



Viewpoint

Operation Burnt Frost: A View From Inside

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ABSTRACT

This viewpoint summarizes my personal involvement in Operation Burnt Frost, the U.S. government interagency undertaking to mitigate the human casualty risk of the reentry of USA-193 in 2008. In fact, my unique involvement dates back to shortly after the launch of the spacecraft, more than a year before its destruction. This operation has been the subject of erroneous public speculations surrounding the origin and motivation of this activity and which remain to this day. Finding no authoritative published work to present a fuller, more accurate picture of the background and exciting 2 months of Operation Burnt Frost, I offer this summary to clarify the endeavor.

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On February 20, 2008, a small homing device, the last element of a multistage missile fired from a U.S. Navy Aegis cruiser, struck an errant satellite only a few weeks before an uncontrolled reentry posed a unique threat of human casualties on Earth. The success of this high priority mission, authorized personally by President George W. Bush, represented the culmination of a herculean effort of thousands of men and women from more than two dozen federal agencies. In only 2 months, daunting challenges ranging from pure physics to complex electronic systems to international relations had to be overcome.

As NASA's Chief Scientist for Orbital Debris, my role in what was to become Operation Burnt Frost actually began a year before this initially highly classified project was even envisioned and took me from my office at the NASA Johnson Space Center to HQ U.S. Strategic Command in Omaha, NE, the White House, and the United Nations in Vienna, Austria. The summary presented here has been undertaken to provide a broader scope of this monumental undertaking and to lay to rest false charges as to its true objective.

1. Malfunction in space

The National Reconnaissance Office (NRO) was officially created in 1961 to manage the country's fledgling space-based reconnaissance program. Declassified in 1992, the office operates a wide variety of satellites to support the intelligence community and the Department of Defense. At the end of 2006, another in a long line of diverse spacecraft was prepared for launching at the Vandenberg

Air Force Base in California by a Delta II launch vehicle. Lift-off came on December 14, followed by insertion into a nearly circular orbit at an altitude of approximately 230 miles.

Primarily known by its international common name USA-193, as well as its NRO designator L-21, the satellite with a mass of more than 5000 pounds, malfunctioned within hours of launch. With no means for Earth-bound operators to control or even communicate with USA-193, the vehicle began a slow inevitable decay from orbit, which would lead to a reentry in a little over a year.

The lack of communication with USA-193 also meant that the reason for the malfunction could not be identified. Commonly in cases like this, analysts begin a fault-tree assessment to establish a root cause of the problem. For example, was there a catastrophic failure in the electrical power or communications system? If so, what component or subsystem was at fault? Alternatively, was an external influence at work? Each possible cause is evaluated, regardless of its perceived likelihood.

Theoretically, the spacecraft could have been struck in a vital location by another object. Therefore, the probability of a hit by a meteoroid or a piece of orbital debris needed to be examined. Thus, a month after the launch of USA-193, a representative of the NRO contacted me with a request for assistance. The NASA Orbital Debris Program Office at the Johnson Space Center supported this assessment for the next few months.

In the course of this work, I raised the issue of the eventual reentry of USA-193. As the head of the U.S. delegation to the Inter-Agency Space Debris Coordinating Committee (IADC), I knew that the reentry of USA-193 would be a subject of discussion. At the time, the IADC consisted of 10 national space agencies plus the European Space Agency. NASA was the official member of the IADC,

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but the NASA delegation included personnel from the Department of Defense, the Department of State, and other U.S. government organizations as deemed appropriate.

One of the concerns of the IADC was the reentry of potentially hazardous objects, e.g., one with a large amount of debris, which would survive reentry or one with hazardous materials, including radioactive ones. Owing to the national security nature of USA-193, such discussions might become difficult, and I suggested that the NRO consider its position and the best way forward. In the spring of 2007, NASA provided software to the NRO to conduct an initial moderate fidelity assessment of the survivability of USA-193 parts.

In August 2007, NASA received additional information about USA-193, which changed the reentry assessment completely. The spacecraft carried 1000 pounds of hydrazine propellant in an approximately spherical titanium tank with a diameter of more than 3 feet. Such tank materials and propellants are commonly used in spacecraft propulsion systems. Moreover, titanium has a high melting temperature, and titanium tanks routinely survive reentry. Several have been recovered after reentry with very little structural damage.

