it's the earth and moon at their

326
00:11:53,910 --> 00:11:51,760
correct relative sizes and the correct

327
00:11:56,310 --> 00:11:53,920
relative spacing between them about 30

328
00:11:57,750 --> 00:11:56,320
earth diameters between the earth and

329
00:11:59,509 --> 00:11:57,760
the moon

330
00:12:01,269 --> 00:11:59,519
and that distance as we all know well

331
00:12:03,910 --> 00:12:01,279
here at jsc is about a quarter of a

332
00:12:06,230 --> 00:12:04,790
and

333
00:12:07,590 --> 00:12:06,240
if you take off three zeros you get

334
00:12:09,030 --> 00:12:07,600
approximately the distance of the space

335
00:12:10,470 --> 00:12:09,040
station from earth

336
00:12:11,829 --> 00:12:10,480
so the moon's about a thousand times

337
00:12:13,430 --> 00:12:11,839
further out into space than the space

338
00:12:16,949 --> 00:12:13,440

station is

339
00:12:19,590 --> 00:12:16,959
but the problem is not the distance

340
00:12:21,190 --> 00:12:19,600
the problem is the speed

341
00:12:22,550 --> 00:12:21,200
let's talk about

342
00:12:24,790 --> 00:12:22,560
the speed you need to get to the moon

343
00:12:26,870 --> 00:12:24,800
and back

344
00:12:28,550 --> 00:12:26,880
so uh we're going to launch into low

345
00:12:29,910 --> 00:12:28,560
earth orbit which takes 20 000 miles per

346
00:12:31,990 --> 00:12:29,920
hour

347
00:12:33,990 --> 00:12:32,000
remember if we get 99 percent of the way

348
00:12:35,430 --> 00:12:34,000
way there we drop wreckage all over you

349
00:12:37,350 --> 00:12:35,440
know africa or europe or something we

350
00:12:39,590 --> 00:12:37,360
don't want to do that

351
00:12:41,670 --> 00:12:39,600
takes another 8 200 miles per hour once

352
00:12:43,750 --> 00:12:41,680
you're in low earth orbit to break out

353
00:12:46,310 --> 00:12:43,760
of low earth orbit and head to the moon

354
00:12:47,750 --> 00:12:46,320
if you only get 8 000 miles per hour you

355
00:12:48,949 --> 00:12:47,760
get in a high earth orbit and you come

356
00:12:50,389 --> 00:12:48,959
right back and you never make it to the

357
00:12:54,790 --> 00:12:50,399
moon it's embarrassing you have to

358
00:12:59,190 --> 00:12:56,550
once you approach the moon you have to

359
00:13:00,870 --> 00:12:59,200
do a burn of about 2 400 miles per hour

360
00:13:03,110 --> 00:13:00,880
to drop into orbit around the moon

361
00:13:04,389 --> 00:13:03,120
otherwise you just fly past the moon and

362
00:13:06,949 --> 00:13:04,399
if you're lucky you come back to earth

363
00:13:08,710 --> 00:13:06,959

the way apollo 13 did if you're unlucky

364
00:13:10,230 --> 00:13:08,720
you get kicked out into orbit around the

365
00:13:11,750 --> 00:13:10,240
sun or you never come back and that's

366
00:13:13,110 --> 00:13:11,760
bad so

367
00:13:16,069 --> 00:13:13,120
it's very important to complete that

368
00:13:20,710 --> 00:13:18,710
once in low lunar orbit you need to kill

369
00:13:22,550 --> 00:13:20,720
off your forward speed in orbit around

370
00:13:24,069 --> 00:13:22,560
the moon so that you can come down to

371
00:13:26,150 --> 00:13:24,079
the surface

372
00:13:28,550 --> 00:13:26,160
that takes a burn of about 3 900 miles

373
00:13:30,389 --> 00:13:28,560
per hour

374
00:13:31,910 --> 00:13:30,399
as you approach the surface you don't

375
00:13:33,670 --> 00:13:31,920
really want to hit orbital speed nor do

376
00:13:34,790 --> 00:13:33,680
you want to drop from orbital height you

377
00:13:36,629 --> 00:13:34,800
need to

378
00:13:37,750 --> 00:13:36,639
expend some gas

379
00:13:40,790 --> 00:13:37,760
to

380
00:13:42,230 --> 00:13:40,800
hover and land softly and that takes

381
00:13:43,509 --> 00:13:42,240
about 700 miles per hour and i didn't

382
00:13:45,030 --> 00:13:43,519
have a picture of that because of course

383
00:13:46,710 --> 00:13:45,040
there was nobody pointing the camera at

384
00:13:49,590 --> 00:13:46,720
the lander as it was landing on the moon

385
00:13:52,389 --> 00:13:49,600
but this is the lunar lander trainer

386
00:13:54,389 --> 00:13:52,399
being flown out at ellington field

387
00:13:56,550 --> 00:13:54,399
one of these actually had a malfunction

388
00:13:58,069 --> 00:13:56,560

in flight and neil armstrong had to bail

389
00:14:01,030 --> 00:13:58,079
out of it it crashed and he landed

390
00:14:02,470 --> 00:14:01,040
safely on his parachute

391
00:14:04,870 --> 00:14:02,480
and there's one of these hanging up in

392
00:14:09,189 --> 00:14:04,880
the uh teague auditorium front hall you

393
00:14:11,910 --> 00:14:10,629
once you're there

394
00:14:13,829 --> 00:14:11,920
you get to do all the fun stuff and we

395
00:14:15,269 --> 00:14:13,839
don't have to burn any propellant we can

396
00:14:16,710 --> 00:14:15,279
collect our samples we can salute the

397
00:14:17,990 --> 00:14:16,720
flag

398
00:14:19,110 --> 00:14:18,000
you can drive around the moon buggy you

399
00:14:20,949 --> 00:14:19,120
can

400
00:14:22,949 --> 00:14:20,959
hit a golf ball

401
00:14:25,990 --> 00:14:22,959
and it's time to come home

402
00:14:27,590 --> 00:14:26,000
700 mile per hour burn to lift off and

403
00:14:30,150 --> 00:14:27,600
support the weight of the spacecraft

404
00:14:32,470 --> 00:14:30,160
while you are re-attaining your orbital

405
00:14:36,550 --> 00:14:32,480
speed again if you fail on this you

406
00:14:41,110 --> 00:14:39,350
another 3 900 miles per hour to regain

407
00:14:42,470 --> 00:14:41,120
lunar orbit speed put yourself in a nice

408
00:14:44,949 --> 00:14:42,480
circular orbit around the moon if you

409
00:14:47,430 --> 00:14:44,959
fail in this you crash on the surface

410
00:14:51,910 --> 00:14:47,440
and perish you may notice a kind of a

411
00:14:55,750 --> 00:14:53,430
once you've achieved low learner orbit

412
00:14:57,350 --> 00:14:55,760
it takes another 2 400 miles per hour to

413
00:14:58,790 --> 00:14:57,360

break out of low lunar orbit and head

414
00:15:00,069 --> 00:14:58,800
back toward the earth if you fail in

415
00:15:01,670 --> 00:15:00,079
this you're stuck in orbit around the

416
00:15:06,629 --> 00:15:01,680
moon until your supplies run out and you

417
00:15:11,030 --> 00:15:08,710
now we finally get a break uh coming

418
00:15:12,470 --> 00:15:11,040
back to the earth's atmosphere we can

419
00:15:13,990 --> 00:15:12,480
use the atmosphere

420
00:15:15,269 --> 00:15:14,000
to slow down

421
00:15:16,710 --> 00:15:15,279
uh that's what space shuttle did every

422
00:15:18,310 --> 00:15:16,720
time it returned from orbit that's what

423
00:15:19,829 --> 00:15:18,320
soyuz does every time and that's what

424
00:15:21,509 --> 00:15:19,839
the apollo capsules did except they came

425
00:15:23,509 --> 00:15:21,519
in at a speed about 40 percent higher

426
00:15:25,269 --> 00:15:23,519
than the shuttle or soyuz the gas

427
00:15:27,110 --> 00:15:25,279
temperature

428
00:15:28,230 --> 00:15:27,120
in front of the spacecraft as it's doing

429
00:15:30,389 --> 00:15:28,240
its atmospheric energy with something

430
00:15:32,790 --> 00:15:30,399
like 18 000 degrees fahrenheit this is

431
00:15:35,030 --> 00:15:32,800
actually a photograph from the ground of

432
00:15:37,670 --> 00:15:35,040
an apollo capsule coming in to the

433
00:15:38,790 --> 00:15:37,680
atmosphere on its way back from the moon

434
00:15:40,230 --> 00:15:38,800
but you don't have to expend any

435
00:15:43,509 --> 00:15:40,240
propellant you just have to carry a

436
00:15:46,550 --> 00:15:44,870
and then finally the earth does have

437
00:15:48,389 --> 00:15:46,560
enough atmosphere that once you get low

