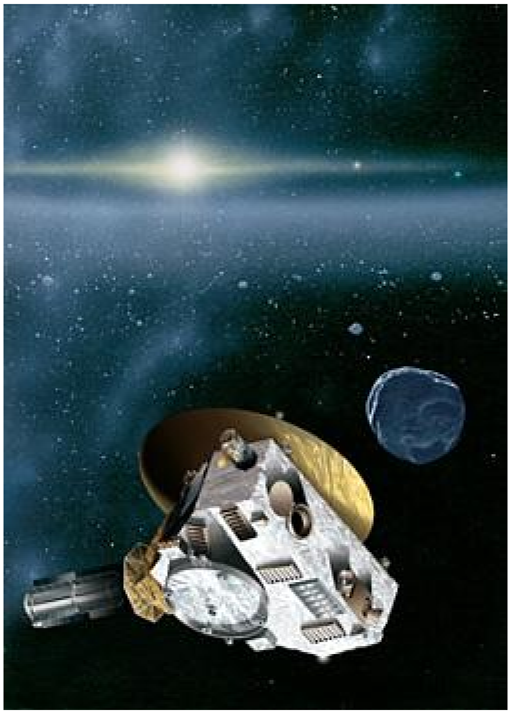
Mission: Pluto



If all goes as planned, the New Horizons observatory designed by researchers at Hopkins' Applied Physics Laboratory will fly past Pluto in July 2015, sending back the first data ever from our solar system's frozen dwarf. Here's what it'll take to get there.

By Dale Keiger

Opening photo courtesy of Johns Hopkins University Applied Physics Laboratory / Southwest Research Institute (JHUAPL/SWRI)

Here is the job: Design and build a spacecraft. A platform to ferry seven scientific instruments across 3 billion miles of space. The instruments must be precisely calibrated and sensitive, yet rugged enough to survive a rocket launch and a voyage of 10 years or more, and require less electrical power than a couple of light bulbs. The spacecraft must be compact, low in mass, and balanced like a spinning top, which it will be for most of its journey. At the end of its 3-billion-mile voyage, it must hit the equivalent of a circle about 120 miles in diameter; an arrow fired at a target 100 miles away with comparable accuracy would hit a dime. The craft must arrive at precisely the right time for an alignment of two planets, a moon, the sun, and an earthbound network of antennas. Every instrument must work to near perfection; in-flight repair will be all but impossible. Finally, the project's engineers, scientists, and administrators must build this spacecraft fast and within a constrained budget.

In November 2001, the Johns Hopkins Applied Physics Laboratory took on this task, to build a planetary observatory named New Horizons, bound for Pluto. APL has delivered the spacecraft to Cape Canaveral, Florida, for launch in January 2006. If the mission fully succeeds, in July 2015 New Horizons will fly past Pluto for the first reconnaissance of that strange little ball of ice and rock, snapping pictures, mapping its terrain, analyzing its atmosphere, and sampling space dust and the solar wind. For nine months after it will transmit data back to Earth as it races toward an even more distant region of the solar system known as the Kuiper Belt, where scientists hope to extend its mission.

APL's New Horizons project manager, Glen Fountain, has built spacecraft before. He thinks about this one and says, in a tone that suggests a man who isn't really complaining, "Each of these missions is like a dog that's just caught a car." You chase it, you grab it, you congratulate yourself, then you think, OK, we've got it ... now what?

When APL first worked on plans for New Horizons, a Pluto mission was already under way in another shop. Caltech's Jet Propulsion Laboratory, NASA's center for robotic exploration of the solar system, was building the Pluto-Kuiper Express. For four decades, JPL had conducted dazzling missions: Pioneer, Mariner, Ranger, Surveyor, Viking, Voyager, Magellan, Mars Pathfinder. But as 2000 wore on, Pluto-Kuiper Express was in trouble. NASA had awarded JPL a contract to build it and another mission, Europa Orbiter, for $650 million. When costs soared to $1.5 billion for craft not yet complete, NASA issued a stop order.

