Comments on "Iran's Ballistic Missile Potential": A Paper by David Montague, Uzi Rubin, and Dean Wilkening

By David Holloway[†] and Theodore Postol[*]

Introduction

We have reviewed the paper "Iran's Ballistic Missile Potential" by David Montague, Uzi Rubin, and Dean Wilkening. Montague et al. assert that the Joint Threat Assessment (JTA) downplays Iran's ballistic missile accomplishments and, in particular, minimizes Iran's development of solid propellant ballistic missiles. They claim that we overstate the weight and lack of mobility, and understate the ease of development, of future possible Iranian solid propellant ballistic missiles that could pose a nuclear-delivery threat to Northern and Western Europe. According to Montague et al., these missiles could be built in the next five to six years using technologies already demonstrated by Iran in the recently tested 2000 km range Sejjil Missile. If these claims were correct, such a rapidly developing threat could have significant implications for US considerations about the need for European missile defenses. Finally, Montague et al. assert that our report has many errors in its contents and findings.

In this response we will do two things.

1. We will show that Montague et al. provide a misleading portrait of the contents and findings of our report by selectively quoting bits and pieces of text from the carefully drafted discussions of the matters they claim to criticize.

2. We will show that their claims about the performance of future postulated Iranian solid-propellant IRBM's are based on hidden and incorrect scientific and engineering assumptions and on large and inexplicable errors in their numerical calculations. The engineering parameters of the missiles they postulate are totally inconsistent with *their* assertions that solid propellant ballistic missiles based on Sejjil technology could be relatively light and mobile and that they would be easy to develop and could be quickly deployed.

To be specific, Montague et al.'s entire technical argument is based on numerical errors in their range calculations and on the assumption that the performance parameters in their postulated missile are higher than those we used in our postulated missile. Our postulated missile has the same performance parameters as those we derived from our analysis of the Sejjil missile launch of May 20, 2009. The missile we postulated could carry 1000 kg to 5000 km range and would weigh slightly more than 65 tonnes. Montague et al's. higher rocket performance parameters and errors in their range calculations led them to the erroneous conclusion that a missile with the same range and payload as ours should instead weigh 40 tonnes rather than 65 tonnes.

In the technical piece of this article, we show that the discrepancies in the weights of our postulated missile and their postulated missile can be traced back to three different and distinct errors:

1. Montague et al. have large numerical errors of more than 20 percent in the ranges they calculated for their model missiles.
2. Montague et al. assume higher rocket performance parameters than we, rather than the performance parameters we derived from an analysis of the Sejjil missile test of May 20, 2009.
3. The higher performance parameters assumed by Montague et al. are not consistent with their claims about how such improvements in rocket performance can be obtained.

When these factors are accounted for, we find that if we correct for the numerical errors in their range calculations, and adopt for our missile the same bogus rocket parameters they used for their postulated 5000 km range missile, our 5000 km range missile actually weighs 20 percent less than the missile they claim to have obtained.

If we instead assume that both their postulated missile and ours have the same rocket parameters we derived by analyzing the May 20, 2009 Sejjil flight test, we find that their 5000 km range missile would weigh about 110,000 kg, roughly 70 percent more than our postulated 5000 km range missile.

Thus, there is no technical basis for Montague et al. to claim that we have somehow downplayed, minimized, or slanted our analysis of Iran's ballistic missile capabilities.

We will therefore show that the only potentially original contributions they might have made in their article are entirely ascribable to computational errors, hidden and misapplied assumptions about rocket technology, and conceptual errors in the basic configuration of their "alternative" 5000 km range solid propellant ballistic missile.

Misrepresentations Made by Montague et al. about the Contents and Findings of the Joint Threat Assessment Report

Here we point out some – but by no means all – of the misstatements about our work in Montague et al. The fact that we do not address numerous other misrepresentations by Montague et al. should not be taken as acceptance by us of those claims.

Page 1, par. 2 (middle of the par.): Montague et al. write:

> The JTA report itself is contradictory in this regard, concluding that "Iran could develop in perhaps 6 to 8 years a ballistic missile capable of delivering a 1000 kg nuclear warhead to a range of 2000 km." when, in fact, the day after the JTA report was released, Iran successfully tested a two-stage solid-propellant ballistic missile (the "Sejjil") capable of delivering a 1000 kg payload to a range between 2000 km and 2500 km (depending on assumptions one makes about the rocket's efficiency and payload). The fact that the report minimizes Iran's development of solid-propellant ballistic missiles, the Sejjil in particular, is perhaps its greatest weakness.

This misrepresentation is repeated (half-heartedly) on page 10, par. 1.

