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MEMORANDUM

To: Paul Dimotakis

From: Peter Fisher

Subject: Model for the Hwasong-15

Date: July 10, 2018

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the Hwasong-15, also known as the KN22, is the highest performance ICBM the North Koreans have made to date and presents the greatest threat. The Hwasong-15 has had one test flight on Nov. 28, 2017, when it flew to an altitude of 4,485 km and a range of 950 km [], implying a burn-out speed of 7.2 km/s, as derived in a previous memo. This memo describes a model of the Hwasong-15 for use in simulations.

The Hwasong-15 is a two stage liquid fueled rocket, shown in Fig. **??**. The physical parameters have been extracted from video [**?**]. Table 1 gives the input parameters.

Parameter	Value	Provenance
Total length	22.5 m	Image analysis
Diameter	2.4 m	Image analysis
Propellant fraction	88%	Assumed
Payload+shroud mass	410 t	Derived
Stage 1 length	13.5 m	Image analysis
Stage 1 burn time	150 s	Assumed
Stage 1 mass	53.7 t	Derived
Stage 2 length	4.5 m	Image analysis
Stage 2 burn time	100 s	Assumed
Stage 2 mass	17.9 t	Derived
Rocket mass	70-72 tons	Estimate
Fuel	UDMH+N_2O_4	Assumed
I_{sp} vacuum	333 s	[2]
$_{sp}$ at STP	285	[2]

Table 1: Input parameters to the Hwasong-15 model.

The simplest model uses the rocket equation,

$$v\left(t\right) = I_{sp} g \ln \frac{m_o}{m_o - \dot{m} t}$$

where m_o is the initial mass, $\dot{m}$ is the constant burn rate, and $I_{sp} = 333$ s. The model takes into account the shedding of the mass of each stage after it burns out and gives $v_{bo} = 7.4$ km/s. Taking $I_{sp} = 285$ gives 6.0 km/s.

A 1 dimensional numerical integration taking into account atmospheric drag, the change in specific impulse with decreasing air pressure, and staging gives $v_{bo} = 7.2$ km/s. The atmospheric drag si given by,

$$F_{drag} = \frac{1}{2} C_D \rho A v^2$$

and ρ varies with altitude using a four factor power law[**?**], Fig. **??**. I_{sp} varies with altitude[2] as well,

$$I_{sp}(a) = 333\text{s} - 48\text{s}\frac{p(a)}{p(0)},$$

Fig. 1. Fig. 2 shows the time variation of key flight parameters.