However, the USA-193 situation was unprecedented. First, previous titanium tanks had begun the reentry process empty or nearly empty of their propellants. The presence of 1000 pounds of hydrazine would affect the ballistic characteristics of the tank, which in turn might alter the fate of the tank. Of even greater importance, however, was a conclusion by spacecraft engineers that the hydrazine was very likely in a deeply frozen state. This complicated the reentry survivability calculation immensely.

Another issue at that time was the highly classified nature of most information concerning USA-193. Some NASA personnel with reentry survivability expertise had insufficient clearance to receive all pertinent data. Consequently, the first detailed efforts to determine if the tank (and its contents) would survive reentry had to be done parametrically. The results, though, indicated a high probability that the tank would survive reentry intact. Importantly, this conclusion was supported by independent analyses performed by other U.S. government organizations.

At the conclusion of this preliminary effort, I received a single-sentence email from one of our NRO colleagues: "If this were a NASA spacecraft that was going to reenter with a full, frozen tank, knowing what you know now, what would you do next?"

2. The decision process

Gen. Kevin Chilton, Commander of U.S. Strategic Command (USSTRATCOM), has publicly revealed that in the first week of December 2007, Mr. Scott Large, the Director of the NRO, briefed to him the subject of a means to mitigate the reentry risk of USA-193. Gen. Chilton suggested that Mr. Large approach the Missile Defense Agency, led by Gen. Henry Obering. The altitude of the satellite had by then dropped to only 190 miles and was expected to reenter in about 3 months.

Contrary to popular belief, the United States did not possess an anti-satellite (ASAT) capability that could address the USA-193 situation. In fact, the last time that the United States had fired a missile to destroy a satellite in Earth orbit occurred in September 1985, when an F-15 aircraft dropped a custom-designed missile to intercept the Solwind satellite in the first and only complete test of a proposed, but later canceled, air-launched ASAT system.

For the sake of full disclosure, I joined this ASAT effort in 1979, soon after its inception, and was present in the Space Surveillance Center in Cheyenne Mountain, Colorado, following the interception of Solwind to monitor the debris consequences of the engagement. This test did demonstrate the potential collateral effects of the physical destruction of objects in space by creating large amounts

of orbital debris. Moreover, the test led, in part, to the creation of national and international norms of conduct for space operations: norms that would later influence Operation Burnt Frost.

Shortly before Christmas, Gen. Chilton was notified by Mr. Large that during the forthcoming holidays, a preliminary feasibility study was to be undertaken by his organization, including support contractors. By the end of the year, the assessment had not found any fundamental obstacle that might prevent the use of MDA assets to negate USA-193. However, a myriad of technical and operational challenges existed with very little time left before reentry of the satellite.

President George W. Bush was briefed on the situation and the potential for a resolution on January 8, 2008. The emphasis during that briefing was on the human casualty risk posed by hydrazine reaching the ground. Important to the President's decision at that time and later was the fact that the casualty risk was not only for the residents of the United States, but for anyone living between 58.5° North Latitude and 58.5° South Latitude, i.e., the vast majority of the world's population. On this date, USA-193's altitude was down to 180 miles, and its descent toward Earth was accelerating.

Gen. Chilton later noted that keeping work regarding USA-193 highly classified was necessary at this stage to preserve the President's "decision space." The day before the briefing to the President, I received an email from a Russian delegate to the IADC inquiring about the forthcoming reentry of USA-193. He recommended that USA-193 would be a good candidate for the annual IADC risk object reentry exercise, where a normal reentering object was tracked as if it were a hazardous object, for the purpose of testing an international tracking data exchange system. For security reasons, I had to delay responding to the inquiry.

Deferring a final decision on the matter, the President did authorize detailed work on options to destroy USA-193 before reentry and on the quantification of the risk to people on Earth should USA-193 reenter in an uncontrolled manner. As a backdrop for the latter, the United States had previously defined and the international community had adopted a human casualty risk of no worse than 1 in 10,000 from the reentry of a single satellite. In other words, the chance of anyone in the world being injured as the result of a reentry should not exceed 0.0001.