The JTA states clearly in par. 3.21 that our assessment of the 6-8 years for Iran to have a missile capable of delivering a 1,000 kg nuclear warhead to a range of 2000 km is "*determined primarily* by the time it would take [Iran] to build a nuclear warhead that is small enough and light enough." Even if we accepted what Montague et al. say about the Sejjil missile, it would not be capable now of delivering a nuclear warhead to a range of 2000 km because such a warhead does not now exist. So the point about a contradiction doesn't stand.

Montague et al.'s statements that "the day after the JTA report was released, Iran successfully tested a two-stage solid-propellant ballistic missile" and "the report minimizes Iran's development of solid-propellant ballistic missiles" ignore what the JTA says about solid propellant missile technology and misrepresents the extent of our analysis, which is much more substantive and complete than the analysis presented by Montague et al.

On page 1, par. 3.2 of the JTA's technical addendum entitled *Iran's Ballistic Missile Program: A Technical Assessment* we stated: "There is no good evidence at this time to support a technical analysis of Iran's solid propellant ballistic missile program, but we expect to add to, and perhaps modify, this report as new information becomes available." In the first paragraph on the first page of the Addendum entitled "*A Technical Analysis of the Sejjil*

Ballistic Missile: Supplement to the Joint Threat Assessment Appendices" we stated

> The JTA Report issued on May 19, 2009 did not provide an analysis of the capabilities of Iranian long-range solid propellant ballistic missiles. It was noted that there were reports that Iran had developed a solid propellant missile with a range of 2000 km, but the available data was insufficient for a serious analysis. On May 20, 2009, one day after the JTA report was released to the public, Iran successfully tested a solid propellant two-stage ballistic missile known as the Sejjil. Information that is now in the public domain, including testimony given to the Congress by Secretary of Defense Robert Gates on the technical characteristics of the Sejjil, makes it possible to provide an accurate and detailed assessment of the military and technical implications of this ballistic missile.

The JTA's supplemental addendum was published on May 31, 2009, only 11 days after the Sejjil launch. It is 19 pages long, contains the first publicly available detailed estimates of the weights, dimensions, accelerations, thrust, specific impulse, and burn times for the Sejjil ballistic missile, based on extensive analysis of videos that were released by Iran and not available prior to the launch. In contrast, Montague et al. provide an analysis with serious numerical, technical, conceptual and logical errors as well as numerous errors of fact. Any further review of Montague et al. (which we would welcome) will show that our analysis of the Sejjil solid propellant ballistic missile is, and remains, the single most accurate and comprehensive publicly available discussion of the potential implications of the Sejjil for European and US security.

Page 2, pars. 1 & 2 (and footnote 5): The argument is made here that Iran will not need to rely heavily on outside help in extending the payload and range capabilities of its missiles, but the argument is weak. First, the point is made that "the Sejjil missile <u>may have been</u> largely produced indigenously (emphasis added);" that doesn't get one very far. Second, it is true that Israel and other countries in the Middle East are under threat from the Shahab and Shahab-3; these missiles are derived from the North Korean Nodong. Third, <u>in contra</u> the opening of par. 2, there is plenty of evidence of Iranian attempts to acquire relevant technologies abroad. Fourth, the Brazilian example could just as well support the case that Iran will continue to rely on external help, since the summary provided actually shows how Brazil had to acquire certain crucial technologies from abroad.

There are several points at which Montague et al. imply that the JTA fails to address a particular issue when in fact the JTA does so. Here are three examples:

Page 3, par. 3: The JTA discusses the possibility of clustering Nodong rocket motors, and the disadvantages of doing so. (JTA pars. 3.22 and 3.23).

Page 5, par. 2: There is an analysis of the Safir-2 SLV and its suitability as a ballistic missile in pars. 3.11 to 3.14 of the JTA and 3.39-3.56 in the Technical Addendum on ballistic missiles. The discussion by Montague et al. doesn't come close to engaging with that analysis.

Page 5, last sentence. We do not have, or know of, good evidence that North Korea has produced the number of engines mentioned here. In fact we know of no good evidence that North Korea has been able to produce indigenously *any* of the engines it has used in its missiles. We would like to see the sources of evidence for Montague et al.'s assertion to the contrary, as the citation they use to support this assertion has nothing to do with their claim.

Assessments of Solid Propellant Ballistic Missile Performance

We start by showing how apparently minor changes in the technical characteristics of ballistic missiles can result in substantial changes in their actual performance. We will then use these insights to show, step by step, that Montague et al.'s claims about missile performance are not credible.

