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COLD WAR THRILLER BRINGS CLASSROOM THEORY TO LIFE

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INTRODUCTION

Most materials science and engineering (MSE) departments include a capstone design course in the senior year for their undergraduate students. These courses are intended to introduce, in great detail, the concepts of materials selection and failure analysis. They also continue the development of the skills that enable students to function as members of a team, including writing technical reports and making technical presentations. The University of Florida (UF) is one of those schools that includes a materials selection and failure analysis (EMA 4714) design course in the spring semester of the senior year.

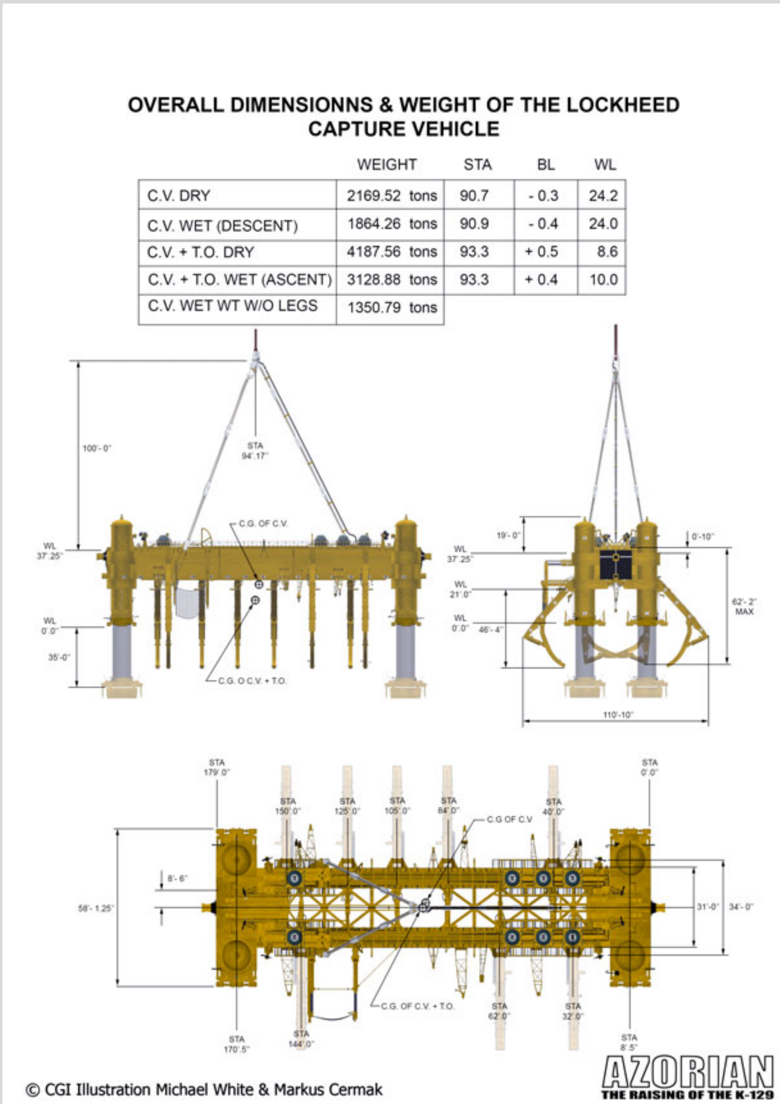
Over the years, UF has selected a number of interesting and challenging materials engineering problems for the student design project, including determination of residual life in aging concrete, selection of materials for lifting chains, ceramic insulators for high-voltage power lines, crack detectors for asphalt, and infrared fiber optics for medical applications. All of these topics served as wonderful vehicles for teaching students the fundamentals of materials selection, design, and failure analysis. However, these types of project themes often don't inspire students to dig deeply into the subject and learn more about the history or context of the problem they are trying to solve. For the senior class of 2013, the University of Florida faculty wanted to find a unique topic that could facilitate teaching the traditional concepts of materials selection and failure analysis, while also really exciting the students. We found our answer in one of the most intriguing covert operations of the Cold War—Project AZORIAN.