The day after the meeting with the President, a classified meeting was held at the Johnson Space Center to address NASA's role in support of an ever-expanding interagency effort. In attendance were the NASA Administrator Michael Griffin, the JSC Center Director Michael Coats, myself, and a few others. DoD personnel were tied in via secure telecommunications.

After receiving a summary of the situation and the President's directive, Administrator Griffin quickly agreed to place the resources of NASA at the disposal of the group, which was now led by USSTRATCOM. The administrator designated me as NASA's technical liaison to the interagency working group and to handle external requests for assistance. NASA's initial tasks included the following: (1) evaluation of the risk that the satellite propellant tank would pose to people on Earth if it reentered the atmosphere intact, (2) determination of the near-term risk to the International Space Station (ISS) and other operational satellites from debris released in the destruction of USA-193, and (3) prediction of the longevity of any USA-193 debris that remained in orbit.

The first task was by far the most difficult. Not only was it necessary to increase our confidence that the titanium tank with frozen hydrazine would reach the ground essentially intact, but also to determine the state of any residual hydrazine. If the tank actually did demise during reentry, then no engagement of USA-193 would be necessary, and interagency activity could be reduced to the handling of standard large-object reentries. If the

tank survived, then knowledge of the state of the hydrazine (solid, liquid, or slush) and its amount was critical.

Any gaseous hydrazine would likely vent, at a minimum, through the broken and inlet and exit propellant lines, and any non-gaseous hydrazine would quickly become gaseous. The hydrazine would naturally spread out over a large area and remain hazardous to anyone who came within a certain range. At low concentrations of the gas, near-term discomfort or long-term human tissue damage was possible. At higher concentrations, the exposure could be fatal. Of course, with time the hydrazine gas would dissipate and no longer pose a threat.

Another human factor, however, increased the overall risk further. Typically, a moderate or large object is found once or twice a year somewhere around the world after the reentry of a spacecraft or rocket body. An understandable human tendency is to approach an object that has just been observed falling from the sky. I recall having to visit a site in Georgetown, TX, to identify a very large object, which had fallen overnight very near a farm residence, as a propellant tank from a U.S. rocket body and to assess any hazard it might still pose. In the case of the USA-193 tank, the presence of hydrazine gas could increase the risk of not only a single casualty, but also multiple casualties. Such scenarios had to be considered and factored into the final risk calculation.

NASA's team of experts, as well as our interagency colleagues, hit the ground running. At the JSC January 9 meeting, the NASA Administrator wanted to know more about the hydrazine tanks that had survived the reentry of the ill-fated Space Shuttle Columbia in 2003. Columbia recovery team members were contacted and data collected. My communications with DoD became increasingly more frequent, and daily interagency classified video teleconferences became the norm. These telecons involved numerous federal organizations, literally from coast to coast and sometimes into the Pacific Ocean.

On the evening of January 10, I received my first midnight call at home from Gen. Chilton. Calls at home after midnight became commonplace as the dedicated personnel at USSTRATCOM and other organizations were working around the clock given the very brief time left before the President had to make his final decision. On January 14, I traveled to Omaha, NE, to work for a few days directly with Gen. Chilton; Rear Adm. Douglas McClain, the Director of Global Operations (J3), and others of their staff at Headquarters USSTRATCOM.

The issue of the safety of human spaceflight was obviously a high priority at NASA. The ISS operated at an altitude slightly above that of USA-193 and might be subject to impacts from debris released by the satellite if the intercept were successful. In addition, Space Shuttle Atlantis was scheduled to be launched on February 7 to carry a new European module to the ISS and then to return to Earth on February 18. Gen. Chilton, a veteran of three Space Shuttle missions and a former Space Shuttle Commander, preferred to delay any attempt to negate USA-193 until after Atlantis had landed. Thus, the window for engagement was very short: from February 18 to early March. Attempting an intercept in the last few days before reentry was problematic because of potential inaccuracies in both targeting and spacecraft signature data.

On Friday, January 25, William Gerstenmaier, NASA Associate Administrator for Human Exploration and Operations, was briefed at NASA Headquarters on the potential for action against USA-193. The following Monday, I briefed Michael Suffredini, the Manager of NASA's International Space Station Program Office, and John Shannon, Deputy Manager of the Space Shuttle Program Office. Both were later kept apprised of updates in the work regarding USA-193.

