

STUDY FOR DEVELOPMENT OF A BLAST LAYER FOR THE VIRTUAL RANGE
PROJECT

by

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ABSTRACT

In this work we develop a Blast-Propellant-Facility integrated analysis study, which evaluates, by using two different approaches, the blast-related impact of an explosive accident of the Space Shuttle during the first ten seconds after launch at Kennedy Space Center. The blast-related risk associated with an explosion at this stage is high because of the quantity of energy involved in both multiple and complex processes.

To do this, one of our approaches employed BlastFX®, a software system that facilitates the estimation of the level of damage to people and buildings, starting from an explosive device and rendering results through a complete report that illustrates and facilitates the evaluation of consequences. Our other approaches employed the Hopkinson-Cranz Scaled Law for estimating similar features at a more distant distance and by evaluating bigger amounts of TNT equivalent. Specifically, we considered more than 500 m and 45,400 kg, respectively, which are the range and TNT content limits that our version of BlastFX® can cover.

Much research has been done to study the explosion phenomena with respect to both solid and liquid propellants and the laws that underlie the blast waves of an explosion. Therefore our methodology is based on the foundation provided by a large set of literature review and the actual capacities of an application like BlastFX®. By using and integrating the lessons from the literature and the capabilities of the software, we have obtained very useful information for evaluating different scenarios that rely on the assumption, which is largely studied, that the blast waves' behavior is affected by the distance.

All of this has been focused on the Space Shuttle system, in which propellant mass represents the source of our analysis and the core of this work. Estimating the risks involved

in it and providing results based on different scenarios augments the collective knowledge of risks associated with space exploration.

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This work is dedicated to my parents.

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CHAPTER 1. OVERVIEW

1.1 Introduction

Aerospace devices are a subject of quantities of variables that interact at the same time, not only at the moment of launching but also during the flight, the accomplishment of the mission itself in the external space, the reentry into the Earth's atmosphere, and finally the landing. These operations are the result of numerous previous and subsequent events such as preparation, performance, and control, all of which eventually can be the subject of unexpected errors and accidents.

This research is a study about probable damage associated with an undesirable explosion at Kennedy Space Center (KSC). Obviously, it is neither the first nor the last such study. Similar works have been developed by NASA during the last forty to fifty years. However, the recent accident of the Columbia Space Shuttle invigorated the need for evaluating damage from new perspectives. In fact, the University of Central Florida is engaged in a project named Virtual Range, that incorporates these situations and integrates them, pursuing the make up of an entire virtual evaluation of risks. This evaluation covers from the launch through the landing operations and the numerous factors involved within an explosion, from the mere blast to the highly complex fragmentation and toxicant agents produced by the fuel decomposition. This work can be integrated to the overarching design in the perspective of the blast and its role in the risk assessment for spacecrafts at KSC.

1.2 Purpose of the Research

The purpose of this research is to evaluate the amount of damage resulting from blast overpressure, whether in a building or spectator locations, when the Space Shuttle has been launched and passed ten seconds of flying. It means that the output of this processing (as we will see later in Chapter 3) is to determine the number of casualties (fatalities, serious injuries, slight injuries, uninjured) and a level of building damage (destroyed, severe, moderate, undamaged) in different scenarios.

Now the first ten seconds of flying has been considered in terms of the altitude that the Space Shuttle reaches after that time (280 m approximately), for getting a relationship that eventually could exist between this fact and the damage that an eventual explosion could generate; in other words, the general rate of decay of a blast wave is high, which indicates that in some range the danger is important for buildings and people, and after that, its importance diminishes significantly. This study will serve to demonstrate this hypothesis.

The sequence of this work starts with the definition of our study, then the results from the literature survey about explosions and propellants, as well as Space Shuttle main characteristics and basic operations at the moment of launch. This sequence should give us the capacity of evaluating probable damage and constructing risk scenarios at KSC, especially when new research is being developed for getting more energetic and powerful fuel sources, which will require reevaluation, maybe from a similar perspective, of the whole problem once again.

So what we intend to do is to re-create or to represent the reality by simulating it through alternatives and administer complementary methods of analysis for answering what would happen if the shuttle explodes at a given height, with a given amount of fuel, over a

specific quantity of people inside of a building or outside in the park for relatives and tourists that watch the launch.

1.3 Questions Being Asked [1]

Now we have to ask some questions in order to establish a starting point for our research. If we can answer them through the work, then we will be able to respond to the subject of the thesis.