438
00:15:50,069 --> 00:15:48,399

and slow you can pop out a parachute and

439
00:15:51,990 --> 00:15:50,079
let the atmospheres

440
00:15:53,670 --> 00:15:52,000
gradually decelerate you land in the

441
00:15:55,269 --> 00:15:53,680
water and that doesn't take any

442
00:15:57,189 --> 00:15:55,279
propellant so let's add it all up and

443
00:16:00,230 --> 00:15:57,199
you get

444
00:16:04,470 --> 00:16:00,240
42 000 miles per hour

445
00:16:08,310 --> 00:16:05,670
and we're doing it all with chemical

446
00:16:11,990 --> 00:16:08,320
rocket engines and that is why

447
00:16:13,269 --> 00:16:12,000
of this 360 foot tall rocket that left

448
00:16:15,829 --> 00:16:13,279
the pad

449
00:16:17,110 --> 00:16:15,839
what we got back was this little 10-foot

450
00:16:18,790 --> 00:16:17,120
cone

451
00:16:21,990 --> 00:16:18,800
that little tiny thing up there on the

452
00:16:23,509 --> 00:16:22,000
top the entire rest of that huge rocket

453
00:16:26,069 --> 00:16:23,519
is either propellant that we throw out

454
00:16:27,990 --> 00:16:26,079
the back or empty propellant tanks which

455
00:16:31,269 --> 00:16:28,000
we throw away because we can't afford to

456
00:16:32,629 --> 00:16:31,279
carry their empty weight any further

457
00:16:35,670 --> 00:16:32,639
you just can't take the propellant

458
00:16:38,069 --> 00:16:35,680
that's like buying a boeing 737 brands

459
00:16:41,269 --> 00:16:38,079
shiny new flying it from houston to san

460
00:16:47,430 --> 00:16:41,279
antonio and scrapping it

461
00:16:50,710 --> 00:16:48,790
let's take a look at that little cone

462
00:16:52,470 --> 00:16:50,720
again

463
00:16:54,629 --> 00:16:52,480

that thing weighed about six tons and

464
00:16:56,550 --> 00:16:54,639
into that we had to put our three brave

465
00:16:58,710 --> 00:16:56,560
explorers

466
00:17:00,470 --> 00:16:58,720
the equivalent of about 33 scuba

467
00:17:03,189 --> 00:17:00,480
cylinders full of oxygen for them to

468
00:17:04,549 --> 00:17:03,199
breathe that's three guys for a week

469
00:17:06,069 --> 00:17:04,559
they carried liquid oxygen so they

470
00:17:07,669 --> 00:17:06,079
didn't actually carry pressurized gas

471
00:17:09,669 --> 00:17:07,679
for them it takes up less room as a

472
00:17:10,870 --> 00:17:09,679
liquid

473
00:17:12,549 --> 00:17:10,880
three people for a week is going to

474
00:17:13,909 --> 00:17:12,559
drink up about four of those great big

475
00:17:15,429 --> 00:17:13,919
plastic bottles you have in the water

476
00:17:17,510 --> 00:17:15,439
cooler

477
00:17:18,549 --> 00:17:17,520
for water and about one cart load of

478
00:17:20,870 --> 00:17:18,559
groceries

479
00:17:22,870 --> 00:17:20,880
to keep them fed for a week

480
00:17:27,429 --> 00:17:22,880
and all that fits into a six-ton vehicle

481
00:17:33,110 --> 00:17:29,510
all right

482
00:17:34,310 --> 00:17:33,120
let's talk about mars now

483
00:17:36,950 --> 00:17:34,320
so

484
00:17:38,870 --> 00:17:36,960
this is where it gets difficult

485
00:17:40,230 --> 00:17:38,880
let's start with the speeds the way we

486
00:17:41,830 --> 00:17:40,240
did for the moon

487
00:17:44,789 --> 00:17:41,840
uh we're going to launch into low earth

488
00:17:46,310 --> 00:17:44,799

orbit on our way to mars this is our sls

489
00:17:47,669 --> 00:17:46,320
space launch system rocket that's under

490
00:17:49,190 --> 00:17:47,679
development right now

491
00:17:50,950 --> 00:17:49,200
in its heavy lift version which should

492
00:17:52,789 --> 00:17:50,960
be able to put 130 tons in low earth

493
00:17:55,669 --> 00:17:52,799
orbit slightly bigger than the saturn v

494
00:17:56,950 --> 00:17:55,679
that we used for the moon

495
00:17:58,549 --> 00:17:56,960
once in low earth orbit we're going to

496
00:18:00,710 --> 00:17:58,559
do a burn to send ourselves on the way

497
00:18:01,669 --> 00:18:00,720
to mars that's about 9 000 miles per

498
00:18:04,630 --> 00:18:01,679
hour

499
00:18:08,789 --> 00:18:04,640
notice that that's like 10 percent more

500
00:18:10,870 --> 00:18:08,799
speed than it took to go to the moon

501
00:18:12,390 --> 00:18:10,880
8200 miles per hour to put yourself on

502
00:18:14,150 --> 00:18:12,400
course from low earth orbit to the moon

503
00:18:16,789 --> 00:18:14,160
just 800 miles per hour more and you're

504
00:18:18,310 --> 00:18:16,799
on your way to mars

505
00:18:20,230 --> 00:18:18,320
that's the advantage you get of doing an

506
00:18:22,950 --> 00:18:20,240
engine burn down deep in a gravity well

507
00:18:24,950 --> 00:18:22,960
little differences in speed down low

508
00:18:28,150 --> 00:18:24,960
make a big difference in your speed once

509
00:18:30,150 --> 00:18:28,160
you get high up away from the earth

510
00:18:32,789 --> 00:18:30,160
after a substantial period of cruise

511
00:18:35,029 --> 00:18:32,799
that we'll go into detail later

512
00:18:36,150 --> 00:18:35,039
you arrive at mars and mars does have

513
00:18:38,070 --> 00:18:36,160

enough of an atmosphere that if you

514
00:18:40,310 --> 00:18:38,080
carry a big heat shield you can use the

515
00:18:41,590 --> 00:18:40,320
atmosphere to slow down so you can slow

516
00:18:42,950 --> 00:18:41,600
down when you get to mars without having

517
00:18:45,990 --> 00:18:42,960
to burn engines and it doesn't cost you

518
00:18:47,830 --> 00:18:46,000
any propellant such a deal however

519
00:18:50,070 --> 00:18:47,840
mars does not have enough atmosphere to

520
00:18:53,430 --> 00:18:50,080
land anything bigger than say one of the

521
00:18:55,110 --> 00:18:53,440
current mars rovers on a parachute

522
00:18:57,909 --> 00:18:55,120
the mars rover that's going to arrive

523
00:18:59,750 --> 00:18:57,919
next month has to use a propulsive

524
00:19:01,350 --> 00:18:59,760
system to slow down because we couldn't

525
00:19:03,430 --> 00:19:01,360
pack in a parachute big enough to slow

526
00:19:04,710 --> 00:19:03,440
it down

527
00:19:06,070 --> 00:19:04,720
and if you put people onboard a

528
00:19:08,150 --> 00:19:06,080
spacecraft it's going to be huge and

529
00:19:09,830 --> 00:19:08,160
there's just not enough air there so

530
00:19:11,270 --> 00:19:09,840
we're going to have to do a propulsive

531
00:19:13,830 --> 00:19:11,280
landing which means supporting the

532
00:19:15,669 --> 00:19:13,840
weight of the spacecraft against the

533
00:19:17,669 --> 00:19:15,679
pull of mars is gravity after you've

534
00:19:18,870 --> 00:19:17,679
slowed down from cosmic speed so that

535
00:19:20,310 --> 00:19:18,880
you can make a soft landing and that's

536
00:19:22,230 --> 00:19:20,320
going to take you about 2000 miles per

537
00:19:25,190 --> 00:19:22,240
hour because mars gravity is stronger

538
00:19:26,390 --> 00:19:25,200

than the moons

539
00:19:30,710 --> 00:19:26,400
once you're there you can have all your

540
00:19:36,710 --> 00:19:31,990
make statements for your corporate

541
00:19:41,190 --> 00:19:38,950
and then it's time to come home

542
00:19:43,190 --> 00:19:41,200
uh a word on this when we get ready to

543
00:19:45,510 --> 00:19:43,200
launch a vehicle

544
00:19:47,190 --> 00:19:45,520
out of florida there are thousands of

545
00:19:49,590 --> 00:19:47,200
dedicated workers down there at kennedy

546
00:19:50,950 --> 00:19:49,600
space center who do all the preparations

547
00:19:52,710 --> 00:19:50,960
they check the spacecraft out they help

548
00:19:54,789 --> 00:19:52,720
the crew get in the capsule they're busy

549
00:19:56,710 --> 00:19:54,799
for months to prepare for a proper

550