The National Security Council for the first time acknowledged publicly that the disabled USA-193 was slowly falling back to Earth

and was expected to reenter sometime in March. In conjunction with this announcement, the Department of State did send notices to a number of foreign governments and space agencies. Of course, no mention was made of the option to attempt an intercept of the satellite. Not surprisingly, numerous inquiries from foreign colleagues, as well as the press, began arriving at NASA, due to our reputation in cases of reentries. By interagency direction and as USA-193 was not an NASA spacecraft, most of the inquiries were forwarded to other U.S. government organizations.

By the end of January, all the remaining risk analyses had been completed, and missile system engineers were confident that the necessary hardware and software modifications could be accomplished by the second half of February. The President was briefed on the final human casualty risk assessment figures in the event of a natural reentry of USA-193. The risks were by far the highest ever associated with a spacecraft or rocket body reentry. Understanding the potentially negative international reaction to the destruction of USA-193, President Bush, nonetheless, gave final approval to prepare for attempts to eliminate the threat. The undertaking was given the code name Operation Burnt Frost.

3. The final weeks

With the Presidential decision to engage USA-193, NASA increased its attention to issues associated with protecting human spaceflight. If Atlantis launched on February 7 as planned, the Space Shuttle would be safely on the ground before the initial negation attempt of the errant satellite, leaving the ISS as the primary subject for risk mitigation measures. By carefully selecting the time of interceptor launch, the risk to ISS from USA-193 debris, already assessed as very low, could be further reduced.

At this time, NASA was increasingly called upon to assist in the handling of geopolitical issues, especially at the United Nations, where the annual meeting of the Committee on the Peaceful Uses of Outer Space's Scientific and Technical Subcommittee (COPUOS STSC) was set to begin on February 11 in Vienna, Austria. I was already scheduled to deliver a presentation on recent orbital debris events and scientific research during the second week of the meeting.

However, on February 5, I found myself flying to Washington for meetings the next day at NASA Headquarters, the State Department, and, most importantly, with the Science Advisor to the President, Dr. John H. Marburger III. This last meeting addressed a number of topics associated with USA-193. Dr. Marburger expressed interest not only in risks on orbit and the ground, but also how the United States would proceed in the event that the attempt to destroy USA-193 was unsuccessful.

During my meeting at NASA Headquarters, I was asked to extend my short visit to Washington to accompany the NASA Deputy Administrator Shana Dale to a meeting of the National Security Council Deputies in the White House Situation Room the next day, January 7. Gen. Chilton was not in Washington at the time, but he was tied in via a video connection. A wide range of topics, both operational and pertaining to international relations, were covered. The altitude of USA-193 was now down to only 165 miles.

The same afternoon as the White House meeting, Space Shuttle Atlantis lifted-off from the NASA Kennedy Space Center in Florida for its logistical visit to the ISS. The nominal flight plan called for a mission of 11 days with the possibility of an extension of one or two days. Each extra day would further erode the window of opportunity to engage USA-193.

Back in Houston on January 8, I received a high-level request from the NRO for NASA to provide two personnel to join an interagency Consequence Team being assembled to fly to anywhere in the world on very short notice in the event that debris from USA-

193 was found. Even if USA-193 were struck during the negation attempt, it was possible that the propellant tank would not be destroyed. The request specifically sought NASA personnel who had experience with the recovery of debris from Space Shuttle Columbia 5 years earlier. The Consequence Team would eventually include 90 people and four C-17 aircraft.

The STS-122 mission to ISS was first extended one day on February 10 and then extended another day on February 13. Although the period to launch an interceptor against USA-193 was already short, no effort was made to influence the duration of the Space Shuttle flight. Atlantis was now scheduled to land on February 20.

The decision to attempt to eliminate the threat from USA-193 was made public on Thursday, February 14. The President was insistent on the need for transparency regarding the rationale for the operation. First, Congress was briefed on the President's directive, including the basic elements of the planned engagement. The timing of the briefing was driven by the fact that Congress would adjourn the next day for an extended Presidents' Day holiday.

In the afternoon after the Congressional presentations, a briefing for the media was held in the Pentagon with the subject "Reentry of U.S. Satellite." Opening statements were provided by a distinguished panel of three: Ambassador James Jeffrey, Deputy National Security Advisor; General James Cartwright, Vice Chair of the Joints Chiefs of Staff; and Dr. Michael Griffin, NASA Administrator.