Step One: Table 1 below shows the characteristics of the "Baseline" Sejjil ballistic missile. We derived these characteristics by analyzing the dimensions, weights, reported flight ranges, and acceleration at launch of the Sejjil missile, on the assumption that the Baseline Sejjil uses first generation solid propellant missile technologies. The range estimates are based on the reported range of the successful Sejjil flight test on May 20, 2009. The dimensions of the missile were obtained from detailed analysis of videos and photographs. In addition, we derived the missile's acceleration at launch by frame-by-frame analysis of multiple videos of a Sejjil launch. We were able to estimate the thrust and burn time of the Sejjil's first stage rocket motor with the help of information derived from the volumetrically based estimate of the missile's weight combined with the acceleration at launch.

We assume that the Baseline Sejjil uses first-generation solid rocket technology, that is, the rocket motor is fabricated with steel casings and uses a well-known solid propellant mix of Ammonium Perchlorate and Aluminum. When these observations and assumptions were combined they led to range predictions that were essentially the same as those reported by the US Department of Defense. We conclude therefore that the model we have developed for the Baseline Sejjil ballistic missile accurately portrays its capabilities. It appears that Montague et al. agree with this model because they use it as the baseline for their analysis.

Figure 1 below shows the dimensions and acceleration at launch of the Baseline Sejjil ballistic missile.

Step 2: Table 2 shows the rocket parameters used by Montague et al. in their model of a postulated "Sejjil 3," which they claim can carry a 1000 kg warhead to 4900 km. The parameters adopted by Montague et al. that differ from those we used as the first-generation parameters of our Baseline Sejjil are highlighted in boxes that have a yellow background. The parameters chosen by Montague et al. have major implications for the performance of their postulated Sejjil 3. As will be shown later, even if the technical advances Montague et al. assert could be implemented quickly by Iran were implemented, they could not produce the increases in performance, and thereby in range and payload, claimed by Montague et al.

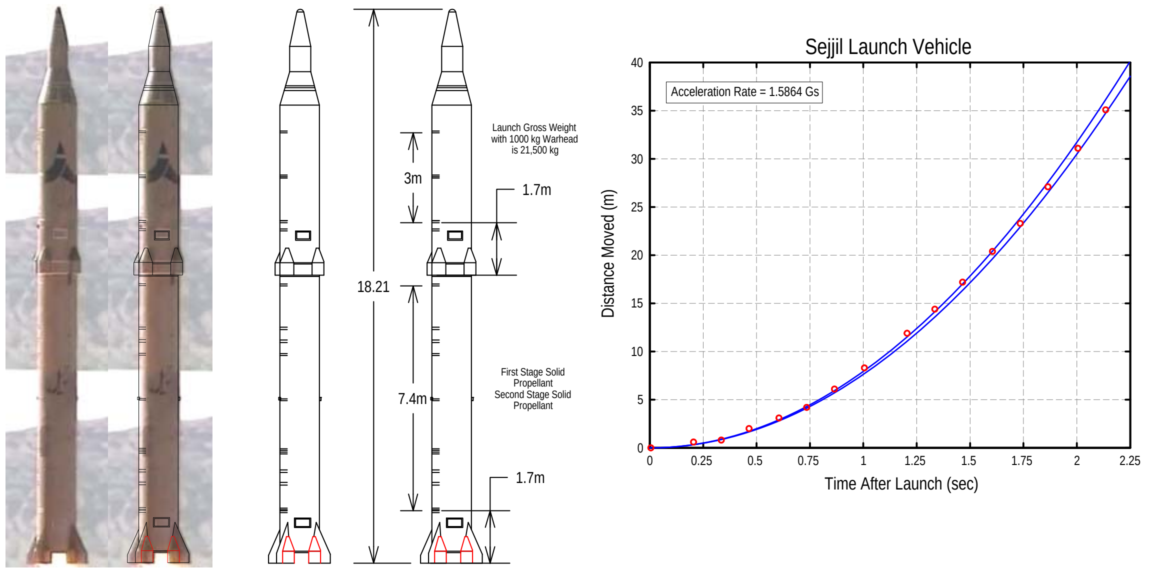

Figure 1

Estimated Performance Characteristics of the Sejjil Missile Rocket Stages

Stage	Full Weight (kg)	Burnout Weight (kg)	Thrust (kgf)	Structure Factor	Specific Impulse (sec)	Burn Time (sec)
Stage 1	14,720	2210	55,600	0.15	220 (SL) 250 (Vac)	50
Stage 2	5780	870	21,800	0.15	250	50

Table 1

Montague et al.'s Performance Characteristics for Sejjil Missile Rocket Stages that are Claimed as "Sejjil Missile Technology"

Stage	Full Weight (kg)	Burnout Weight (kg)	Thrust (kgf)	Structure Factor	Specific Impulse (sec)	Burn Time (sec)
Stage 1	14,720	2210	55,600	0.12	262 (Vac)	50
Stage 2	5780	870	21,800	0.15	270	50