00:19:58,870 --> 00:19:56,720
launch when you get to mars and it's

551
00:20:00,870 --> 00:19:58,880
time to come home you will do all of

552
00:20:02,950 --> 00:20:00,880
that yourself

553
00:20:04,950 --> 00:20:02,960
with no help

554
00:20:06,710 --> 00:20:04,960
so the systems have to be really

555
00:20:09,029 --> 00:20:06,720
autonomous they have to be very simple

556
00:20:10,149 --> 00:20:09,039
to work because you don't get any help

557
00:20:12,870 --> 00:20:10,159
when you're getting ready to launch off

558
00:20:15,029 --> 00:20:12,880
mars so 17 000 miles per hour is what it

559
00:20:17,669 --> 00:20:15,039
takes both to get off mars

560
00:20:19,510 --> 00:20:17,679
and then the extra boost you need to

561
00:20:21,350 --> 00:20:19,520
send yourself on a course back to the

562
00:20:23,270 --> 00:20:21,360
earth and notice that that is almost

563
00:20:25,190 --> 00:20:23,280

what it took to get into low earth orbit

564
00:20:26,950 --> 00:20:25,200
so this is a lot of propellant you're

565
00:20:31,990 --> 00:20:26,960
gonna have a very big rocket a very

566
00:20:37,190 --> 00:20:34,310
after another lengthy cruise period you

567
00:20:38,710 --> 00:20:37,200
return to the earth and here it has

568
00:20:40,630 --> 00:20:38,720
enough atmosphere to slow you down from

569
00:20:42,470 --> 00:20:40,640
cosmic speed um you're going to come

570
00:20:45,110 --> 00:20:42,480
into the atmosphere even faster than you

571
00:20:46,070 --> 00:20:45,120
did when you return from the moon

572
00:20:46,950 --> 00:20:46,080
um

573
00:20:49,590 --> 00:20:46,960
maybe

574
00:20:51,430 --> 00:20:49,600
an extra 10 faster

575
00:20:53,510 --> 00:20:51,440
this means your heat shield has to have

576
00:20:55,590 --> 00:20:53,520
a higher performance than a lunar heat

577
00:20:56,630 --> 00:20:55,600
shield but we have brought capsule

578
00:20:57,990 --> 00:20:56,640
shapes

579
00:21:00,230 --> 00:20:58,000
into the earth's atmosphere at those

580
00:21:03,110 --> 00:21:00,240
speeds before the stardust sample

581
00:21:05,590 --> 00:21:03,120
returned cancer which was a little tiny

582
00:21:08,070 --> 00:21:05,600
apollo capsule shape with a heat shield

583
00:21:09,350 --> 00:21:08,080
came in at roughly mars return speed and

584
00:21:10,549 --> 00:21:09,360
it did all right but that was a little

585
00:21:12,710 --> 00:21:10,559
tiny thing we'll have to build a bigger

586
00:21:14,070 --> 00:21:12,720
one the orion space capsule by the way

587
00:21:16,630 --> 00:21:14,080
that are developing right now is

588
00:21:18,390 --> 00:21:16,640

designed for mars return so they have

589
00:21:20,070 --> 00:21:18,400
that in mind but the

590
00:21:21,190 --> 00:21:20,080
initial version of the heat shield won't

591
00:21:24,310 --> 00:21:21,200
be

592
00:21:25,590 --> 00:21:24,320
sized for mars return speeds

593
00:21:27,350 --> 00:21:25,600
but at least you don't have to spend any

594
00:21:29,669 --> 00:21:27,360
propellant to do it

595
00:21:31,350 --> 00:21:29,679
then once again earth has of atmosphere

596
00:21:33,029 --> 00:21:31,360
that you can land softly on a parachute

597
00:21:35,750 --> 00:21:33,039
this is an actual orion capsule drop

598
00:21:41,510 --> 00:21:37,510
so we'll add them all up

599
00:21:44,630 --> 00:21:41,520
and we get 48 000 miles per hour

600
00:21:47,110 --> 00:21:44,640
only about 20 percent more speed than it

601
00:21:49,510 --> 00:21:47,120
took to get to the moon

602
00:21:51,270 --> 00:21:49,520
that's hardly any difference at all

603
00:21:53,590 --> 00:21:51,280
so how come 40 years after we went to

604
00:21:57,270 --> 00:21:53,600
the moon we can't get to mars

605
00:22:01,190 --> 00:21:57,280
and the answer is it's not the speed

606
00:22:04,789 --> 00:22:03,350
so here's our picture of the earth and

607
00:22:07,270 --> 00:22:04,799
moon with a quarter million miles in

608
00:22:09,830 --> 00:22:07,280
between them and let's pull the camera

609
00:22:11,350 --> 00:22:09,840
back one more time

610
00:22:12,549 --> 00:22:11,360
and pull it back

611
00:22:14,950 --> 00:22:12,559
pull it back

612
00:22:16,950 --> 00:22:14,960
hard to see things so i'm going to have

613
00:22:20,149 --> 00:22:16,960

to draw uh some extra stuff for you to

614
00:22:21,909 --> 00:22:20,159
look at that dashed line is the circle

615
00:22:23,669 --> 00:22:21,919
that the moon makes in its orbit around

616
00:22:25,750 --> 00:22:23,679
the earth the diameter of that circle

617
00:22:26,549 --> 00:22:25,760
about a half a million miles the moon is

618
00:22:28,070 --> 00:22:26,559
now

619
00:22:30,470 --> 00:22:28,080
much smaller than the dashes you can't

620
00:22:32,870 --> 00:22:30,480
see it anymore and the earth is just a

621
00:22:36,230 --> 00:22:35,029
and we'll back out the camera some more

622
00:22:41,669 --> 00:22:36,240
and more

623
00:22:43,590 --> 00:22:41,679
until

624
00:22:44,950 --> 00:22:43,600
now even my circle of the earth's orbit

625
00:22:46,710 --> 00:22:44,960
around them or the moons orbit around

626
00:22:48,630 --> 00:22:46,720
the earth is tiny and i'll have to draw

627
00:22:50,390 --> 00:22:48,640
you another landmark

628
00:22:52,149 --> 00:22:50,400
so the big

629
00:22:55,350 --> 00:22:52,159
blue dash circle is the orbit of the

630
00:22:57,830 --> 00:22:55,360
earth around the sun the yellow dash

631
00:22:59,350 --> 00:22:57,840
circle is the orbit of the planet venus

632
00:23:01,029 --> 00:22:59,360
around the sun

633
00:23:03,190 --> 00:23:01,039
and at their closest approach the

634
00:23:05,110 --> 00:23:03,200
planets are about 26 million miles apart

635
00:23:06,710 --> 00:23:05,120
this happened just last month when venus

636
00:23:08,230 --> 00:23:06,720
did a transit of the sun was directly

637
00:23:10,070 --> 00:23:08,240
between the earth and sun it was about

638
00:23:12,470 --> 00:23:10,080

26 million miles away from us at that

639
00:23:14,950 --> 00:23:14,070
but we're not done pulling the camera

640
00:23:18,149 --> 00:23:14,960
out

641
00:23:21,110 --> 00:23:18,159
orbit of mercury now coming into view

642
00:23:23,190 --> 00:23:21,120
and the sun coming into view

643
00:23:25,510 --> 00:23:23,200
and we're going to pull out and pull out

644
00:23:28,630 --> 00:23:25,520
until finally i'm sorry that's hard to

645
00:23:31,110 --> 00:23:28,640
see you can see this red circle

646
00:23:32,630 --> 00:23:31,120
and that's the orbit of mars

647
00:23:34,310 --> 00:23:32,640
so those are the orbits of the four

648
00:23:36,149 --> 00:23:34,320
inner planets around the sun the planets

649
00:23:38,630 --> 00:23:36,159
themselves are invisibly tiny at this

650
00:23:40,630 --> 00:23:38,640
scale and even the symbol for the sun is

651
00:23:42,549 --> 00:23:40,640
artificially big just so you can see

652
00:23:44,950 --> 00:23:42,559
where it is

653
00:23:46,549 --> 00:23:44,960
so let's de-clutter the inner planets

654
00:23:49,190 --> 00:23:46,559
and

655
00:23:51,269 --> 00:23:49,200
put some scale on here so the earth is

656
00:23:52,950 --> 00:23:51,279
on average about 93 million miles from

657
00:23:53,990 --> 00:23:52,960
the sun it takes it 12 months to go

658
00:23:56,390 --> 00:23:54,000
around

659
00:23:58,310 --> 00:23:56,400
mars on average about 140 million miles

660
00:24:00,070 --> 00:23:58,320
from the sun it takes it 22 and a half

661
00:24:01,590 --> 00:24:00,080
months to go around and everything in

662
00:24:03,590 --> 00:24:01,600
the solar system circles around the sun

663
00:24:05,750 --> 00:24:03,600