PROJECT AZORIAN BACKGROUND

At the height of the Cold War between the United States and the Union of Soviet Socialist Republics (USSR), the Soviet submarine *K-129* inexplicably sank in March 1968, with all hands, while engaging in a routine patrol in the central North Pacific Ocean.[1–4] A diesel-powered ballistic missile warship, the *K-129* was carrying three of the most advanced nuclear-tipped ballistic missiles available at the time, as well as nuclear-tipped torpedoes and cryptographic equipment. Although the Soviet Navy could not find the sunken submarine, the U.S. Navy and intelligence agencies were able to identify the location and later photograph the wreckage without being detected by the Soviets. The *K-129* had broken into three primary pieces, but the forward two-thirds of the vessel containing the missiles, torpedoes, and cryptographic equipment was intact. The wreckage, however, was resting at a depth of about 16,500 feet. No attempt had ever been made to salvage anything from that far beneath the surface of the ocean, let alone a 2,000 ton submarine.

Undeterred, the U.S. Central Intelligence Agency (CIA) developed a plan, code named Project AZORIAN, to use a string of pipes and a claw-like assembly, referred to as the "CV" (capture vehicle), to salvage the submarine (Figures 1 and 2). To prevent discovery of the effort to secretly raise the submarine, a cover story was created

Figure 1. CGI Illustration of the AZORIAN capture vehicle (CV), being lowered on its pipe-string from the Hughes Glomar Explorer. Courtesy Michael White.



	WEIGHT	STA	BL	WL
C.V. DRY	2169.52 tons	90.7	- 0.3	24.2
C.V. WET (DESCENT)	1864.26 tons	90.9	- 0.4	24.0
C.V. + T.O. DRY	4187.56 tons	93.3	+ 0.5	8.6
C.V. + T.O. WET (ASCENT)	3128.88 tons	93.3	+ 0.4	10.0
C.V. WET WT W/O LEGS	1350.79 tons			

Figure 2. CGI illustration of the capture vehicle (CV), including dimensions and weights of the CV and the target object (TO). Courtesy Michael White.

that involved a company owned by the colorful American business magnate and aviator, Howard Hughes, and the development of deep ocean mining technology. A specialized ship, the *Hughes Glomar Explorer*, was built for the sole purpose of picking up the submarine—referred to as the target object (TO)—the 4 million pound CV, and 8 million pounds of pipe string. During the attempt in the summer of 1974 to raise the submarine off the ocean bottom and into the massive well area of the *Hughes Glomar Explorer*, several of the CV's eight "fingers" (Figure 3), or tines—each consisting of a beam and a davit—failed and a significant portion of the submarine fell back to the ocean bottom. The forward 38 feet of the submarine was successfully brought to the surface and examined by the CIA (Figure 4). The results of that target exploitation for intelligence purposes are still classified, as are many other elements of the AZORIAN operation.

In November 2009, the documentary, *AZORIAN: The Raising of the K-129*, written, directed, and produced by Michael White, was released. This film was the first accurate documentary of the mission, and the first public confirmation that the mission's code name was AZORIAN. For the previous 36 years, it was known to the world only as Project JENNIFER. In January 2010, eight weeks after the film came out, the CIA released a highly redacted program history describing some of the details of Project AZORIAN. While the CIA's internal analysis of the cause of the CV failure has never been released to the public, some information regarding it has been reported in the open literature. In the last few years, two books have also been published that have provided insights into the remarkable engineering challenge that was Project AZORIAN.

BRINGING PROJECT AZORIAN TO THE CLASSROOM

The tale of Project AZORIAN has all the elements of a Hollywood thriller, with the problem-solving abilities of engineers playing a starring role. In fact, Project AZORIAN served as the script source for the 1976 James Bond film, *The Spy Who Loved Me*. After becoming familiar with the details of the story, the UF faculty believed that the failure analysis and design of the CV would be an amazing project for the 2013 senior design course. In addition to being a perfect teaching device for concepts of materials selection and failure analysis, it offered the opportunity for an integrated study of the history, international politics, geopolitical conflict, military competition, and the "spy versus spy" activities that existed between the United States and the USSR during the Cold War. The goals of the project were to review the failure of the critical components (i.e., the tines) of the Project AZORIAN recovery system, bringing to bear the advantage of almost 40 years of technological and metallurgical advances, to assess the likely cause of the failure that occurred during the recovery mission and perhaps offer some alternative design concepts that could have been used for the CV.