Basic specifics of the plan were revealed. The system chosen for engaging USA-193 was an SM-3 missile fired from a U.S. naval surface vessel. Three missiles and three ships (not identified at that time) had been modified from their normal ballistic missile defense role for this unique mission. A naval platform had been selected, in part, for its great mobility, which was important because the path of USA-193 shifted every day with respect to the ground. If a launch opportunity had to be deferred for some reason, especially if the cause was ship-related, another ship could be in position to take the next day's shot.

Even more importantly, the use of a naval platform permitted the selection of precisely where the engagement would occur. After a successful engagement about half of the resultant debris would reenter the dense portion of the atmosphere within about an hour. Therefore, a downrange ground-track could be chosen to maximize the amount of surviving debris over broad ocean areas or sparsely populated regions, reducing the residual human casualty risk from solid debris.

Gen. Cartwright and Administrator Griffin emphasized that the attempt to negate the threat from USA-193 could not make the situation worse. In the event of a miss or a glancing blow, the spacecraft would still reenter as before. However, a hit in which the tank was breached would eliminate the hydrazine risks completely. After the prepared remarks, the floor was opened for questions from the media.

The attendees of the COPUOS STSC meeting in Vienna were completing the first week of their 2-week session and were already aware of the forthcoming reentry of USA-193. Upon hearing of the plan to attempt a destruction of USA-193, several national delegations requested additional details, particularly of a more technical nature, from the U.S. delegation. I was selected to provide that information for three reasons.

First, I was intimately familiar with all aspects of the plan and knew what information was still not releasable. Secondly, I had been the technical lead for the United States at the United Nations during a multiyear process to develop Space Debris Mitigation Guidelines. These COPUOS guidelines had just been endorsed by the UN General Assembly 2 months earlier (December 2007).

Finally, I was already scheduled to leave for Vienna in less than 2 days (on February 16) to deliver the U.S. annual update on orbital debris matters during the second week of the STSC meeting.

On the morning of February 15, I quickly drafted a new eight-page presentation entitled Space Debris Assessment for USA-193 and sent it out for U.S. government interagency review. By the end of the day, all pertinent federal organizations, including the White House and the State Department, had signed-off on the package. Such a quick approval cycle in Washington is rare, attesting to the very high importance given to this issue.

The principal topics of the presentation were as follows: (1) anticipated characteristics of the debris, which would form in the event that USA-193 was destroyed; (2) how this action was completely compatible with the new Space Debris Mitigation Guidelines; (3) the orbital longevity of the remaining debris; and (4) the transitory risks to the operation of existing satellites in low Earth orbit.

The UN guidelines explicitly addressed the potential, albeit rare, necessity to intentionally break-up a spacecraft or large launch vehicle stage. For instance, the risk to people and property from a nuclear-powered spacecraft falling back to Earth in an uncontrolled manner could be dramatically reduced by destroying the vehicle and its nuclear power supply (e.g., nuclear reactor) shortly before reentry. In such an event, the guidelines noted that the destruction "should be conducted at sufficiently low altitudes to limit the life-time of resulting fragments." This is precisely what was intended for USA-193, making the planned U.S. action fully compliant with the UN guidelines. The U.S. presentation contained a chart indicating that 99% of the debris left in orbit were expected to reenter the atmosphere within only 1 week.

The reception of the STSC delegates to the presentation, which was given on the morning of February 19 (Vienna time), was better than the United States had hoped. Not a single delegation expressed criticism or disapproval of the planned interception during the meeting. In fact, one delegate from a major space-faring nation spoke with me afterwards and commended the United States for its decision given the difficult circumstances. Early the next morning, I left Vienna to return to Houston with a short layover in Washington, unaware of what the day might bring.

Space Shuttle Atlantis had undocked from the ISS on February 18, conducted a post-mission assessment of the vehicle the following day, and landed without incident at 9:07 a.m. EST on February 20. The stage was now set to execute the USA-193 engagement plan. When I landed at Washington Dulles Airport in the afternoon, I called my wife and was informed that she had received a message from USSTRATCOM for me to contact them in Omaha. In a brief conversation, I learned that the first attempt to intercept USA-193 was given a "Go" for that evening.