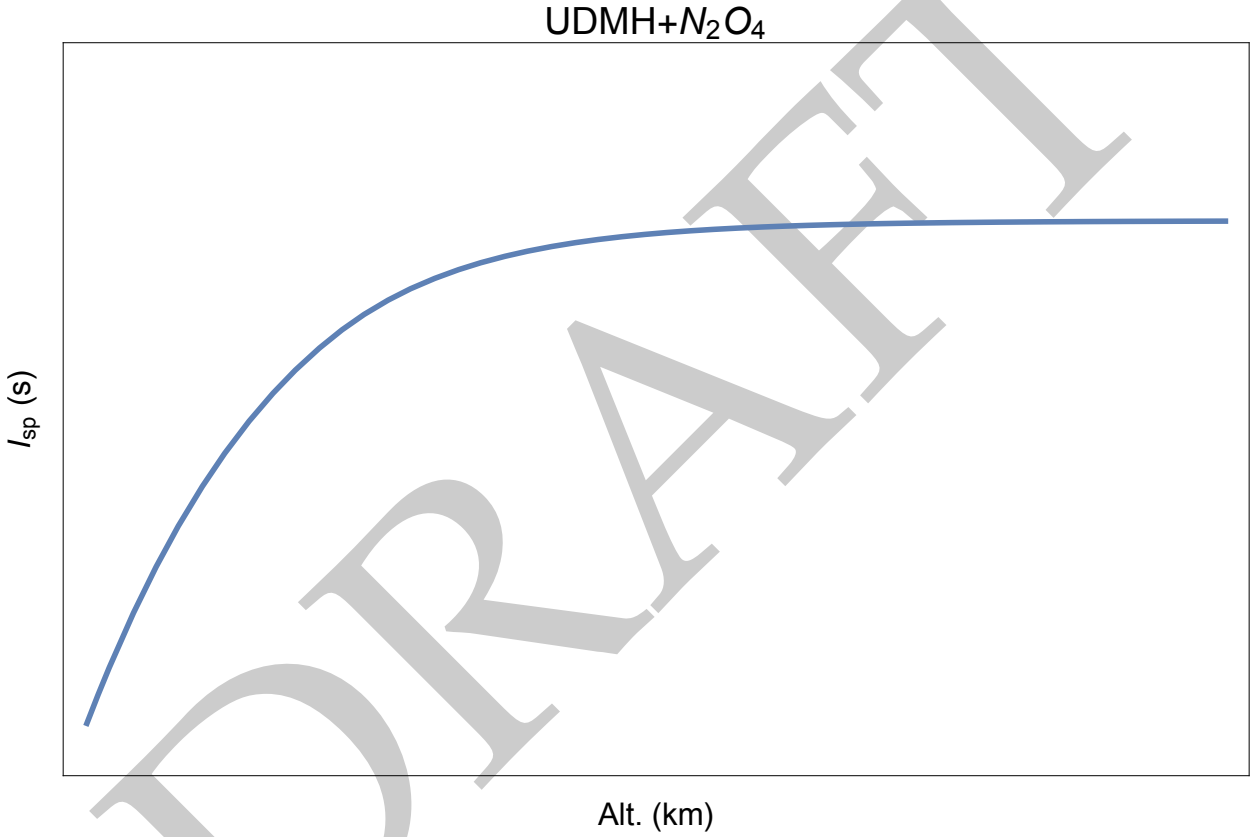

Figure 1: I_{sp} of UDHM+N_2O_4 as a function of altitude using linear interpolation.

A two dimensional simulation, including a pitch over maneuver to 20° angle above the horizon at 50 km altitude. Fig. 3 shows the results. At burn out of the second stage, the missile is 275 km downrange at an altitude of 220 km and moving at 7.4 km/s.