All of the students in the class had been born after the collapse of the USSR and the fall of the Berlin Wall. None of these students had to do the regular air raid drills that were com-

Figure. 3. CGI illustration of the failed CV tines (left) and the CV tines prior to use. Note that the fractures occurred in different locations and the fractures do not appear brittle (i.e., straight). The fractures in all of the three fractured tines appear quite tortuous. Tine #4 failed on the ocean bottom and tines #5 and 6 failed during the final phase of the lift operation. Courtesy Michael White.

mon in the 1960s and 1970s. The students also had no idea what "mutually assured destruction" meant. It should be noted that it was very hard to explain how the concept of "mutually assured destruction" made sense—almost as difficult as explaining how putting your hands over the back of your neck while "assuming the position" under your desk would protect you from the detonation of a thermonuclear device.

To further increase the educational benefit to the students, the documentary, *AZORIAN: The Raising of the K-129*, was shown to the class. In addition, the authors of two recent books on AZORIAN were contacted. Michael White, co-author of the book, *Project AZORIAN: The CIA and the Raising of the K-129*, and David H. Sharp, author of *The CIA's Greatest Covert Operation: Inside the Daring Mission to Recover a Nuclear-Armed Soviet Sub*, both agreed to help with the project. They assisted the students by clarifying the open literature information and answering questions regarding the information in the books and the film. Michael White also provided high-resolution images of the operation, some of which have been used to illustrate this article.

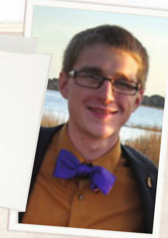
Some details of the CIA's own 1974 failure analysis, performed by a team of experts referred to as the "Tiger Team," have become available through open sources. This public information does not include, unfortunately, any fractography or microstructural characterization of the failed components. The University of Flordia sent a Freedom of Information Act (FOIA) letter to the CIA in October 2012 requesting additional information on the failure analysis. The university also offered to provide the CIA with all of the information generated during this senior project, including giving them a presentation on the results. However, the CIA indicated that they had received a large number of FOIA requests and any response would take a while. To date, no response from the CIA has been received.

Despite this slight setback, the class moved forward with the failure analysis and used the available open literature information from the books, the authors, and the documentary. Six groups, ranging in size from six to nine students, were created and tasked with first performing a failure analysis and then identifying the optimum material for fabrication of the CV tines. This could include the maraging 200 steel that had been originally used for the tines if the group thought that was appropriate. The groups were not given any information that could bias their work on either the failure analysis or the materials selection.

Student Project Dossier

Name:

Austin Wells



PERSONAL BACKGROUND:

As a college freshman, I attended a day-long presentation by the MSE department and was intrigued by the research projects that were being done. I will be working for T.H. Hill, an oil consulting company, after graduation.

PROJECT TEAM BACKGROUND:

I informally acted as the team leader, creating the group and ensuring that everyone was on the same page.

PROJECT CHALLENGES:

The most difficult challenge was finding the data we needed to determine what materials would be best to use. The properties we were looking for were relatively simple to understand. Yet, since the tines would be thousands of feet underwater, they would need to operate in a high-pressure, low-temperature environment. Most metals are tested at temperatures between 30–1,000°C, but few are tested at lower temperatures. In addition, most mechanical properties are only tested at atmospheric pressure, not the high pressures at the ocean bottom.

I chose to look into high-strength steels developed by QuesTek Innovations and licensed to Latrobe Specialty Metals. After finding some basic materials information on these alloys, I contacted a sales representative at the company to learn more and obtained non-published values of toughness at lower temperatures, all of which I included and cited in my section of the team's report.

OBSERVATIONS:

I sincerely enjoyed the uniqueness of this project. Decades ago, when Project AZORIAN was actually completed, it was a fantastic engineering feat. Furthermore, this kind of application requires information that isn't commonly found in the data generated. This presented a unique challenge which allowed for more creative methods and sources to find the necessary data.