Table 2

Figure 2 below shows the flight trajectory of our Baseline Sejjil for a non-rotating earth. Montague et al. report their missile ranges for a rotating earth and a trajectory azimuth of 310 degrees (this trajectory goes from the northwestern corner of Iran to slightly south of Ireland). If we assume a rotating earth on the same azimuth, the range of our Baseline Sejjil missile, which is the same as the one used by Montague et al., is roughly 2000 km. The rotating earth-range reported by Montague et al. of the baseline Sejjil is 2500 kilometers. Hence, the range Montague et al. calculate for our Baseline Sejjil is essentially 25 percent larger than the range we calculate using *exactly the same model missile!* This indicates that Montague et al.'s basic calculations of range and payload are wrong by a factor of 20 to 25 percent, independent of the erroneous hidden assumptions about technology improvements used in their calculations.

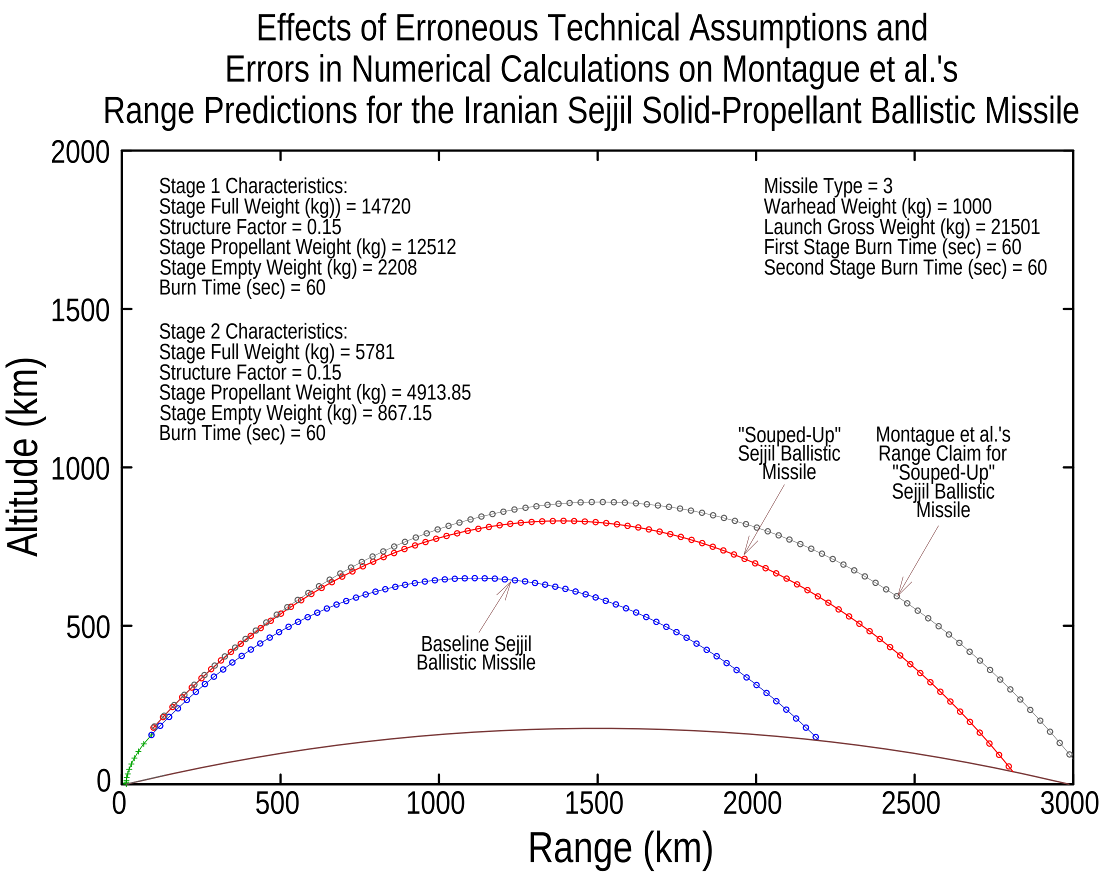

Figure 2

Figure 2 shows the flight trajectory of the Baseline Sejjil if we assume that it is built with rocket technologies that Montague et al. assert could be readily incorporated into it; those technologies would produce their Sejjil 3 (with the rocket parameters shown in Table 2). If Montague et al.'s assertions about readily achievable advances in rocket technology were correct, the Baseline Sejjil recently flown by Iran could be quickly improved to a "souped-up" Sejjil that had a nearly 30% gain in non-rotating earth-range – an increase in range from about 2200 km to more than 2800 km.