Meanwhile, APL had become a canny, aggressive competitor for NASA contracts. It was much smaller than Jet Propulsion but had built a reputation with successful missions like the Near Earth Asteroid Rendezvous (NEAR), and ACE, the first space weather station, launched in 1997 and still gathering data. Stamatios Krimigis, then head of APL's space department, was a member of NASA's advisory Solar System Exploration Subcommittee. At an October 2000 meeting the subcommittee recommended that NASA solicit proposals for a more economical mission to Pluto. Krimigis saw new opportunity. Just before Thanksgiving he convened a meeting of APL engineers, briefed them on the science to be done on a Pluto mission, and asked them to sketch ideas within a week for a spacecraft.

They came back with a rough plan for an interplanetary observatory, powered by the radioactive decay of plutonium. They predicted it would cost $500 million. Yanping Guo, a mission design specialist at APL, plotted a trajectory that first would send the spacecraft swooping past Jupiter, near enough for that planet's gravity to whip the craft into a higher velocity and subtract at least three years from the travel time to Pluto. In December 2000, NASA made a formal announcement of opportunity for a new Pluto mission, and APL was ready. It allied with Alan Stern, a space scientist at the Southwest Research Institute (SwRI) in Boulder, Colorado, who had been pursuing a mission to Pluto since 1988. Eleven months later, APL and SwRI learned that they'd won the job. The dog had caught the car.

Pluto is an odd world. The four inner planets of the solar system — Mercury, Venus, Earth, and Mars — are balls of rock. The next four —

Jupiter, Saturn, Uranus, and Neptune — are giant spheres of gas. Seven of the eight follow circular orbits (Mercury is an exception) aligned on a single plane. Then there's Pluto. It's a frozen dwarf, two-thirds the size of our moon and probably around three-fourths ice in composition, on a highly elliptical orbit that inclines 17 degrees off the orbital plane of the other planets. It is strikingly reflective, the second most reflective object in the solar system, probably because most of its surface is covered by frozen nitrogen, methane, and carbon dioxide. Pluto has a thin atmosphere, part of which it is losing to space; when the planet is farthest from the sun, astronomers expect this atmosphere to freeze and all but disappear. Pluto's single moon, Charon, is so big scientists regard the pair as a double planet. That is, if Pluto is a planet at all. Beyond it lies a deep band of orbiting objects known as the Kuiper Belt, what Stern calls "the solar system's attic." Many astronomers now consider Pluto less a planet than a strikingly large KBO (Kuiper Belt Object). APL's Hal Weaver, New Horizons' project scientist, is a comet man, and to him Pluto resembles a giant comet.

Researchers conducted a "fit check" of the spacecraft's dish antenna last Februry at APL.
Photo courtesy JHUAPL/SWRI

Comet, planet, KBO — whatever it is, Pluto is a long way off. Were you to stand on its surface facing the sun, you'd be turned to what looks like no more than an unusually bright star, "basking" in light that left five hours before, warmed to a balmy -420 degrees Fahrenheit. No earthbound telescope has ever captured a clear image of the planet. For all its extraordinary acuity, the Hubble Space Telescope has managed only to discern the largest of surface features, whetting astronomers' appetites. No one knows in sufficient detail what Pluto looks like, what it's made of, or why it's in such an eccentric orbit. No spacecraft has ever come remotely close to it. Pluto may represent a large sample of the original gas and dust from which the sun and planets formed, so scientists have been searching for some way to get a close look and perhaps answer major questions. What was the process of early planet formation? What is the history of volatile compounds, especially water, across the solar system? Could water, air, even primordial organic matter have come to Earth via a collision with a KBO? Finally, scientists want to go to Pluto and the Kuiper Belt simply because no one has. In its 2002 decadal survey, the National Research Council listed exploration of Pluto-Charon as among its highest priorities. Twenty months earlier, the Solar System Exploration Subcommittee had told NASA, simply, "We must go there."

Stern finds the ninth planet irresistible. Krimigis calls the New Horizons principal investigator "Mr. Pluto." On December 20, 2000, when NASA announced it wanted proposals for a new mission, Stern says, "I watched the press conference and within an hour my phone started ringing." He weighed his options, which included partnering with JPL on a new plan, and decided to work with APL. "APL's space division is a small, very well-run organization with a tremendous track record."