SIFTING THROUGH CLUES AND CONVENTIONAL WISDOM

Some metallurgists on the CIA's 1974 Tiger Team believed that the maraging 200 steel used for the tines was at least partly to blame for the failure of the tines during the lift operations.[1,3,4] At the time, maraging steel was a relatively new material and not a lot was known about it. In particular, these metallurgists felt that the maraging steel would be susceptible to hydrogen embrittlement, particularly at the high pressures and cold temperatures experienced at a depth of 16,500 feet. However, as we know today, maraging steel is one of those unique materials that exhibit very high strength, while having an excellent balance of strength, ductility, and toughness.[5] In addition, maraging steel is less prone to hydrogen embrittlement when compared to materials of similar strength, due to the slower diffusion of hydrogen in the material.[6–8] In fact, the materials used for the fabrication of the lift system would have been more likely to exhibit hydrogen embrittlement than the maraging steel.

It should also be noted that computer generated images (CGI), derived from actual videos taken during the recovery operation and used in White's book and documentary, do not appear to be flat, straight fractures typical of embrittled steel. Instead, the fracture surfaces appear quite tortuous, which would be typical of ductile maraging steel. Therefore, it seems unlikely that the failure of the tines was related to materials selection or embrittlement.

Several unforeseen circumstances also complicated the process of lifting the *K-129* from the ocean bottom. During the sequence of CV operations on the ocean floor leading up to the liftoff of the *K-129*, several anomalies occurred. These included the fact that the soil under the submarine appeared to be harder than expected (Figure 5), requiring a greater-than-anticipated load to be placed on each tine to drive it under the vessel. There was also an equipment failure on board the surface ship that required the CV to rest on the ocean bottom for a period of almost 20 hours while holding the *K-129*. The designers of the CV never anticipated the need for it to remain on the ocean floor with the four million pound submarine cradled in the tines for a prolonged period of time. It was during these anomalous "bottom operations," as they have become known, that the #4 tine failed and fractured. The broken beam was later photographed standing up on the ocean bottom. In addition, review of the video from the bottom operations indicated that cracks had formed in several other tines. However, the cracks in these tines did not result in immediate fracture, as would be expected if the material was embrittled as suggested by some of the metallurgists on the Tiger Team.

Two additional tines, #5 and #6, also failed during the lift operations to bring the submarine and the CV to the surface, although these tine failures did not occur until the submarine had been raised a significant way from the ocean bottom. The fact that these tine failures did not occur immediately at the ocean bottom, but probably occurred during shifting of the submarine in the CV during the lift, indicates that the failures were not due to a materials problem, such as hydrogen embrittlement.

It should be noted that the CIA did attempt to measure the soil hardness in the area of the sunken submarine prior to the mission, but a system failure during the core sampling operation resulted in a loss of the data. Since it was not possible to return again to the wreckage site, for fear of raising the suspicions of the USSR, only rough estimates of soil hardness could be utilized. As it turned out, these estimates may have been much lower than the real soil hardness at the site of the sunken submarine.

FRESH INSIGHTS INTO A 40-YEAR-OLD MYSTERY

The conclusions of the six student groups working on the Project AZORIAN senior project can be summarized, as follows:

1. Almost all of the groups identified "bottom operations" as the root cause of the ultimate loss of most of the TO. The groups felt that the suspected harder soil conditions, combined with the failure of one of the ship's lift system components