However, Montague et al.'s rotating-earth range for our Baseline Sejjil was 2500 km, indicating that the non-rotating-earth range that Montague et al. report for our Baseline Sejjil is about 2700 km, rather than the 2200 km non-rotating earth-range in our Report for the Baseline Sejjil. Montague et al.'s "souped-up" Sejjil has a range of 2800 km relative to the 2200 km range of our Sejjil. Since Montague et al. have errors of 25% in their range calculations, they will get a non-rotating-earth range of 1.25×2800 = 3500 km for the "souped up" Sejjil. Adjusting for the roughly 200 km loss in range due to the earth's rotation, we conclude that Montague et al. would calculate a rotating-earth range of roughly 3300 km for their souped-up Baseline Sejjil.

Thus, if Montague et al. are to be believed, the current Baseline Sejjil should be able to achieve a range improvement of greater than 50% *simply* by incorporating into the existing missile the technologies they assume for their postulated Sejjil 3!

Their faulty analysis could lead to the erroneous conclusion that the current Iranian Sejjil could be easily "souped-up" to produce a missile that could deliver a 1000 kg payload to a rotating-earth range of about 3100 km – putting Prague, Vienna, Bucharest, and Warsaw suddenly within range of their postulated souped-up Sejjil missile!

Step 3: We now show that when Montague et al.'s faulty analytical techniques and errors in calculations are corrected, their conclusions about the range and payload performance of their postulated "Sejjil 3" result in errors that are both more serious and more dramatic than those exposed in the previous discussion.

According to Montague et al., their Sejjil 3 has a rotating-earth range of 4900 km. The actual non-rotating-earth range for this missile should therefore be about 5100 km (due to a range loss from the eastward rotation of the earth for a ballistic missile launched to the west – as noted earlier, they assume a 310 degree azimuth). In fact, the correct rotating-earth range of their Sejjil 3 is about 15% lower, around 4265 km (see Table 3).

If all of the parameters of the Montague et al. Sejjil 3 are held constant, except for the specific impulse of the fuel they assume for the second stage, the specific impulse that the second stage motor needs to achieve the 5100 km non-rotating-earth range would be about 292 sec! Such a specific impulse is close to the highest that has been achieved in modern Western solid propellant motors and thus has to be considered as being well beyond Iran’s present capabilities.

Hence, Montague et al.’s basic numerical calculations, and their claims about the technological advances that would be needed to achieve the performance improvements they postulate are both in serious error.

Step 4: Figure 3 and Table 3 quantify the performance contributions for each of the new rocket technologies assumed by Montague et al. to lead to the range and payload improvements they incorrectly claim for their postulated Sejjil 3.