counterclockwise is seen from the north

664
00:24:09,350 --> 00:24:05,760
so the direction of the arrows indicates

665
00:24:13,669 --> 00:24:11,750
so uh that doesn't look too bad

666
00:24:15,590 --> 00:24:13,679
why don't we just wait until the planets

667
00:24:17,990 --> 00:24:15,600
line up where mars is at its closest

668
00:24:19,110 --> 00:24:18,000
approach to earth and fly there like

669
00:24:27,669 --> 00:24:19,120
that

670
00:24:31,590 --> 00:24:27,679
around

671
00:24:32,390 --> 00:24:31,600
250 000 miles per hour

672
00:24:34,070 --> 00:24:32,400
and

673
00:24:36,390 --> 00:24:34,080
once again

674
00:24:38,789 --> 00:24:36,400
we have yet to develop warp drive we

675
00:24:40,710 --> 00:24:38,799
can't do that

676
00:24:44,470 --> 00:24:40,720
so instead we're going to have to use

677
00:24:48,230 --> 00:24:46,470
our transfer orbit is an elliptical

678
00:24:49,669 --> 00:24:48,240
orbit around the sun

679
00:24:51,510 --> 00:24:49,679
you can put anything on that orbit and

680
00:24:52,710 --> 00:24:51,520
it will continue to orbit the sun until

681
00:24:54,710 --> 00:24:52,720
it hits something or gets kicked out of

682
00:24:58,070 --> 00:24:54,720
the solar system

683
00:25:00,310 --> 00:24:58,080
in this case our transfer orbit is

684
00:25:03,190 --> 00:25:00,320
at its closest point to the sun it's as

685
00:25:05,269 --> 00:25:03,200
far from the sun as the earth is

686
00:25:07,269 --> 00:25:05,279
and at its furthest point from the sun

687
00:25:09,430 --> 00:25:07,279
it's as far from the sun as the planet

688
00:25:11,190 --> 00:25:09,440

mars is

689
00:25:12,789 --> 00:25:11,200
i say we just go ahead and put something

690
00:25:14,710 --> 00:25:12,799
on that orbit and we'll continue to

691
00:25:17,350 --> 00:25:14,720
shuttle back and forth between the orbit

692
00:25:18,630 --> 00:25:17,360
of the earth and the orbit of mars

693
00:25:20,470 --> 00:25:18,640
forever

694
00:25:23,830 --> 00:25:20,480
and it takes about 17 months for it to

695
00:25:28,310 --> 00:25:25,830
and that is the orbit that we used when

696
00:25:30,149 --> 00:25:28,320
we calculated those speeds earlier so

697
00:25:33,029 --> 00:25:30,159
this is our minimum energy trajectory to

698
00:25:37,510 --> 00:25:34,549
you could think about trying to go

699
00:25:39,590 --> 00:25:37,520
faster but then you're wasting fuel and

700
00:25:41,350 --> 00:25:39,600
wasting fuel means bigger than necessary

701
00:25:44,149 --> 00:25:41,360
tank bigger than necessary rocket and

702
00:25:45,269 --> 00:25:44,159
bigger than necessary budget

703
00:25:47,909 --> 00:25:45,279
people are going to give you trouble for

704
00:25:50,789 --> 00:25:49,110
another thing to remember about our

705
00:25:52,390 --> 00:25:50,799
transfer orbit

706
00:25:54,710 --> 00:25:52,400
there are no boomerang flights when you

707
00:25:56,710 --> 00:25:54,720
go to mars once you have done that burn

708
00:25:58,310 --> 00:25:56,720
to set yourself on the way to mars we

709
00:25:59,669 --> 00:25:58,320
can't carry enough propellant to turn

710
00:26:01,430 --> 00:25:59,679
around and come home if we decide we

711
00:26:02,549 --> 00:26:01,440
don't like the way things are going

712
00:26:07,430 --> 00:26:02,559
once you're

713
00:26:11,029 --> 00:26:09,510

so

714
00:26:12,789 --> 00:26:11,039
let's make it go here

715
00:26:14,470 --> 00:26:12,799
here's our map of the solar system sun

716
00:26:17,190 --> 00:26:14,480
in the center orbit of the earth orbit

717
00:26:19,350 --> 00:26:17,200
of mars our transfer orbit in white the

718
00:26:20,870 --> 00:26:19,360
dots the blue dot represents the earth

719
00:26:23,510 --> 00:26:20,880
remember the earth itself is invisibly

720
00:26:25,830 --> 00:26:23,520
tiny at this scale red dot

721
00:26:28,310 --> 00:26:25,840
represents mars the mars itself is much

722
00:26:30,549 --> 00:26:28,320
too small to see white dot represents

723
00:26:33,750 --> 00:26:30,559
our spacecraft and of course it's way

724
00:26:37,830 --> 00:26:35,750
so we will start and we're going to

725
00:26:38,870 --> 00:26:37,840
count months down here and see how it

726
00:26:41,110 --> 00:26:38,880
goes

727
00:26:42,870 --> 00:26:41,120
we're going to launch off of earth we're

728
00:26:44,870 --> 00:26:42,880
going to give ourselves a little excess

729
00:26:46,390 --> 00:26:44,880
speed in orbit around the sun so we pull

730
00:26:47,909 --> 00:26:46,400
away from the earth

731
00:26:49,830 --> 00:26:47,919
leading it

732
00:26:52,470 --> 00:26:49,840
and then that extra speed will carry us

733
00:26:55,830 --> 00:26:52,480
uphill out toward the orbit of mars as

734
00:26:57,269 --> 00:26:55,840
the months go by six seven eight months

735
00:27:01,950 --> 00:26:57,279
eight and a half months

736
00:27:04,870 --> 00:27:01,960
we have arrived at the orbit of mars

737
00:27:06,549 --> 00:27:04,880
unfortunately the planet itself is 80

738
00:27:08,390 --> 00:27:06,559

million miles away from us behind it

739
00:27:09,750 --> 00:27:08,400
behind in orbit it's further away from

740
00:27:12,950 --> 00:27:09,760
us than when we started and we're

741
00:27:12,960 --> 00:27:16,470
and we got to explain that later

742
00:27:19,590 --> 00:27:17,990
but it gets worse remember once we're

743
00:27:21,990 --> 00:27:19,600
launched we're committed we don't have

744
00:27:23,909 --> 00:27:22,000
the propellant to do anything different

745
00:27:26,710 --> 00:27:23,919
we will continue in our orbit around the

746
00:27:28,870 --> 00:27:26,720
sun just like asteroid or comet

747
00:27:32,870 --> 00:27:28,880
until 17 months after launch we have

748
00:27:35,110 --> 00:27:32,880
arrived back at the orbit of the earth

749
00:27:36,310 --> 00:27:35,120
but unfortunately the earth itself is

750
00:27:38,230 --> 00:27:36,320
clear over on the other side of the sun

751
00:27:39,669 --> 00:27:38,240
160 million miles away we're nowhere

752
00:27:41,430 --> 00:27:39,679
near it and we're just going to keep

753
00:27:42,870 --> 00:27:41,440
going around the sun like an asteroid or

754
00:27:45,590 --> 00:27:42,880
comet until our supplies run out and we

755
00:27:48,710 --> 00:27:47,350
ah that didn't work out so well so let's

756
00:27:50,470 --> 00:27:48,720
uh

757
00:27:52,230 --> 00:27:50,480
be smarter about our departure timing

758
00:27:53,510 --> 00:27:52,240
shall we

759
00:27:54,789 --> 00:27:53,520
so this time we're going to cleverly

760
00:27:56,470 --> 00:27:54,799
wait

761
00:27:58,070 --> 00:27:56,480
until the earth is here in its orbit and

762
00:27:59,990 --> 00:27:58,080
mars is uh

763
00:28:00,870 --> 00:28:00,000

40 degrees or so ahead of the earth in

764
00:28:02,389 --> 00:28:00,880
orbit

765
00:28:03,669 --> 00:28:02,399
when the planets reach that relative

766
00:28:05,190 --> 00:28:03,679
alignment

767
00:28:07,029 --> 00:28:05,200
that happens by the way about once every

768
00:28:08,549 --> 00:28:07,039
26 months

769
00:28:10,630 --> 00:28:08,559
imagine two cars on a racetrack going

770
00:28:12,630 --> 00:28:10,640
around at different speeds the earth

771
00:28:14,710 --> 00:28:12,640
has a smaller circle to go around and it

772
00:28:16,389 --> 00:28:14,720
travels faster in orbit than mars about

773
00:28:18,389 --> 00:28:16,399
every 26 months

774
00:28:20,549 --> 00:28:18,399
they are in the right alignment to send

775
00:28:21,590 --> 00:28:20,559
something from the earth to mars

776
00:28:23,990 --> 00:28:21,600
so we're going to be smart about our

777
00:28:25,590 --> 00:28:24,000
departure time we'll launch out of earth