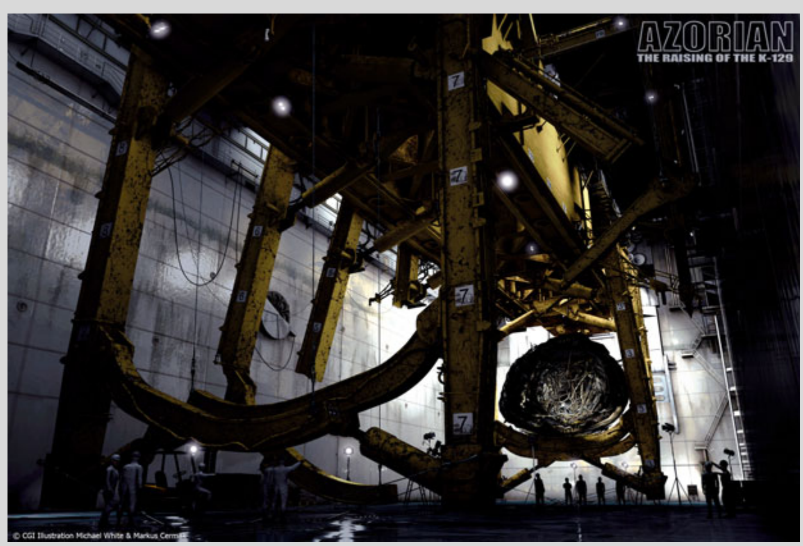


Figure 4. The above CGI illustration depicts the scene inside the well of the *Hughes Glomar Explorer* on August 7, 1974. As the water was pumped out of the well, the broken tines #4, #5, and #6 became bitterly obvious. Tine #4 had failed prior to liftoff six days earlier. Tines #5 and #6 had finally failed, causing the loss of most of the *K-129* TO, after the CV had been raised more than one-third of the way to the surface. In the forward portion of the CV, cradled in tines #1, #2, and #3, the recovered 38-foot bow section of the *K-129* can be seen. This illustration was one of three that were created by Michael White in 2011 for donation to the CIA Museum in Langley, Virginia. The donation was subsequently turned down by the CIA without explanation. Courtesy Michael White.

during the initial phases of the lift operation, resulted in cracks forming in several of the tines and the complete failure of tine #4 while still on the ocean bottom.

2. None of the six groups identified the maraging 200 steel as the source of the failure. In fact, all of the groups concluded that the maraging steel selected for the CV would have had an excellent balance of strength, ductility, and toughness, as well as having a low susceptibility to hydrogen embrittlement.
3. More than half of the groups identified maraging steel as the best possible material for this application. Two groups identified higher strength versions of maraging steel as the optimal choice, since the higher strength versions might have survived the suspected harder soil conditions that could have contributed to the failure of tine #4 and the cracking of the other tines.
4. None of the student teams felt that those portions of the Tiger Team report that are available in the open literature accurately identified the causes of the CV tine failures.
5. It should also be noted that fewer than 20% of the students in the class were considered “metals” specialty students. The remaining students were specializing in a variety of other areas, such as electronic materials, ceramics, polymers, and biomaterials. Yet, all of them enjoyed and contributed to a project that was predominantly about metals.

Some other interesting ideas that were developed by a few of the groups included selecting a different material for the tines, notably HY-100 steel. This was the material used as the backbone of the CV. Interestingly, it was also selected as the tine material for the modified CV to be used for a follow-on program, code-named MATADOR, to retrieve the remaining portion of the *K-129* in 1975. (The CIA plan to pick up the lost portion of the TO was compromised before the mission could be attempted, resulting in cancellation of the project.) However, the lower strength of the HY-100 material, in comparison to the maraging 200 steel, would have resulted in a much greater wall thickness. The extra weight of a CV with HY-100 tines would have probably precluded the use of the HY-100 material for the AZORIAN application.

One of the groups also suggested a redesign of the tips of the CV tines so that penetration of the tines into the soil could be eased. The Project AZORIAN design had tines with a flat face. The group proposed that conical shaped tips be produced from wear-resistant material and mechanically fastened to the tips. Since the tips would only be needed during the soil penetration—when the tips would be in compression against the tine face—the conical tips could be considered “disposable” once the tines had been positioned under the submarine. The use of pointed tine tips is a very creative solution to help with the unknowns, such as soil hardness.

The students also considered changing the shape of the tines from the welded box construction used on the CV to an I-beam construction. The I-beam design would accommodate a greater amount of torsional loading and may have reduced the loads to drive the tines under the submarine. However, the students felt that the lack of support on the sides of the I-beam faces might have resulted in excessive amounts of deflection of the I-beam surface against the submarine, possibly resulting in failure. In the end, all of the groups maintained the welded box construction.

All of these “conclusions” are based on the limited amount of information in the open literature on the fracture of the CV tines. The failure analysis report produced by the CIA’s Tiger Team in 1974 would be expected to be a lengthy document, but only a small amount of information from the report is available in the open literature. Perhaps, since the open literature information is somewhat limited, it would be better to refer to the students’ “conclusions” as “suggestions.” However, it is important to note that none of the groups believed that the maraging steel was to blame for the failure, and instead determined that maraging steel was the best choice for the application.