He and a team of scientists that included APL's Andy Cheng planned the basic science. New Horizons would be a fly-by reconnaissance mission; to go into orbit around the planet, the speeding spacecraft would have to slam on the brakes so hard it would need a thousand times more fuel for thrusters than it could carry. The scientists listed a trio of primary goals for that fly-by: observe the geology and morphology (characteristics of rocks and land forms) of Pluto and Charon, map their surfaces, and study Pluto's atmosphere. Secondary objectives included studying Pluto's ionosphere and interaction with the solar wind, searching for an atmosphere around Charon, producing high-resolution maps of selected areas, and mapping surface temperatures. If the mission could also search for additional Plutonian satellites and refine the parameters of Pluto-Charon's orbits, so much the better. One slide in a mission PowerPoint presentation noted that the team meant to do all of this "on time, within budget, and at low risk." The same slide urged, "Keep it simple."

Stern mandated three instruments on board the observatory. A close-encounter imager named Ralph would create visible light and infrared images, as well as thermal maps of the planet, plus use a spectrometer to study Pluto's surface composition. An ultraviolet imaging spectrometer called Alice — Stern named them after Ralph and Alice Kramden, characters from the 1950s television comedy series *The Honeymooners* — would analyze the composition of Pluto's skimpy atmosphere. REX, a radio experiment, would study that atmosphere by observing the bending of radio waves from Earth as they passed through it.

APL wanted some of its own experiments on New Horizons. Placing instruments on a mission means prestige for the institution and employment for its scientists and engineers. Says Cheng, "If we decide to use Instrument X, which comes with certain people, then other people doing similar things don't have a job. Choosing instruments is a very big deal." From APL came LORRI, a long-range telescopic imager that would begin surveying Pluto when New Horizons was 200 days out from its fly-by. Cheng had been working for JPL on a particle spectrometer called PEPSSI; now he brought it over to the Pluto mission to study ions escaping from the atmosphere.

PEPSSI — Pluto Energetic Particle Spectrometer Science Investigation, a name that does much to justify acronyms — occasioned some debate. The science team wanted to study Pluto's atmosphere interacting with the solar wind. APL thought it could extend PEPSSI's range to accomplish that. But SwRI wanted a separate instrument. The team agreed to the latter course, adding SWAP, the Solar Wind Around Pluto instrument. Finally, a space dust collector devised by undergraduates at the University of Colorado became the last instrument added to the package.

Now the real fun could begin.

Though it wouldn't pay to run far with the generalization, on New Horizons the scientists posed problems and the engineers tried to solve them. The scientists knew that New Horizons might be the only mission to Pluto in their lifetime, so they wanted to make as many observations as possible. The engineers wanted to make possible all that the scientists hoped for, but they faced constraints. For the rocket to blast it into space with sufficient velocity to reach Pluto, the spacecraft would have to be light, about 1,000 pounds. Everything had to fit in a platform, which the engineers call the bus, that's about seven feet across, so the instruments would have to be compact. Nothing could demand much power, because a mission so far from the sun could not use solar panels. Electricity would come from a radioisotope thermoelectric generator capable of producing only about 195 watts when the spacecraft approached the planet. Everyone wanted to avoid mechanical parts that could break, stick, or otherwise malfunction in numerous ways. But New Horizons would have instruments that needed to be aimed. If they were not mounted on mechanical gimbals, then to point them in the right direction the entire craft would have to be pointed, which would consume precious fuel. To conserve that fuel during the 10-year voyage, engineers decided to spin the spacecraft around the axis of its antenna, to impart gyroscopic stability. But that meant the craft had to be perfectly balanced, or else it would wobble. There were few decisions that didn't affect other parts of the mission. Says Cheng, "The most innocent things can cause you problems. Where to put a cable? You put it here, and it rubs against something else and ultimately causes a failure. Anything can cause a problem."

Key APL players involved in the New Horizons mission include (l to r): Weaver, Krimigis, Bowman, Fountain, and Cheng.
Photo by John Davis

One of APL's instruments, LORRI (Long Range Reconnaissance Imager), can be thought of as a digital camera with a long telephoto lens. The scientists want to begin imaging the planet starting more than six months out from the closest encounter. That requires a powerful scope with an eight-inch aperture and a body about two feet long. The exterior end of the instrument will be subject to cold, -150 Fahrenheit or so. The interior end, inside the body of the bus, will be warmed by the power source and the craft's electronics. This stands to create a thermal gradient — one area cold, another area warmer — that could distort the telescope's shape and, like an astigmatism, ruin the sharpness of its images. To solve the problem, APL's engineers specified a special material called silicon carbide that had never been used for an instrument so big. Extraordinary care had to be exercised in fabricating and handling the scope because silicon carbide may be rigid, but it's also brittle.