778
00:28:27,029 --> 00:28:25,600
we'll count the months just like before

779
00:28:28,710 --> 00:28:27,039
we'll head out away from the sun on our

780
00:28:31,190 --> 00:28:28,720
transfer orbit

781
00:28:32,710 --> 00:28:31,200
once we get out toward the orbit of mars

782
00:28:34,230 --> 00:28:32,720
we're actually traveling slower than

783
00:28:36,070 --> 00:28:34,240
mars in orbit and it will catch up

784
00:28:37,590 --> 00:28:36,080
behind us

785
00:28:39,669 --> 00:28:37,600
and

786
00:28:41,029 --> 00:28:39,679
we made it we have arrived at the orbit

787
00:28:43,029 --> 00:28:41,039
of mars

788
00:28:44,070 --> 00:28:43,039

is not the same thing as mars orbit you

789
00:28:46,710 --> 00:28:44,080
read the newspaper you think oh yeah

790
00:28:48,070 --> 00:28:46,720
orbit of mars mars orbit same thing no

791
00:28:49,669 --> 00:28:48,080
orbit of mars

792
00:28:51,029 --> 00:28:49,679
the circle around the sun mars orbit

793
00:28:53,269 --> 00:28:51,039
that means you're going around mars in

794
00:28:55,510 --> 00:28:53,279
orbit we have arrived at

795
00:28:57,510 --> 00:28:55,520
the orbit of mars at the same time and

796
00:28:59,590 --> 00:28:57,520
place that mars itself is there we've

797
00:29:00,789 --> 00:28:59,600
arrived at the planet we plant the flag

798
00:29:02,710 --> 00:29:00,799
we make our footprints we thank our

799
00:29:07,909 --> 00:29:02,720
corporate sponsors and

800
00:29:10,230 --> 00:29:09,110
heading back in toward the orbit of

801
00:29:13,029 --> 00:29:10,240
earth and you can already tell that

802
00:29:14,470 --> 00:29:13,039
we're going to

803
00:29:16,149 --> 00:29:14,480
all right well we solved problem number

804
00:29:17,350 --> 00:29:16,159
one we got to mars but the problem

805
00:29:18,950 --> 00:29:17,360
number two

806
00:29:20,389 --> 00:29:18,960
where we have arrived back at the orbit

807
00:29:21,909 --> 00:29:20,399
of the earth

808
00:29:22,950 --> 00:29:21,919
and the earth itself is nowhere near us

809
00:29:25,430 --> 00:29:22,960
and we're going to circle around the sun

810
00:29:26,789 --> 00:29:25,440
until our supplies run out and we perish

811
00:29:31,590 --> 00:29:26,799
so

812
00:29:33,750 --> 00:29:31,600
third time pace for all

813
00:29:36,149 --> 00:29:33,760

we'll try one more time here

814
00:29:38,710 --> 00:29:36,159
we're gonna launch off of earth

815
00:29:40,470 --> 00:29:38,720
on our same transfer orbit

816
00:29:42,149 --> 00:29:40,480
we'll time our launch so that we arrive

817
00:29:44,470 --> 00:29:42,159
at the orbit of mars at the same time

818
00:29:45,750 --> 00:29:44,480
and played as places the planet does

819
00:29:46,789 --> 00:29:45,760
and eight and a half months later we

820
00:29:50,149 --> 00:29:46,799
arrive

821
00:29:54,630 --> 00:29:50,159
now we land and now we are going to wait

822
00:29:56,549 --> 00:29:54,640
for a good time to return to the earth

823
00:29:58,710 --> 00:29:56,559
since on mars we have

824
00:29:59,750 --> 00:29:58,720
at least 50 radiation protection because

825
00:30:01,430 --> 00:29:59,760
when you're standing on the surface you

826
00:30:03,029 --> 00:30:01,440
don't get radiation from underneath you

827
00:30:04,789 --> 00:30:03,039
have an atmosphere you can work with you

828
00:30:07,110 --> 00:30:04,799
have a lot of things you can do

829
00:30:08,710 --> 00:30:07,120
uh it's a good place to wait compared to

830
00:30:10,630 --> 00:30:08,720
deep space

831
00:30:12,070 --> 00:30:10,640
so we're going to wait on mars for the

832
00:30:13,990 --> 00:30:12,080
planets to line up so that we can safely

833
00:30:16,149 --> 00:30:14,000
come back to earth

834
00:30:18,389 --> 00:30:16,159
we're going to wait

835
00:30:26,149 --> 00:30:18,399
and wait

836
00:30:27,190 --> 00:30:26,159
until almost two years after we left the

837
00:30:29,029 --> 00:30:27,200
earth

838
00:30:32,630 --> 00:30:29,039

the planets have come around to the to

839
00:30:35,350 --> 00:30:32,640
an orientation where we can get back

840
00:30:36,710 --> 00:30:35,360
so we'll launch off of mars onto our

841
00:30:39,110 --> 00:30:36,720
it's the same

842
00:30:39,909 --> 00:30:39,120
transfer orbit except rotate it around

843
00:30:41,830 --> 00:30:39,919
now

844
00:30:43,990 --> 00:30:41,840
so that it connects where mars is when

845
00:30:45,510 --> 00:30:44,000
we left with with where earth will be

846
00:30:48,630 --> 00:30:45,520
when we get there

847
00:30:50,950 --> 00:30:48,640
we come falling in toward the sun

848
00:30:53,510 --> 00:30:50,960
when we get close to the earth we catch

849
00:30:55,669 --> 00:30:53,520
up from it to it from behind and finally

850
00:30:58,470 --> 00:30:55,679
32 months after we left

851
00:31:00,230 --> 00:30:58,480
we returned safely

852
00:31:03,190 --> 00:31:00,240
32 months

853
00:31:05,110 --> 00:31:03,200
that's like three years

854
00:31:06,230 --> 00:31:05,120
so

855
00:31:07,669 --> 00:31:06,240
we're going to spend three years in

856
00:31:11,110 --> 00:31:07,679
space

857
00:31:12,549 --> 00:31:11,120
design

858
00:31:14,310 --> 00:31:12,559
we're going to put our intrepid crew

859
00:31:15,590 --> 00:31:14,320
this is the crew of the mars 500

860
00:31:18,630 --> 00:31:15,600
simulation that was recently done in

861
00:31:19,909 --> 00:31:18,640
russia six people the uh psych folks

862
00:31:21,430 --> 00:31:19,919
tell us that six would be a good number

863
00:31:22,310 --> 00:31:21,440

to send to mars because if you get fewer

864
00:31:23,509 --> 00:31:22,320
than that

865
00:31:24,710 --> 00:31:23,519
you can get conflicts you know don't

866
00:31:26,070 --> 00:31:24,720
send three because two will gang up on

867
00:31:27,909 --> 00:31:26,080
one don't send two because two old gang

868
00:31:29,190 --> 00:31:27,919
up on two

869
00:31:30,470 --> 00:31:29,200
six is go and you can't send less than

870
00:31:31,750 --> 00:31:30,480
four because the international partners

871
00:31:33,830 --> 00:31:31,760
won't sign up unless their people get to

872
00:31:35,350 --> 00:31:33,840
go and

873
00:31:36,950 --> 00:31:35,360
we need international cooperation to be

874
00:31:38,789 --> 00:31:36,960
able to afford this

875
00:31:39,990 --> 00:31:38,799
so six is a good number now in 32 months

876
00:31:42,870 --> 00:31:40,000
six people are going to breathe up about

877
00:31:45,590 --> 00:31:42,880
9 000 scuba cylinders

878
00:31:47,029 --> 00:31:45,600
about 1100 big bottles of water you know

879
00:31:49,590 --> 00:31:47,039
one of those bottles weighs 40 pounds so

880
00:31:52,230 --> 00:31:49,600
40 000 pounds that's 20 tons of water

881
00:31:57,269 --> 00:31:52,240
and 280 carts full of groceries

882
00:32:00,470 --> 00:31:58,710
after 32 months they're not going to be

883
00:32:01,190 --> 00:32:00,480
appetizing anymore

884
00:32:03,509 --> 00:32:01,200
so

885
00:32:05,590 --> 00:32:03,519
that's a lot of supplies

886
00:32:08,070 --> 00:32:05,600
but it turns out we have a spacecraft

887
00:32:09,990 --> 00:32:08,080
that is sized properly for that big a

888
00:32:11,509 --> 00:32:10,000

crew and about that amount of supplies

889
00:32:13,509 --> 00:32:11,519
and it's called the international space

890
00:32:15,669 --> 00:32:13,519
station

891
00:32:18,549 --> 00:32:15,679
it's in orbit right now it weighs about

892
00:32:22,070 --> 00:32:18,559
420 tons

893
00:32:24,630 --> 00:32:22,080
and just as a reminder to build that

894
00:32:26,870 --> 00:32:24,640
took 27 of those

895
00:32:28,950 --> 00:32:26,880