- What is to be included in the simulation model?
- Does useful and updated data about NASA Space Shuttle basics exist?
- Does collected data about the rate of fuel waste in NASA exist?
- Does that fuel have an appropriate TNT equivalent?
- Is that data available as an open source?
- Are there legal constraints on how the systems operate?
- Does a map of the area with distances, facilities, path, and other data, for constructing the model exist?
- Are there building and worker data available for the study area involved?
- At what level of detail should they be included?
- What tasks or operations does the system perform before, during, and after the launch stage?
- Are process plans or process flow diagrams available?
- Who will provide data estimates if data are not available?
- How does BlastFX® render the data?
- What kind of output is required?

— How many scenarios will be considered?

All these questions should be answered by the present work in order to reach its purpose. The majority of the questions were developed in terms of data collection (1-10, 12) and some others in terms of methodology (11, 13, 14, and 15). The summation of the answers will give us the capacity of establishing the real capacity of this work in terms of predicting damage caused by explosions.

1.4 Theoretical Framework

This work is based on data provided by NASA through multiple and known publications and websites. Likewise, it is based on an exclusive application and on a vast literature survey. The application, called BlastFX®, could be a subject of discussion in terms of what it says or maybe how it does what it does, but in this particular case we will discuss the results with respect to the blast and conclude with ways of providing room for further developments, improvements, or updates.

Basically, every component of this framework will participate as Figure 1.1 shows. At the moment of the launch and up to ten seconds after we will evaluate the accident, considering always the worst scenario, i.e., that the whole propellant mass explodes.

Therefore, we will need consistent data for knowing *when* the accident occurred and *how much* fuel the Shuttle tank contains at that moment. Actually, this latter data can become irrelevant if the consumption rate is considerably low before ten seconds, in which case we would work with just a fixed amount of propellant mass (i.e., the initial amount). Knowing this, in any case, and converting the fuel to TNT equivalent (TNTeq), this sequence should

be capable of telling us what would happen in case of an accident and the damage associated with it.