References

[1] https://en.wikipedia.org/wiki/Hwasong-15#cite_note-reuters.com-9

[2] https://en.wikipedia.org/wiki/Unsymmetrical_dimethylhydrazine

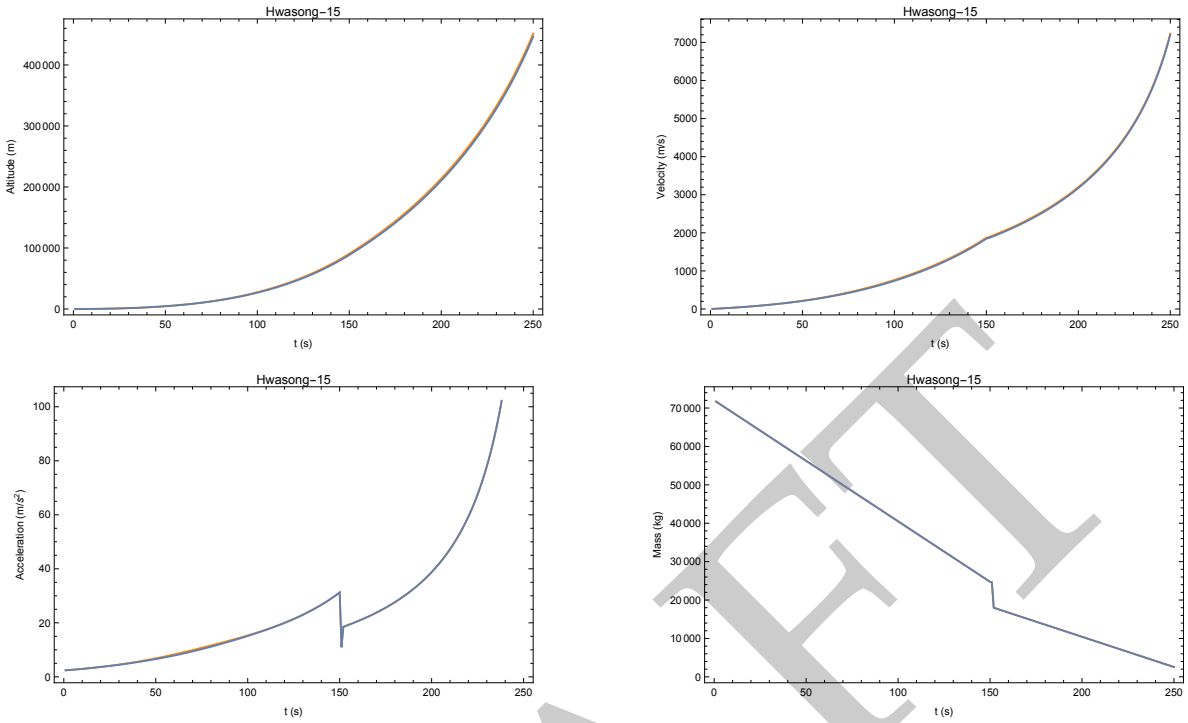

Figure 2: Results of calculation. Organe curve is without drag, red includes drag.

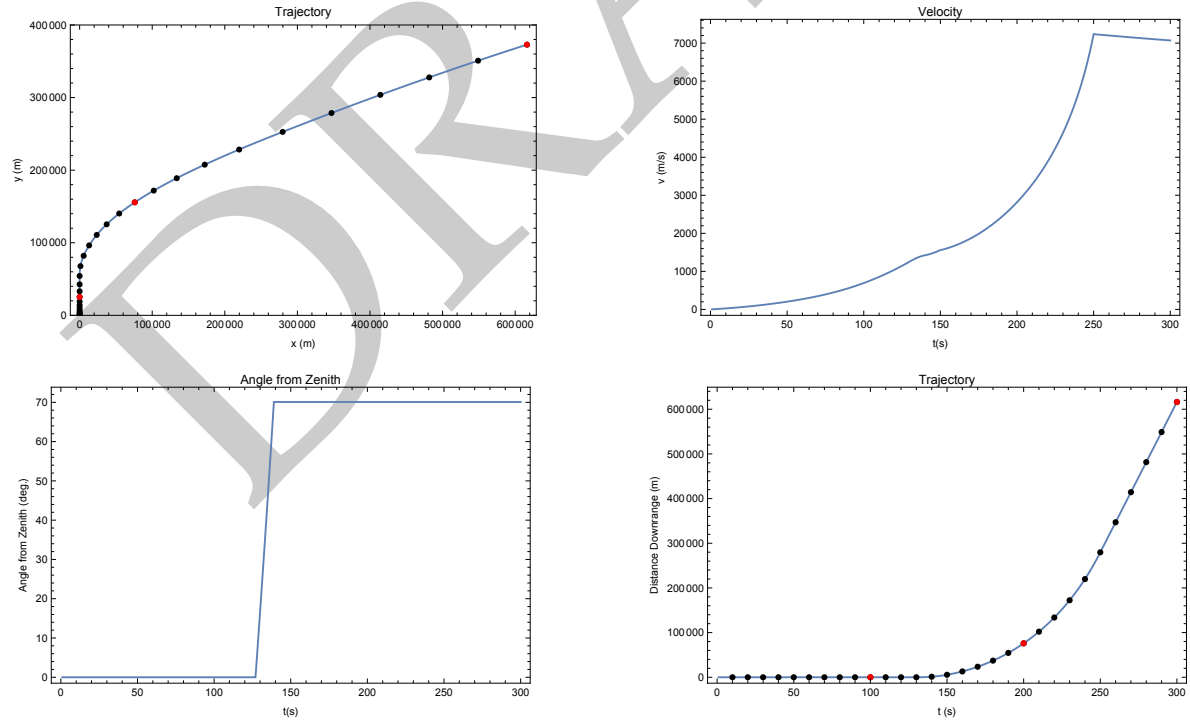

Figure 3: Results for two dimensional calculation. Black points show 10 s intervals, red points show 100 s intervals.