The manufacturer, SSG Precision Optronics, succeeded in working with the silicon carbide, but when APL tested LORRI after delivery, they found a new problem. The coating on the lenses admitted too much infrared light, creating internal reflections that caused ghost images. That wasn't the only problem. When they tried the scope, says Weaver, "We saw a big blotch. We called it 'the divot.'" Further investigation revealed that the manufacturer had nicked the lens during assembly. Software could compensate for the instrument's visual impairment, but the flaw approached the threshold of the instrument's structural integrity standard. The engineers feared the stress of launch might break it. They didn't want to disassemble LORRI, which would eat valuable time and invite new problems, but finally they concluded they couldn't afford the chance. They took the scope apart — "We crossed our fingers a little bit," says Fountain — replaced the flawed optics, and took advantage of the chance to apply a better coating that solved the infrared problem.

Another piece of New Horizons that cannot deform is the dish of its radio antenna. Radio transmissions to and from the spacecraft will require extraordinary precision. For example, the scientists want to do an occultation experiment. As New Horizons swings around Pluto, they plan to beam a radio transmission from Earth that will pass through Pluto's atmosphere; the REX instrument on board the spacecraft will measure the atmosphere's effect on the radio waves, which will reveal information about its composition. The bigger the antenna's dish, the greater the tolerance for error in aiming the beam. But to save weight, New Horizons couldn't carry a massive dish. So the engineers had to design a small one that would keep its precise shape no matter the temperature gradient or other stresses.

Throughout the design and assembly process, all sides needed to talk. "The engineers need to understand what the scientists need to do," says Cheng. "And the scientists need to understand the engineers. They say, 'Let's fly the spacecraft a certain way.' They may not always understand the implications, that one thing may be much harder to do than something else that would be just as good for the science and much easier to accomplish. That's where these missions often hit the rocks, when communications fail."

Every design, test, and repair decision had to be made with one eye on the clock. Krimigis had bet the house by assuring NASA that APL and its partners could produce New Horizons from scratch in three to four years. The launch dates of some missions, like certain space shuttle flights, can be delayed for weeks without incurring major problems. There was no such flexibility with New Horizons. Once it had abandoned an overly optimistic December 2004 target date, APL faced a 35-day launch window: January 11 to February 14, 2006. Miss the first

23 days of that window and New Horizons could not swing by Jupiter, and would require an additional three to five years to reach Pluto. The next chance to get a gravity boost from Jupiter would not come until 2016. "The planets line up right on a certain date," Cheng says. "If you miss that date, you've missed the whole party."

Photo courtesy of JHUAPL/SWRI

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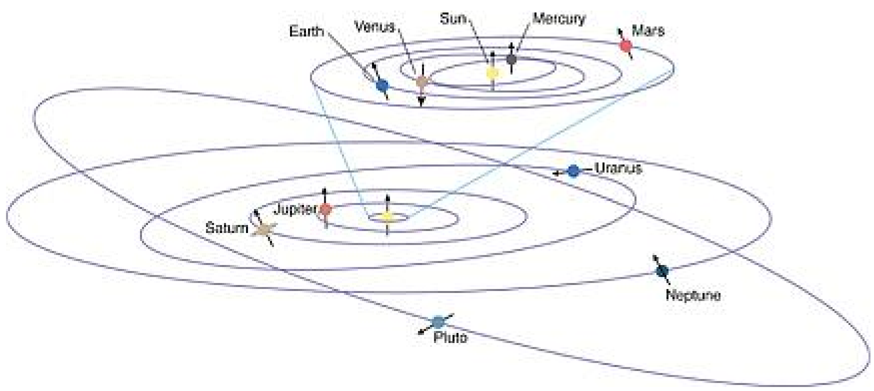
Work on New Horizons slowed twice when the Bush administration killed funding for the program, only to have Congress put the money back, largely at the insistence of Sen. Barbara Mikulski (D-MD). A three-month delay in the launch of MESSENGER, APL's mission to Mercury, held up the reassignment of experienced engineers and technicians from that project to New Horizons. APL was stretched thin by missions like MESSENGER, CONTOUR, STEREO, and New Horizons. Says Mark Perry, mission systems engineer, "APL has a reputation for really strong engineers, but there aren't that many of us. For four years, we would have three missions building at any one time. Every time we finished one, there'd be another in the stack. That is a phenomenal amount of work for a small group of people." APL hired new personnel, but they took time to integrate with the project. NASA has become so risk-averse, the agency demands exhaustive documentation and numerous project reviews; that meant additional work, which sometimes caused further delays.