two of those that's a proton and two of

896
00:32:31,029 --> 00:32:28,960
those as a soyuz that's just to bring

897
00:32:32,789 --> 00:32:31,039
the parts up that has nothing to do with

898
00:32:34,389 --> 00:32:32,799
the crew rotations the resupplies and

899
00:32:36,630 --> 00:32:34,399
all the other things that had to happen

900
00:32:39,269 --> 00:32:36,640
while we were building and have been

901
00:32:44,310 --> 00:32:39,279
operating the space station it takes all

902
00:32:47,990 --> 00:32:46,149
so that's kind of big and we'd like to

903
00:32:49,190 --> 00:32:48,000
make it smaller and there's a couple of

904
00:32:50,310 --> 00:32:49,200
ways that we can do that that we're

905
00:32:52,389 --> 00:32:50,320
investigating right now on the

906
00:32:54,230 --> 00:32:52,399
international space station the first is

907
00:32:55,590 --> 00:32:54,240
to try to recycle things especially that

908
00:32:58,870 --> 00:32:55,600
water

909
00:33:01,190 --> 00:32:58,880
breath and it's

910
00:33:02,630 --> 00:33:01,200
water vapor you can condense that and

911
00:33:04,310 --> 00:33:02,640
basically get distilled water which you

912
00:33:06,549 --> 00:33:04,320
can drink again you're also producing

913
00:33:08,149 --> 00:33:06,559

water in other ways

914
00:33:11,350 --> 00:33:08,159
which are also being recycled on the

915
00:33:13,029 --> 00:33:11,360
space station as my

916
00:33:14,710 --> 00:33:13,039
friend mike thinks says we're turning

917
00:33:16,870 --> 00:33:14,720
yesterday's coffee into tomorrow's

918
00:33:18,310 --> 00:33:16,880
coffee

919
00:33:19,669 --> 00:33:18,320
onboard the international space station

920
00:33:21,990 --> 00:33:19,679
so recycling

921
00:33:23,509 --> 00:33:22,000
is a great way to do this

922
00:33:25,990 --> 00:33:23,519
and we have

923
00:33:27,269 --> 00:33:26,000
machines on the station that can distill

924
00:33:29,350 --> 00:33:27,279
condensate and waste water to make

925
00:33:30,870 --> 00:33:29,360
drinkable water they can also take water

926
00:33:32,950 --> 00:33:30,880
that's not drinkable but still pure

927
00:33:35,110 --> 00:33:32,960
enough to do chemical reactions on and

928
00:33:35,830 --> 00:33:35,120
split that into oxygen and hydrogen they

929
00:33:37,430 --> 00:33:35,840
can

930
00:33:39,590 --> 00:33:37,440
bring the oxygen back into the cabin

931
00:33:40,950 --> 00:33:39,600
vent the hydrogen overboard and start to

932
00:33:42,070 --> 00:33:40,960
recycle some of the materials that we're

933
00:33:43,190 --> 00:33:42,080
using

934
00:33:45,110 --> 00:33:43,200
although

935
00:33:48,070 --> 00:33:45,120
truth be told those systems are not our

936
00:33:52,149 --> 00:33:49,029
the

937
00:33:55,990 --> 00:33:52,159
environmental control and life support

938
00:34:00,389 --> 00:33:57,669

and together they're called the regen

939
00:34:02,470 --> 00:34:00,399
ecolis system

940
00:34:04,470 --> 00:34:02,480
the thermal

941
00:34:06,870 --> 00:34:04,480
engineers who are helping to operate the

942
00:34:09,829 --> 00:34:06,880
space station put out this joke a couple

943
00:34:11,909 --> 00:34:09,839
years ago which was a joke copy of the

944
00:34:13,510 --> 00:34:11,919
space station warning board it's in

945
00:34:14,869 --> 00:34:13,520
mission control tells all the current

946
00:34:16,869 --> 00:34:14,879
malfunctions onboard the space station

947
00:34:19,190 --> 00:34:16,879
usually it's clear thank goodness

948
00:34:22,470 --> 00:34:19,200
but it said warning regen eclipse not

949
00:34:26,950 --> 00:34:25,510
so they were poking fun at the ecli

950
00:34:28,230 --> 00:34:26,960
it's not for any lack of work it's just

951
00:34:29,750 --> 00:34:28,240
the first time we've ever tried to build

952
00:34:31,510 --> 00:34:29,760
a closed environmental life support

953
00:34:33,190 --> 00:34:31,520
system like this and it's hard to do but

954
00:34:36,389 --> 00:34:33,200
we're working hard on it

955
00:34:41,430 --> 00:34:37,909
if you're on your way to mars you cannot

956
00:34:42,869 --> 00:34:41,440
get resupply and things must not break

957
00:34:44,230 --> 00:34:42,879
things do break on the space station i

958
00:34:46,389 --> 00:34:44,240
mentioned on our shuttle flight we

959
00:34:47,589 --> 00:34:46,399
brought back a control moment gyroscope

960
00:34:49,909 --> 00:34:47,599
one of the big heavy gyroscopes the

961
00:34:51,109 --> 00:34:49,919
station uses to orient itself in space

962
00:34:52,710 --> 00:34:51,119
one of those had broken we brought it

963
00:34:54,550 --> 00:34:52,720

back to be refurbished and then flown

964
00:34:55,990 --> 00:34:54,560
back so that it can be used as a spare

965
00:34:57,990 --> 00:34:56,000
things do break

966
00:34:59,990 --> 00:34:58,000
but we need to make huge improvements in

967
00:35:02,390 --> 00:35:00,000
our reliability

968
00:35:03,510 --> 00:35:02,400
of all the systems in a spacecraft if

969
00:35:05,190 --> 00:35:03,520
we're going to be able to get to mars

970
00:35:06,390 --> 00:35:05,200
and back

971
00:35:08,150 --> 00:35:06,400
and again

972
00:35:09,990 --> 00:35:08,160
we do have a platform to practice all

973
00:35:14,790 --> 00:35:10,000
that and it's orbiting the earth right

974
00:35:18,069 --> 00:35:16,790
so we think if we are very careful about

975
00:35:19,589 --> 00:35:18,079
sparing oh and one other thing i should

976
00:35:21,349 --> 00:35:19,599
mention the last few shuttle flights to

977
00:35:23,270 --> 00:35:21,359
visit the space station carried nothing

978
00:35:24,870 --> 00:35:23,280
but spare parts

979
00:35:25,910 --> 00:35:24,880
to be placed up there because we knew we

980
00:35:27,109 --> 00:35:25,920
weren't going to get any more shuttle

981
00:35:28,710 --> 00:35:27,119
flights

982
00:35:31,270 --> 00:35:28,720
and so

983
00:35:33,430 --> 00:35:31,280
several flights worth of uh payload were

984
00:35:34,790 --> 00:35:33,440
just spares we think if we're very good

985
00:35:36,390 --> 00:35:34,800
about reliability we can keep the number

986
00:35:38,470 --> 00:35:36,400
of spares down we think if we're very

987
00:35:39,910 --> 00:35:38,480
good about recycling and don't have to

988
00:35:41,589 --> 00:35:39,920

carry fresh air and fresh water can

989
00:35:43,190 --> 00:35:41,599
recycle those things we might be able to

990
00:35:44,790 --> 00:35:43,200
get the spacecraft down to about 100

991
00:35:46,390 --> 00:35:44,800
tons and for you sticklers out in the

992
00:35:48,069 --> 00:35:46,400
audience that's the mass that completes

993
00:35:49,430 --> 00:35:48,079
the trans earth injection burn we're

994
00:35:50,550 --> 00:35:49,440
probably going to leave parts all the

995
00:35:53,349 --> 00:35:50,560
way there and all the way back just like

996
00:35:57,990 --> 00:35:55,589
still 100 tons

997
00:36:01,349 --> 00:35:58,000
let's review for a moment

998
00:36:03,030 --> 00:36:01,359
back in apollo we had a 6 ton capsule

999
00:36:05,430 --> 00:36:03,040
and it launched on a booster that

1000
00:36:08,710 --> 00:36:05,440
weighed 3 350 tons when it was sitting

1001
00:36:14,230 --> 00:36:12,550
for our 100 ton spacecraft

1002
00:36:17,829 --> 00:36:14,240
our mass sitting on the pad is going to

1003
00:36:19,910 --> 00:36:17,839
be something like 85 000 tons

1004
00:36:21,430 --> 00:36:19,920
so that's the same mass ratio for apollo

1005
00:36:22,950 --> 00:36:21,440
but boost it up a little bit because the

1006
00:36:25,510 --> 00:36:22,960
speed requirement to get to mars and

1007
00:36:27,670 --> 00:36:25,520
back is a little bit higher

1008