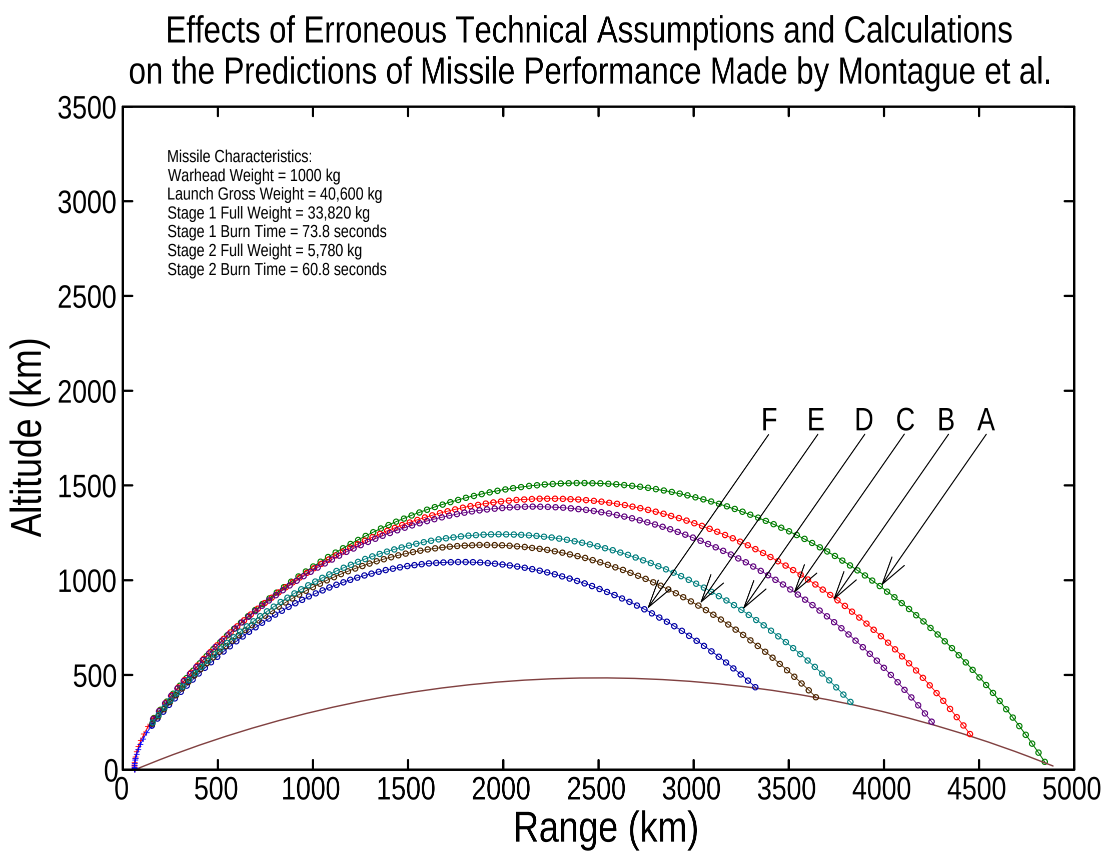

Figure 3

Missile A is Montague et al.’s postulated Sejjil 3 missile, except that it is assumed that the propellant in the second stage has a specific impulse of 285 seconds, rather than the 270 second specific impulse assumed by Montague et al. The rotating-earth range for this missile, which is the range that would be reported by Montague et al., is less than 4700 km.

Effects of Various Assumptions and Calculational Errors on the Range Predictions for the Postulated Missile that Montague et al. Called the "Sejjil 3"

	Missile A	Missile B	Missile C	Missile D	Missile E	Missile F
Comments	Assumptions About Missile Modified to Give Claimed 4,900 km Range ↓	Baseline Missile Claimed to Have a 4,900 km Range ↓	Baseline Modified to Have Second Stage I_{sp} Equal to First Stage I_{sp} ↓	Additional Modification for First and Second Stage Fuel Fractions Equal ↓	Additional Modification for First and Second Stage I_{sp} Jet Vane Loss of 3% ↓	Estimated Characteristics of Sejjil Solid Propellant Rocket Technology ↓
Range (km)†	4,900	4,500	4,300	3,860	3,660	3,350
Range for Rotating Earth (km)**		4,265	4,075	3,645	3,465	3165
Range Reported by Montague et al.		4900	?	?	?	?
Throw weight (kg)	1,000	1,000	1,000	1,000	1,000	1,000
Launch Mass (kg)	40,600	40,600	40,600	40,600	40,600	40,600
Boost Time (sec)	135	135	135	135	135	135
1st Stage						
Stage Mass (kg)	33,820	33,820	33,820	33,820	33,820	33,820
Propellant Fraction	0.88	0.88	0.88	0.85	0.85	0.85
Stage Diameter (m)	1.8	1.8	1.8	1.8	1.8	1.8
Stage Length (m)	8.2	8.2	8.2	8.2	8.2	8.2
CS Area (m^2)	2.55	2.55	2.55	2.55	2.55	2.55
Nozzle Area (m^2)	1.63	1.63	1.63	1.63	1.63	1.63
Vacuum Thrust (kN)	1,035	1,035	1,035	1,035	1,035	1,035
Vacuum Isp (sec)	262	262	262	262	256.5	250
Burn time (sec)	73.8	73.8	73.8	73.8	73.8	73.8
2nd Stage						
Stage Mass (kg)	5,780	5,780	5,780	5,780	5,780	5,780
Propellant Fraction	0.85	0.85	0.85	0.85	0.85	0.85
Stage Diameter (m)	1.25	1.25	1.25	1.25	1.25	1.25
Stage Length (m)	2.96	2.96	2.96	2.96	2.96	2.96
CS Area (m^2)	1.23	1.23	1.23	1.23	1.23	1.23
Nozzle Area (m^2)	0.785	0.785	0.785	0.785	0.785	0.785
Vacuum Thrust (kN)	214	214	214	214	214	214
Vacuum Isp (sec)	285	270	262	262	256.5	250
Burn time (sec)	60.8	60.8	60.8	60.8	60.8	60.8

† Assumes a non-rotating earth.

** Montague et al. report their range estimates for a rotating earth and a trajectory azimuth of 310°. This results in an average range loss of roughly 200 km relative to the non-rotating earth-ranges reported in this table. The actual ranges for a 310° azimuth are summarized in the table row called *"Range for Rotating Earth."*

Table 3

Missile B is Montague et al.'s postulated Sejjil 3. It has a non-rotating-earth range of 4500 km and a rotating-earth range of 4265 km. Assuming that such a rocket could be built, its range would be 15 percent less than that claimed by Montague et al.

Missile C assumes that the second stage of Montague et al.'s postulated Sejjil 3 has the same specific impulse as the first stage (262 seconds). Missile C has a rotating-earth range of 4075 km, 20% lower than that claimed for the postulated Sejjil 3.