Student Project Dossier

Name: **Maria C. Di Bonaventura**

PERSONAL BACKGROUND:
I was born in Venezuela and moved to the United States when I was 12. I immediately became interested in materials science and engineering when I realized, in my freshman year of college, that every time I would go to an aviation museum, I would constantly question, ‘Why is this material chosen?’ That was when I realized that materials engineering was what I really wanted to do. After graduation, I will be completing an eight-month co-op with BP America in Houston, Texas, and then pursue my master’s degree in materials science and engineering, with a metals specialty.

PROJECT TEAM BACKGROUND:
I analyzed three different materials chosen by the group for the CV. These were directly compared with the original chosen alloy. The properties of the materials, such as specific strength, cost, and fracture toughness, were taken into consideration in order to determine the best material, using a criteria comparison matrix.

PROJECT CHALLENGES:
Our team’s greatest challenge was identifying materials suitable for application. At the time the original capture vehicle was designed, there was a limited number of databases for materials that could be used. Nearly 50 years later, that is still the case. A material that can withstand the requirements of the capture vehicle is not easily identified.

OBSERVATIONS:
We were surprised at how massive this entire design was. Its dimensions, specifications, requirements and—most importantly—cost, made Project AZORIAN very challenging. It is not every day that you work on a project that requires a material to withstand around 280 ksi.

TOP SECRET

Student Project Dossier

Name:

Michael Ashton

PERSONAL BACKGROUND:
I will be staying at UF for the next four years to pursue a Ph.D. in materials science. My focus as a Ph.D will be in computational materials research, where I'll mostly be modeling surfaces. My hope is to become a research assistant and then one day a professor.

PROJECT TEAM BACKGROUND:
My role in the project group was two-fold—to perform the initial stress calculation estimate at the fracture location on the first tine that failed, and then to research and report on a nickel alloy (MP35N) that we identified as a potential material substitute.

PROJECT CHALLENGES:
The greatest challenge was probably limited access to critical information, especially with respect to the stress calculations. To address this, my team simplified the CV geometry and its orientation with respect to the ocean floor when it first penetrated. I used values that Dr. Fuchs supplied for the loads and tine dimensions in my calculation. To the best of my knowledge, all of the estimates and simplifications I used represented a worst-case scenario, so my final calculation of the maximum tensile stress at the point of fracture (in theory) included some sort of inherent safety factor.

OBSERVATIONS:
Probably the most surprising insight gained during the project was that the stress that would have been on the tine, without the unexpected load during the improvised bottom operations, was below the maraging steel's yield strength. The maraging steel appears to have been strong enough for the task it was meant to do.

I liked that we were really left to our own devices to perform relevant calculations and report about the alternative alloys we evaluated. I also appreciated the perceived importance of our project by having Michael White and David Sharp express interest in what we were doing.

Figure 5. CGI illustration of the CV tines being driven into the ocean bottom soil. The sunken Soviet submarine can be seen to the left. Note that the harder-than-expected soil under the submarine resulted in a significantly greater load being required to drive the tines under the vessel. Courtesy Michael White.

CONCLUSION

All in all, the Project AZORIAN senior project was a huge success. Each of the groups gave technical presentations and turned in reports describing the failure analysis and the selection of the materials for a CV tine. The students became very engaged in learning more about the engineering aspects of Project AZORIAN, while also gaining a valuable history lesson on what the Cold War was all about. In addition, they had an opportunity to interact with two experts in the field and caught a glimpse inside the cloak-and-dagger world of classified, "dark" programs. The project also fostered class discussion on the engineering and military reasons for completing such an enormous and difficult task as raising a sunken Soviet submarine, as well as ethical considerations related to disturbing what could be considered a "sacred burial ground."

The only thing that could have made this project better would have been the CIA's release of the failure analysis, fractography, and/or materials characterization of the CV tine materials. Perhaps some time in the future, that information will be made available and could be factored into the results of this project.

ACKNOWLEDGEMENTS

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