00:36:32,950 --> 00:36:27,680
so that's not so bad we have ships that

1009
00:36:40,710 --> 00:36:35,990
except uh the avengers notwithstanding

1010
00:36:45,670 --> 00:36:43,270
so 85 000 tons and just to put that into

1011
00:36:49,109 --> 00:36:45,680
uh space terms for you

1012
00:36:55,910 --> 00:36:49,119
that would be 39 of those

1013
00:36:58,950 --> 00:36:57,670

now we think we might be able to get

1014
00:37:00,710 --> 00:36:58,960
those numbers down too and there's a

1015
00:37:02,150 --> 00:37:00,720
bunch of ways we can do it

1016
00:37:04,230 --> 00:37:02,160
first of all

1017
00:37:06,470 --> 00:37:04,240
the bigger your launcher on the ground

1018
00:37:07,829 --> 00:37:06,480
is the better fraction of mass you can

1019
00:37:09,670 --> 00:37:07,839
get up into orbit because you don't have

1020
00:37:11,109 --> 00:37:09,680
to duplicate systems to have whole

1021
00:37:12,790 --> 00:37:11,119
bunches of little parts that you put

1022
00:37:15,670 --> 00:37:12,800
together if you can throw it up in big

1023
00:37:17,349 --> 00:37:15,680
sections it makes things a lot easier

1024
00:37:20,470 --> 00:37:17,359
the assembly of your big spacecraft in

1025
00:37:22,069 --> 00:37:20,480
orbit gets easier so heavy lift

1026
00:37:24,790 --> 00:37:22,079
super important we are not going to

1027
00:37:26,950 --> 00:37:24,800
leave home without it

1028
00:37:28,550 --> 00:37:26,960
another possibility uh shown here in the

1029
00:37:31,430 --> 00:37:28,560
right-hand corner this is from 2001 a

1030
00:37:33,430 --> 00:37:31,440
space odyssey that ship was

1031
00:37:34,950 --> 00:37:33,440
nuclear powered

1032
00:37:37,510 --> 00:37:34,960
all the stories i've been telling you

1033
00:37:39,589 --> 00:37:37,520
about difficult uh propulsion systems

1034
00:37:41,270 --> 00:37:39,599
and burns and huge amounts of fuel those

1035
00:37:42,870 --> 00:37:41,280
arguments become

1036
00:37:45,109 --> 00:37:42,880
less of a problem

1037
00:37:47,109 --> 00:37:45,119
if you can use a power source that's

1038
00:37:49,589 --> 00:37:47,119

stronger than chemical

1039
00:37:50,390 --> 00:37:49,599
and nuclear could do it

1040
00:37:52,630 --> 00:37:50,400
next

1041
00:37:53,990 --> 00:37:52,640
if we're clever about staging stuff in

1042
00:37:55,990 --> 00:37:54,000
mars orbit

1043
00:37:58,230 --> 00:37:56,000
and on the surface of mars so that we

1044
00:37:59,910 --> 00:37:58,240
don't have to carry our entire supply

1045
00:38:01,510 --> 00:37:59,920
throughout the entire profile that we're

1046
00:38:03,589 --> 00:38:01,520
doing we think we might be able to save

1047
00:38:04,950 --> 00:38:03,599
a little mass that way

1048
00:38:07,030 --> 00:38:04,960
and finally

1049
00:38:09,190 --> 00:38:07,040
mars has resources that we can use it

1050
00:38:11,030 --> 00:38:09,200
has an atmosphere it has ice caps it has

1051
00:38:13,349 --> 00:38:11,040
dirt and rocks we think we can make

1052
00:38:14,790 --> 00:38:13,359
propellant out of some of that stuff

1053
00:38:16,630 --> 00:38:14,800
a lot of the weight that we're dragging

1054
00:38:17,829 --> 00:38:16,640
to mars and back is just the propellant

1055
00:38:20,230 --> 00:38:17,839
that we're going to use for the very

1056
00:38:22,230 --> 00:38:20,240
last engine burn and if we can make that

1057
00:38:24,550 --> 00:38:22,240
on mars we can save a lot of weight and

1058
00:38:26,150 --> 00:38:24,560
this is a picture of a prototype that we

1059
00:38:27,510 --> 00:38:26,160
have um

1060
00:38:29,349 --> 00:38:27,520
out in hawaii i think it's arriving

1061
00:38:32,550 --> 00:38:29,359
there like now and it's going to be

1062
00:38:35,109 --> 00:38:32,560
tested later this month to try to

1063
00:38:36,470 --> 00:38:35,119

make oxygen from rocks

1064
00:38:38,150 --> 00:38:36,480
so that's an experiment that's happening

1065
00:38:41,190 --> 00:38:38,160
right now so these four things might be

1066
00:38:42,630 --> 00:38:41,200
able to reduce the huge mass of the ship

1067
00:38:44,390 --> 00:38:42,640
that we think we would need

1068
00:38:47,190 --> 00:38:44,400
to go to mars

1069
00:38:48,630 --> 00:38:47,200
and make it back safely

1070
00:38:49,910 --> 00:38:48,640
so i want to change gears a little bit

1071
00:38:50,950 --> 00:38:49,920
here

1072
00:38:53,190 --> 00:38:50,960
we've been talking a lot about

1073
00:38:54,550 --> 00:38:53,200
technology and rockets but the other

1074
00:38:57,109 --> 00:38:54,560
interesting thing about sending humans

1075
00:38:58,950 --> 00:38:57,119
to mars is that it's got humans

1076
00:39:01,430 --> 00:38:58,960
we sent robots to mars all the time we

1077
00:39:03,589 --> 00:39:01,440
got another one arriving next month

1078
00:39:04,630 --> 00:39:03,599
they almost make it look easy

1079
00:39:06,870 --> 00:39:04,640
of course they never have to bring

1080
00:39:08,870 --> 00:39:06,880
anything back

1081
00:39:09,910 --> 00:39:08,880
but sending people out on long missions

1082
00:39:11,349 --> 00:39:09,920
like that

1083
00:39:13,190 --> 00:39:11,359
has some problems that we need to solve

1084
00:39:15,510 --> 00:39:13,200
as well

1085
00:39:17,190 --> 00:39:15,520
first of all you get out of gravity you

1086
00:39:18,550 --> 00:39:17,200
unload your muscles

1087
00:39:20,550 --> 00:39:18,560
they don't have to work against gravity

1088
00:39:21,750 --> 00:39:20,560

to move around pick things up and they

1089
00:39:26,470 --> 00:39:21,760
your muscles say

1090
00:39:30,069 --> 00:39:28,069
but we think we have a handle on that

1091
00:39:31,670 --> 00:39:30,079
there's good resistive exercise on the

1092
00:39:33,349 --> 00:39:31,680
space station right now

1093
00:39:35,109 --> 00:39:33,359
and crews after six months in

1094
00:39:36,230 --> 00:39:35,119
weightlessness are coming back in pretty

1095
00:39:37,589 --> 00:39:36,240
good shape

1096
00:39:39,750 --> 00:39:37,599
um

1097
00:39:41,430 --> 00:39:39,760
i get to see the returning crew members

1098
00:39:43,030 --> 00:39:41,440
usually a couple of days after they get

1099
00:39:45,030 --> 00:39:43,040
back from the space station they're in

1100
00:39:47,670 --> 00:39:45,040
the astronaut gym starting their

1101
00:39:50,230 --> 00:39:47,680
rehabilitation and most of them strength

1102
00:39:51,910 --> 00:39:50,240
wise are in quite good shape

1103
00:39:54,390 --> 00:39:51,920
despite having just spent six months in

1104
00:39:58,550 --> 00:39:56,390
another problem is your sense of balance

1105
00:40:00,150 --> 00:39:58,560
it's famously known that when you get up

1106
00:40:04,630 --> 00:40:00,160
into space your sense of balance goes

1107
00:40:05,990 --> 00:40:04,640
nuts and it makes you feel queasy um

1108
00:40:07,430 --> 00:40:06,000
almost everybody feels a little ill

1109
00:40:09,109 --> 00:40:07,440
about a third of people actually feel

1110
00:40:10,710 --> 00:40:09,119
ill enough to throw up

1111
00:40:13,270 --> 00:40:10,720
but after a couple of days if you don't

1112
00:40:14,950 --> 00:40:13,280
try to do too much

1113
00:40:16,230 --> 00:40:14,960

it gets better

1114
00:40:17,990 --> 00:40:16,240
same thing with returning you come back

1115
00:40:20,069 --> 00:40:18,000
to the ground you've got the spins you

1116
00:40:21,910 --> 00:40:20,079
feel dizzy feel faint you feel weak

1117
00:40:22,710 --> 00:40:21,920
a couple of days don't try to do too

1118
00:40:24,150 --> 00:40:22,720
much

1119
00:40:25,589 --> 00:40:24,160
it'll get better they don't let you

1120
00:40:27,510 --> 00:40:25,599
drive your car for the first three days