Missile D is further modified to have a missile casing that weighs the same as a steel casing, rather than the filament-wound casing implied by the choice of a structure factor of 0.88 assumed by Montague et al. for their postulated Sejjil 3. Missile D has a rotating-earth-range of 3645 km, 35% below that claimed for the Sejjil 3.

Missile E is further modified to have a specific impulse of 256.5 seconds for both the first and the second stages. This is a realistic estimate of the potential gain in specific impulse that could *theoretically* be achieved if it were simple, as *wrongly* claimed by Montague et al., to remove the jet vanes and substitute a hydraulic swiveling rocket nozzle for control of the missile. When the *proper* *theoretical* increase in specific impulse is used, the rotating-earth range of Missile D is 3465 km, 40% lower than the postulated Sejjil 3.

Missile E is Montague et al.'s postulated Sejjil 3 with parameters (i.e. structure factors and rocket motor specific impulses) identical to those achieved in the Baseline Sejjil missile that was tested by Iran on May 20, 2009. This missile has a rotating-earth range of 3165 km, 55% less than the range claimed by Montague et al for their postulated Sejjil 3!

Our analysis shows that Montague et al.'s claims about missile performance can be ascribed entirely to serious numerical errors in their calculations and to unjustified and inadequately explained assumptions about missile performance parameters that they misrepresent as being of "minor" consequence. In the next section, we examine further deficiencies in their analysis that follow from conceptual errors in the design of their proposed Sejjil 3, numerical errors in their calculations, and faulty estimates of the improvements in missile performance parameters associated with what they claim are readily implemented and minor advances in rocket technology. According to Montague et al., these advances in technology could lead to a rapid and unprecedented enlargement of the threat to Northern and Western Europe from Iranian solid propellant ballistic missiles.

Assertions About Improvements in the Technology of Iranian Solid Propellant Ballistic Missiles

In the previous section we showed that our range estimates for exactly the same Baseline Sejjil missile model differ substantially from the ranges claimed by Montague et al. In our case we get a non-rotating-earth range of 2200 km for the Baseline Sejjil ballistic missile while Montague et al. report a non-rotating-earth range of 2700 km, a serious and meaningful discrepancy of more than 20%. Montague et al. state that they agree with our range and payload calculations for liquid propellant ballistic missiles. We calculated the range for the Baseline Sejjil missile, and the ranges for their postulated missiles, using the same techniques and computer programs that were carefully checked and rechecked during the analysis and writing of our Report. Hence, we can only assume that the discrepancies in Montague et al.'s range calculations are due to numerical errors in their work.

In the previous section we examined the range estimates that Montague et al. derive for a Sejjil ballistic missile variant they call the "Sejjil 3." We showed large and significant discrepancies in their calculations of ballistic missile ranges.

There are further substantial technical discrepancies in Montague et al.'s findings due to unrealistic, and in some cases incorrect, assumptions about improvements in rocket technology.

First, Montague et al. quote with approval George P. Sutton's book, *Rocket Propulsion Elements* (see reference 22 on page 7 of Montague et al.). On p. 200 of that book's third edition Sutton writes:

"… at zero deflection there is a 2 to 3% drag loss [from jet vanes]."

It is well known among knowledgeable experts that the SCUD ballistic missile has a specific impulse penalty of about 5 seconds due to the use of jet vanes. The vacuum specific impulse of that motor is around 252 seconds, which indicates that the jet vane losses for the SCUD are about 2%. Yet Montague et al. assert that the first stage of their postulated "Sejjil 3" gets a nearly 5% increase in specific impulse as a result of removing the jet vanes while the second stage gets a nearly 8% increase in specific impulse. As we have seen, such apparently small differences in specific impulse would lead to significant and unjustified improvements in the calculated range of such missiles. One would expect that Montague et al. would provide some justification for assuming such unwarranted increases in specific impulse due to the removal of jet vanes. They do not do so, and the assumption skews their analysis in a serious way.

Second, the model "Sejjil 3" proposed by Montague et al. has an extremely inefficient staging weight ratio for obtaining a "relatively" light missile that could deliver a 1000 kg payload to 5000 km range relative to the configuration of the 65 tonne three-stage solid propellant ballistic missile we postulated in the JTA. We will show that when Montague et al.'s Sejjil 3, with its souped-up parameters is scaled up to a mass that would allow it to deliver 1000 kg to a 4900 km rotating earth-range, it would have to weigh 52,000 kg. Alternatively, if we assume, as summarized in Tables 3 and 4, that our postulated three-stage ballistic missile were souped-up using the same assumptions adopted by Montague et al., the resulting missile would weigh only 40,600 tons. Thus, Montague et al.'s choice of staging ratios results in a two-stage missile that would have to weigh at least 20 percent more than our postulated three-stage missile which they cite as evidence of dishonesty in our Report!