At various points, the project fell three months behind, then six. Did the engineers ever look at each other and ask if they were going to make it? "Oh yeah, that happens all the time," says Cheng. "The only way to be competitive in this business is to dance close to the edge. I literally cannot remember any mission where that question didn't come up."

Last June, APL shipped the fully assembled New Horizons for testing to NASA's Goddard Space Flight Center in Greenbelt, Maryland. APL's Mike Colby and his integration-and-testing team subjected the spacecraft to the simulated rigors of launch and space flight to see if anything broke. Shake tables vibrated the craft. In a sound chamber, immense speakers subjected it to the noise that the rocket will generate. Spin testing whirled New Horizons on a turntable to check its balance. It was subjected to the conditions of deep space for more than 40 days in a giant vacuum chamber. The tests did what they were supposed to do: reveal problems. New Horizons has a star tracker — like a 16th-century seafarer, the craft will navigate by the stars — and on the shake table the device that mounts the tracker to the bus began "oil canning," or bowing to an unexpected degree. It had to be redesigned and replaced. A more serious issue was with a data drive that wouldn't play back. When New Horizons' instruments make observations, they will write data to a solid-state recorder. That SSR subsequently will play back that data for transmission to Earth. The faulty recorder had to be swapped out.

Meanwhile, back at APL's mission control room, Alice Bowman was overseeing mission simulations. Bowman is the New Horizons operations manager. Ops, as it's called, takes over as soon as the rocket leaves the launch pad. "Our job," says Bowman, "is to get it to Pluto." During the mission, flight controllers monitor telemetry from the spacecraft, watching for problems. Each minute of the flight has been scripted. Improvisation is risky, because any command expends the spacecraft's resources and can affect other parts of the mission. The sequence of orders to the instruments has been thought out so that every observation takes place at precisely the right time in precisely the right manner, and carefully meters the craft's limited power supply. An inadvertent excessive power demand could shut down the spacecraft. Any deviation, any mis-sequenced command, could wreck an instrument, or require abandonment of an observation that a scientist has waited 10 years to make. So all procedures must be tested and rehearsed, as Ops learns the hardware. Says Bowman, "You actually don't know the spacecraft until you code up the commands and test them."



Pluto's "egg-shaped" orbit puts it closer to the sun than Neptune for about 20 years in each orbit.
Photo courtesy of JHUAPL/SWRI

Of particular concern is what the engineers call "the autonomy." Once New Horizons whips past Jupiter, it will enter an eight-year dormancy, becoming what Hal Weaver calls "a spinning Thermos bottle." For most of that time, the spacecraft will monitor and regulate itself. The fault-protection systems that do that are what the engineers refer to as autonomy, and they're extremely important. Says Perry, "If something goes wrong, the spacecraft can't die. It has to survive long enough for the ground to figure out what's wrong. If a processor dies, for example, you have to have autonomy that will automatically take over and use the redundant processor." But autonomy had to be constructed so it wouldn't ruin the craft in trying to save it. Perry: "A common fix for a bulky processor is to reset it. You do that with a home computer all the time. It sounds simple, but it's extremely dangerous here. What if something goes wrong with autonomy and it just starts to reset processors in a continuous loop?" One processor has to be in control, but if they keep resetting, says Perry, "that's it. The spacecraft is dead. Gone." Chris Hersman, APL's spacecraft systems engineer, says autonomy has been one of his biggest concerns. "But what I've learned," he says, "is that it's usually not your biggest worry that ends up surprising you. You're focused on a potential problem and suddenly there's something that comes out of nowhere."

One by one, engineers fixed each glitch, and APL delivered the spacecraft to Cape Canaveral on time. To that point, mission accomplished, though not without a lot of missed sleep. Mike Colby of the mission's integration-and-testing team has a card in his office that reads HAPPY HOUR IS A NAP.