1121
00:40:28,950 --> 00:40:27,520
after you return from space

1122
00:40:31,190 --> 00:40:28,960
and even just walking around the the

1123
00:40:32,870 --> 00:40:31,200
hallways in the in the office is kind of

1124
00:40:35,750 --> 00:40:32,880
fun on day two after returns you walk

1125
00:40:41,510 --> 00:40:35,760
around you turn a corner and whoa

1126
00:40:44,470 --> 00:40:42,630
another thing that we have to contend

1127
00:40:46,790 --> 00:40:44,480
with on a long duration space mission is

1128
00:40:48,950 --> 00:40:46,800
radiation both from the sun and from

1129
00:40:50,710 --> 00:40:48,960
sources in deep space produce

1130
00:40:55,349 --> 00:40:50,720
dangerous radiation

1131
00:41:00,790 --> 00:40:57,589
and the one thing

1132
00:41:02,390 --> 00:41:00,800
that blocks radiation is mass

1133
00:41:04,790 --> 00:41:02,400
and the one thing we can't afford to

1134
00:41:06,710 --> 00:41:04,800
launch is mass

1135
00:41:09,190 --> 00:41:06,720
so lead bricks which work great on the

1136
00:41:10,309 --> 00:41:09,200
ground for radiation protection

1137
00:41:12,790 --> 00:41:10,319
you can't really use those in the

1138
00:41:14,710 --> 00:41:12,800

spacecraft or today

1139
00:41:16,230 --> 00:41:14,720
so maybe one possibility is you hide in

1140
00:41:17,829 --> 00:41:16,240
your water bottles if there's a solar

1141
00:41:19,750 --> 00:41:17,839
storm

1142
00:41:21,190 --> 00:41:19,760
you carry a bunch of water uh you have a

1143
00:41:22,790 --> 00:41:21,200
wedge of water containers and inside

1144
00:41:24,470 --> 00:41:22,800
that you build your solar storm shelter

1145
00:41:26,950 --> 00:41:24,480
and if there's a radiation design you go

1146
00:41:28,309 --> 00:41:26,960
hide in your waterfalls but

1147
00:41:30,550 --> 00:41:28,319
and

1148
00:41:32,550 --> 00:41:30,560
it might work it might not this is not a

1149
00:41:37,510 --> 00:41:32,560
problem we consider to have lake at this

1150
00:41:41,430 --> 00:41:39,670
another issue is bone loss just like

1151
00:41:42,870 --> 00:41:41,440
your muscles when you unload your bones

1152
00:41:44,630 --> 00:41:42,880
you take away the

1153
00:41:46,309 --> 00:41:44,640
weight of your body that is always

1154
00:41:47,910 --> 00:41:46,319
pushing on your bones

1155
00:41:50,790 --> 00:41:47,920
your bones are always sensing those

1156
00:41:52,550 --> 00:41:50,800
loads and reforming them reforming

1157
00:41:54,550 --> 00:41:52,560
themselves in response to those loads

1158
00:41:56,150 --> 00:41:54,560
it's really interesting active material

1159
00:41:58,309 --> 00:41:56,160
young look they say we're not needed

1160
00:41:59,910 --> 00:41:58,319
we're out of here

1161
00:42:01,190 --> 00:41:59,920
um especially in the early days when

1162
00:42:02,710 --> 00:42:01,200
people weren't doing a lot of exercise

1163
00:42:07,270 --> 00:42:02,720

on long duration people came back with

1164
00:42:13,190 --> 00:42:10,870
these days with good resistive exercise

1165
00:42:15,430 --> 00:42:13,200
most people are coming back without bone

1166
00:42:16,630 --> 00:42:15,440
loss of the ones that do come back with

1167
00:42:18,950 --> 00:42:16,640
loss

1168
00:42:20,550 --> 00:42:18,960
most of them get it back but there's

1169
00:42:22,309 --> 00:42:20,560
still a small fraction of people who

1170
00:42:24,150 --> 00:42:22,319
return from space station with a little

1171
00:42:25,349 --> 00:42:24,160
bit of bone loss that doesn't that

1172
00:42:26,470 --> 00:42:25,359
doesn't come back once they get back

1173
00:42:27,270 --> 00:42:26,480
under loading

1174
00:42:29,030 --> 00:42:27,280
so

1175
00:42:30,710 --> 00:42:29,040
this problem again we're we're on the

1176
00:42:33,510 --> 00:42:30,720
way to solving it but we haven't quite

1177
00:42:37,430 --> 00:42:35,910
and then finally when you take a small

1178
00:42:42,829 --> 00:42:37,440
group of people and isolate them in a

1179
00:42:47,349 --> 00:42:45,430
sometimes they may end up being kind of

1180
00:42:48,790 --> 00:42:47,359
unhappy

1181
00:42:51,589 --> 00:42:48,800
uh

1182
00:42:53,670 --> 00:42:51,599
this is a possibility

1183
00:42:55,430 --> 00:42:53,680
we don't know what to do to fix it but

1184
00:42:58,550 --> 00:42:55,440
if you go back to

1185
00:43:01,030 --> 00:42:58,560
the early part of the last century

1186
00:43:03,670 --> 00:43:01,040
and look at polar exploration

1187
00:43:05,829 --> 00:43:03,680
where we had small crews isolated under

1188
00:43:07,190 --> 00:43:05,839

horrible conditions there was a group of

1189
00:43:08,870 --> 00:43:07,200
people in antarctica they were trying to

1190
00:43:10,870 --> 00:43:08,880
get on the ship at the end of the season

1191
00:43:12,230 --> 00:43:10,880
to sail away and before winter closed in

1192
00:43:13,990 --> 00:43:12,240
but the wind blew the ship offshore they

1193
00:43:15,430 --> 00:43:14,000
couldn't get back and this handful of

1194
00:43:16,470 --> 00:43:15,440
people were stranded in this little

1195
00:43:18,390 --> 00:43:16,480
cabin

1196
00:43:19,750 --> 00:43:18,400
uh on the coast of antarctica for two

1197
00:43:22,550 --> 00:43:19,760
years

1198
00:43:24,550 --> 00:43:22,560
and there were no murders

1199
00:43:27,030 --> 00:43:24,560
so it's possible to get through that but

1200
00:43:28,550 --> 00:43:27,040
it's hard but again

1201
00:43:31,349 --> 00:43:28,560
we don't have this problem completely

1202
00:43:34,390 --> 00:43:33,109
and finally a brand new problem that we

1203
00:43:36,069 --> 00:43:34,400
wouldn't even have known about without

1204
00:43:38,230 --> 00:43:36,079
the space station is some folks are

1205
00:43:41,109 --> 00:43:38,240
coming back from the space station with

1206
00:43:43,349 --> 00:43:41,119
damage in their eyeball which comes from

1207
00:43:45,109 --> 00:43:43,359
high fluid pressure inside the eyeball

1208
00:43:46,309 --> 00:43:45,119
which is related to high fluid pressure

1209
00:43:48,870 --> 00:43:46,319
inside the

1210
00:43:51,349 --> 00:43:48,880
the brain and spinal column

1211
00:43:52,870 --> 00:43:51,359
we don't know what causes this uh it's

1212
00:43:54,150 --> 00:43:52,880
fairly serious some people are not able

1213
00:43:55,589 --> 00:43:54,160

to get their full eyesight back when

1214
00:43:57,430 --> 00:43:55,599
they return

1215
00:43:59,990 --> 00:43:57,440
and we don't know enough about it to be

1216
00:44:02,309 --> 00:44:00,000
able to fix it yet

1217
00:44:03,910 --> 00:44:02,319
but again we only found out about this

1218
00:44:05,430 --> 00:44:03,920
because we have the space station and

1219
00:44:07,430 --> 00:44:05,440
that's a six month trip on the space

1220
00:44:09,190 --> 00:44:07,440
station that can cause this and how much

1221
00:44:10,630 --> 00:44:09,200
worse would it have been if we'd sent

1222
00:44:12,470 --> 00:44:10,640
somebody on an eight and a half month

1223
00:44:13,670 --> 00:44:12,480
trip to mars and weightlessness and had

1224
00:44:15,670 --> 00:44:13,680
them not be able to read the checklist

1225
00:44:17,990 --> 00:44:15,680
when they landed so at least we found

1226
00:44:20,829 --> 00:44:18,000
out about it and we have a good platform

1227
00:44:23,349 --> 00:44:20,839
for finding an answer to this

1228
00:44:24,550 --> 00:44:23,359
one so

1229
00:44:26,230 --> 00:44:24,560
we've talked about the rockets we've

1230
00:44:28,790 --> 00:44:26,240
talked about the people you guys should

1231
00:44:29,910 --> 00:44:28,800
all be certified rocket scientists now

1232
00:44:31,430 --> 00:44:29,920
and