At 10:26 p.m. EST, an SM-3 missile was launched from the USS Lake Erie located north of Hawaii. Four minutes later, USA-193 was impacted at high speed. The collision between missile and satellite had occurred at an altitude of approximately 150 miles while the latter was traveling in a northeasterly direction toward northern Canada. The preliminary strike assessment suggested that the hydrazine tank had, in fact, been destroyed. I learned of the success from USSTRATCOM after finally reaching home just before midnight Houston time.

4. The aftermath

The men and women of Operation Burnt Frost were justly satisfied and proud that their considerable efforts had been rewarded with the negation of USA-193 and its tank. Details of the achievement, including radar, optical, and infrared images, were soon released to the public. No debris were ever found, and the

contingency recovery team stood-down. The remaining two missiles and all three ships were returned to their normal design states, as promised.

Since the public announcement on February 14 of the U.S. intention to engage USA-193, much speculation arose as to rationales for the mission other than the stated protection of human life. Many of these ruminations arose from self-proclaimed experts in policy and physics and were extensively carried by the press. Moreover, these unsubstantiated and unjustified accusations have continued for many years, taking on a life of their own, like so many conspiracy theories.

Some hypothesized that the action was in some way in response to the Chinese antisatellite test during the previous year. This theory falls apart on many levels with only a little scrutiny. Geopolitically, the President and his national security advisors were well aware of how the U.S. actions could be misconstrued. In fact, this was a major argument considered, but rejected, in the inter-agency community for not attempting to destroy the satellite. Even if the mission had not succeeded, the United States would undoubtedly still have been accused of a military objective.

The United States had marshalled world-wide criticism of China for its ASAT test, not only for the enormous amount and long-lived nature of the orbital debris created, but also for escalating tensions and risking an arms race in space. Due, in part, to this global outrage, China ceased performing overt tests of its offensive space system. The test of an ASAT system by the United States would have freed them from future constraints.

As was pointed out at the time, the United States had long before demonstrated the capability for hit-to-kill systems in space, not to mention numerous successful tests of endo-atmospheric intercepts. The U.S. Army had first demonstrated the technology during the Homing Overlay Experiment in 1984, the year before the U.S. Air Force's negation of the Solwind satellite noted above. Hence, merely repeating such a test offered little or no gain, especially since the SM-3 missile was not tied to a formal ASAT program. In fact, the SM-3 would be completely inadequate for an ASAT weapon system because of its inherent flight performance limitations.

Undertaking such a stressing scenario with no preparation, only a 2-month timeline, and extremely difficult conditions is not a hallmark of the development of a new major weapons system,

which would require Congressional approval, nor were hurried meetings with the President.

Another frequent claim by detractors of the USA-193 undertaking was that the satellite propellant tank would not survive reentry with its load of hydrazine. Hence, there was no reason to destroy the satellite. The NASA Orbital Debris Program Office is not only the agency's center of excellence for assessing the uncontrolled reentry of unmanned satellites and rocket bodies, but it provides support to other federal organizations and the aerospace industry in this highly technical discipline.

For Operation Burnt Frost, NASA reentry results were not taken at face value but were reviewed and compared with the independent analyses of other participating organizations. In addition, NASA reentry survivability models are time-tested, validated, complex computer simulations that have been compared to analogous foreign models. To ensure the highest possible confidence in determining tank survivability, NASA used extensive parametric techniques to identify any potential influence of input uncertainties and final result sensitivities. I personally reviewed multiple reentry survivability assessments for the tank offered by members of the public, and, however well-intentioned the efforts might have been, I found them deficient in their methodologies and physical considerations.

The fact that concern about the potential hazard posed by the hydrazine tank dated back to the summer of 2007 also refutes the suggestion that human safety was a last-minute cover story for the mission. In countless highly classified in-person meetings and videoconferences up to the most senior levels of the U.S. government, not once did I ever hear of a reason to consider taking mitigation measures against USA-193 other than to protect human life. To do nothing in the face of this threat would have been much easier.

Gen. Chilton has said that only the United States could have achieved such a demanding action in such a short time. I believe that only the United States would have even tried.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.