Once the Atlas V 551 rocket carrying New Horizons lifts off from Cape Canaveral, Alice Bowman's first nerve-racking moment will come about 40 minutes into the flight. Until then, Ops will have no contact with New Horizons as the Atlas blasts it into space. At about the 40-minute mark, ground controllers will anxiously listen for the first burst of telemetry from the craft. If all has gone well, it will be functioning and on its way and the APL Ops team will check its health, commissioning each subsystem, then each instrument, and making sure nothing has been damaged in launch. After 13 months, New Horizons will approach Jupiter, take advantage of the chance to calibrate its instruments and make some observations there, then catch a boost from the planet's gravity and veer off for Pluto. For about eight years, New Horizons will spin in virtual hibernation. Once a week, the craft will beep, assuring Ops that it's sleeping peacefully. For 50 days each year, ground controllers will wake it up and run a series of tests, to check on the instruments and, not incidentally, keep the controllers sharp. In 2012, Stern and the Ops team will rehearse the Pluto encounter. "It's a fly-by mission," Bowman reminds. "You get one chance."

In the fall of 2014, Ops will bring New Horizons out of hibernation. Two hundred days from Pluto, nine years after launch, the real work of New Horizons will begin as LORRI starts making images. By 90 days out from the planet, those pictures will be superior to anything obtainable from Earth, resolving features on Pluto's surface as small as a football field. Each of those images will take 12 hours to arrive from the spacecraft. Sometime in July 2015, 14 years of effort will come down to a frenzied 24 hours as New Horizons approaches Pluto at 8.6 miles per second. PEPSSI will meter plasma escaping Pluto's atmosphere and SWAP will measure the solar wind. Ralph, using less power than a nightlight, will record close-up color images. Alice will probe Pluto's atmosphere with its ultraviolet imaging spectrometer. At its closest, New Horizons will pass 6,000 miles from Pluto. As it swings around Pluto-Charon on the trajectory plotted by Yanping Guo, the spacecraft will observe occultations of both the sun and Earth, to make more measurements of the planet's atmosphere. From New Horizons' transmitter will flow all the collected data, a 3-billion-mile stream of 0s and 1s that will travel to Earth for the ensuing nine months.

Pluto will begin to recede in New Horizons' rear-view mirror (or it would if the spacecraft had one), but the mission team hopes that its work will not be done. Though NASA has not yet approved, APL and SwRI hope to direct the spacecraft to a new destination, the largest Kuiper Belt object they can find, for another fly-by sometime between 2017 and 2020; the scientists already are searching for the right KBO. Then New Horizons will head into interstellar space, drifting forever unless it collides with some other body.

Krimigis, who marshaled the effort to bring New Horizons to APL, wonders how long the laboratory can pull off missions like it. APL has built 62 spacecraft, and it's been able to do that, in large part, because it is a lean operation with nimble, creative engineers and scientists, and a culture that encourages freewheeling problem solving. Cheng describes that culture as "give a project to a small group of people and they just go off and do it." But after some well-publicized failures of planetary missions, and especially after the Columbia disaster that killed the shuttle's entire crew, NASA has become, in Krimigis' estimation, risk-averse to the point that every decision and step has to be documented, every process reviewed, every potential hazard avoided. That may make less expensive, creative missions impossible in the future. Says Krimigis, "NASA is in the process of dismantling this type of organization. You end up having a significant part of the staff either preparing for a review, doing a review, or responding to many action items in the aftermath of a review. It saps the initiative for doing state-of-the-art pioneering work. Talented people find it difficult to do a terrific amount of paperwork and explain to an MBA what they're doing and how they're doing it."

But as New Horizons awaits launch this January, Krimigis, now the emeritus head of APL's space department, is proud of what his colleagues have done. The spacecraft is ready to fly, assembled, tested, and vetted. NASA wanted the mission to cost $650 million; it should come in at around $700 million, with most of the excess cost, Krimigis says, generated by factors beyond APL's control. Krimigis began building instruments for planetary exploration in 1963, when he worked on the Mariner IV mission to Mars. If New Horizons and the MESSENGER Mercury missions succeed, by 2015 Krimigis will be, he believes, the only planetary scientist to have been involved in missions to all nine planets. He ponders that for a moment, then says, "It's great fun to be in this business."

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