An alternative way to examine Montague et al.'s assertion that the three-stage missile we postulated is heavier than necessary is to compare Montague et al.'s Sejjil 3 two-stage missile with our three-stage missile by assuming that both use the same Baseline Sejjil rocket technology. Under these assumptions, we find that the payload that can be carried by their "*de*-souped-up Sejjil 3" to a rotating-earth range 4900 km range is only 370 kg. In this case, in order for the *de*-souped-up Sejjil 3 to be able to carry 1000 kg to a rotating-earth range of 4900 km, it would have to weigh 1000/370×40,600=110,000 kg!

These results make it clear that any discrepancies between the weights for a 5000 km solid-propellant ballistic missile reported in the JTA and those reported by Montague et al. *are entirely ascribable to their computational errors and misapplied assumptions about rocket technology*.

Furthermore, if one accepts the assertions made by Montague et al. about how easily their (misapplied) assumptions about rocket technologies could be realized, our 40,600 kg three stage configuration would *by every measure* be easier to build. Since the souped-up missile parameters used by Montague et al. would result in our postulated three stage missile weighing 40,600 kg versus theirs, which would weigh 65,000 kg, each of the three stages that would need to be constructed to build our postulated three stage missile would be considerably smaller, and therefore considerably easier to manufacture, relative to the stages required for Montague et al.'s postulated Sejjil 3. The first stage of our postulated three-stage missile would weigh about 28,125 kg while the first stage of Montague et al's postulated Sejjil 3 would weigh about 43,360 kg.

Thus, Montague et al.'s postulated approach to achieving a 4900 km range ballistic missile would require the manufacturing of a first stage that would be more than 50% heavier, and commensurably more challenging to build, than our postulated alternative.

Estimated Performance Characteristics of the 5000 km Range 3 Stage Missile Described in the Joint Threat Assessment

Stage	Full Weight (kg)	Burnout Weight (kg)	Thrust (kgf)	Structure Factor	Specific Impulse (sec)	Burn Time (sec)
Stage 1	45,000	6750	157,270	0.15	220 (SL) 250 (Vac)	60
Stage 2	14,720	2210	55,600	0.15	250	60
Stage 3	5780	870	21,800	0.15	250	60

Table 4

Estimated Performance Characteristics of a *"Souped-up"* 5000 km Range 3 Stage Missile Based on Assumptions Used by Montague et al.

Stage	Full Weight (kg)	Burnout Weight (kg)	Thrust (kgf)	Structure Factor	Specific Impulse (sec)	Burn Time (sec)
Stage 1	28,125	3375	108,000	0.12	238 (SL) 262 (Vac)	60
Stage 2	9,200	1380	34,150	0.15	262	60
Stage 3	3,613	542	14,807	0.15	270	60

Table 5

Furthermore, Montague et al. assume that the first stage casing of their Sejjil 3 is reduced in weight by 20% (that is, they assume a structure factor for the empty weight of the motor of 0.12 rather than 0.15), which implies that the casings are made of materials that are considerably lighter than steel. All the experience with solid rocket motors indicates that it is far easier to wind motor casings for smaller, rather than larger rocket motors. It is also a well-known fact that reducing the casing weight on the upper stage of a two stage rocket results in a much larger improvement in range performance relative to a similar reduction on the first stage. It is therefore surprising to us that they did not instead assume a lighter casing for the relatively small and light second stage of their postulated Sejjil 3.

At this point it is clear that there are so many basic conceptual and computational errors, unjustified and obviously false engineering assumptions, errors of fact, and internal logical inconsistencies in Montague et al., that there is little purpose to go into further detail about their technical claims and results. It is simply best for us to confess that we find the technical arguments in their article to be baffling, without merit, and without credibility.

Conclusion

Assessing Iran's missile potential is a complex business, and we had many lively discussions while writing the JTA. It is not helpful, however, when the arguments and analyses in the JTA are misrepresented and misleading technical analyses are advanced. We have tried to set the record straight in this response to Montague et al. The only *potentially* original contribution they might have made in their article would have been the possibility of a ballistic missile based on demonstrated Sejjil technology that was optimally configured for range, payload and manufacturability. Instead they present the results of an analysis that when analyzed itself is entirely ascribable to computational errors, hidden and misapplied assumptions about rocket technology, and conceptual errors in the basic configuration of their "alternative" 4900 km range solid propellant ballistic missile. We predict that any careful review of their article, which we would welcome, will be hard pressed to find anything in it that is correct or has not been misrepresented.