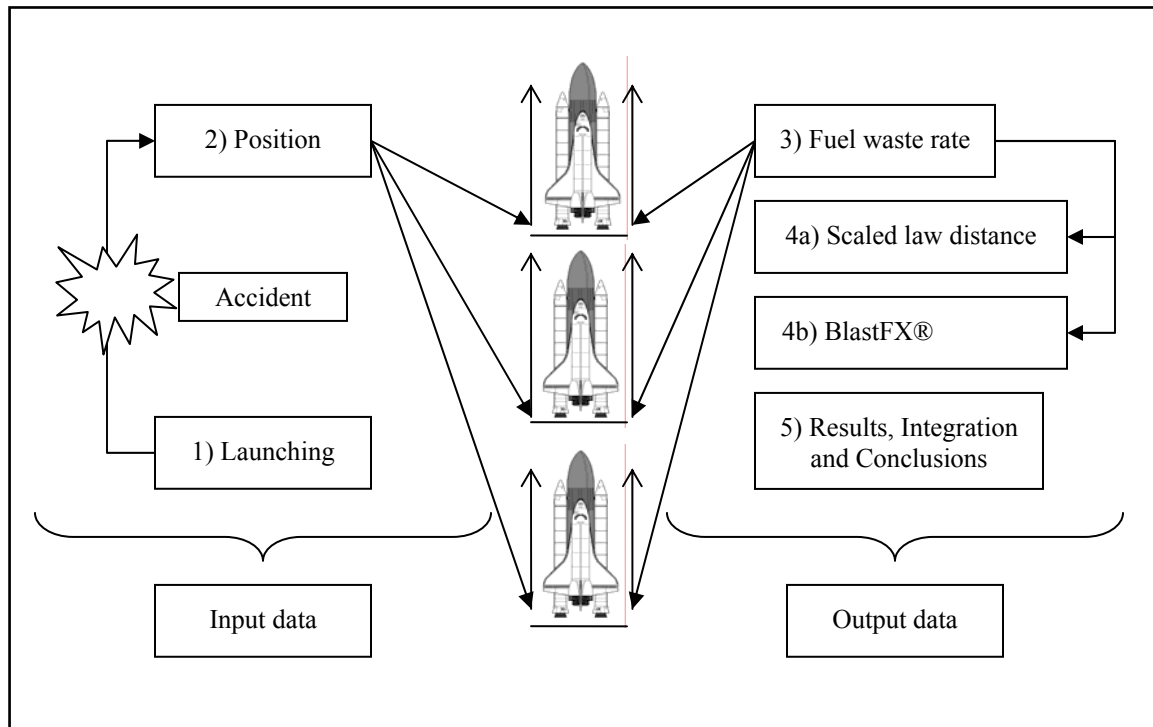


Figure 1.1: Interacting components of this work

1.5 A Brief Overview of Methodology

As mentioned before, this is a research about *the overpressure rate caused by unexpected explosions at the moment of the Space Shuttle launch*, or particularly speaking, *what would occur with people and buildings if the explosion takes place in the surrounding area*. We are going to work with two buildings for representing the level of damage to people and facilities. These are the Launch Control Center (LCC) and the Press Site, both located near launch Pad 39 or LC-39A. So we will have two zones of damage for evaluation. The former will serve for representing people *inside* of a building, the latter for representing people *outside* of a building.

So what we are going to do is to define a distance of 5,500 m (in length) under the effect of a blast caused by an explosion of the whole propellant mass of the Space Shuttle. This distance has its core in launch Pad LC-39A, and runs along a path up to reach the location of the LCC and the Press Site, at 5,000 m approximately (see figures 3.7 and 4.1).

As a consequence, we will determine what happens in terms of blast overpressure along this path if an accident occurs, and, especially, what happens with the people and the buildings at that distance through the scaling law. Conversely, by using BlastFX® we will review the level of damage caused by different amounts of TNT equivalent (11,350 to 45,500 kg) in the close proximity (500 m and less). This latter approach is related to the probability of an accident at the moment of the Space Shuttle assembly operations, or at the moment it is being transported from there to the launch pad. Finally we will take the results, compare them, and conclude.

1.6 Thesis Organization

Chapter 1 provides an overview of the research study, its purpose, and goals. Chapter 2 presents a synthesis of the literature survey with focus on the NASA Space Shuttle, its propellant mass and the TNT equivalency. Chapter 3 is a description of the methodology which supports this work and the flow diagram of it. Chapter 4 includes three examples of the execution of the methodology in a case study over 2 different scenarios and from different perspectives, the results, the discussion, and a brief conclusion with respect to these exercises. Chapter 5 provides the specific and general conclusions and recommendations for further developments.

CHAPTER 2. LITERATURE SURVEY

2.1 Explosives and Explosions

Explosives may be divided into two categories, high and low. In the former the explosives detonate, in the latter they deflagrate. The difference, according to this classification, lies in that in detonating explosives, such as TNT, the mechanism is based on creating mechanical shock, whereas in deflagrating explosives, the mechanism is thermal in nature [2].

An explosion, generally speaking, is an amount of energy released in a very short period of time or the rapid conversion of a solid into a gas at high temperature [3]. This explosion occurs as a consequence of a chemical reaction. “The generation of heat in large quantities accompanies every explosive chemical reaction. It is this rapid liberation of heat that causes the gaseous products of reaction to expand and generate high pressures” [4].

These definitions are highly conventional, but they are not absolute and enclose some degree of overlapping, and the limits are not as clear as we probably would want. This means that given several conditions of pressure and temperature, a propellant can explode, so it would behave as an explosive even though it is not.

2.1.1 Blast effects

“Blast is a brief and rapid movement of air or fluid away from a center of outward pressure, as in an explosion.” [5] This rapid movement of air determines the damage over many different objects that surround the explosion in a rate that is related with the yield of the explosive. Thus, increasing the amount of the explosive increases the radius of the damage. The blast effect of an explosion is determined by the overpressure, which means that there exists a relationship between the explosive and the distance at which any object is going to be affected by the explosion. The overpressure is the rise “from the ambient pressure to a peak

incident pressure” [4], or the pressure exceeding the ambient pressure [6]. The gas that the explosion generates moves radially from the source of the explosion toward the perimeter. In a detonation the movements of the molecules of the gas go faster than the movements of the sonic velocity of the medium. This effect is proportional to the cube root of the weapon (or device) yield. “As the shock front expands into increasingly larger volumes of the medium, the peak incident pressure at the front decreases and the duration of the pressure increases.” [4] And also as the blast pressure decays exponentially, it eventually becomes negative (see Figure 2.1). This phenomenon affects buildings, which are subject to “pressures acting in the direction opposite to that of the original shock front.” [7]

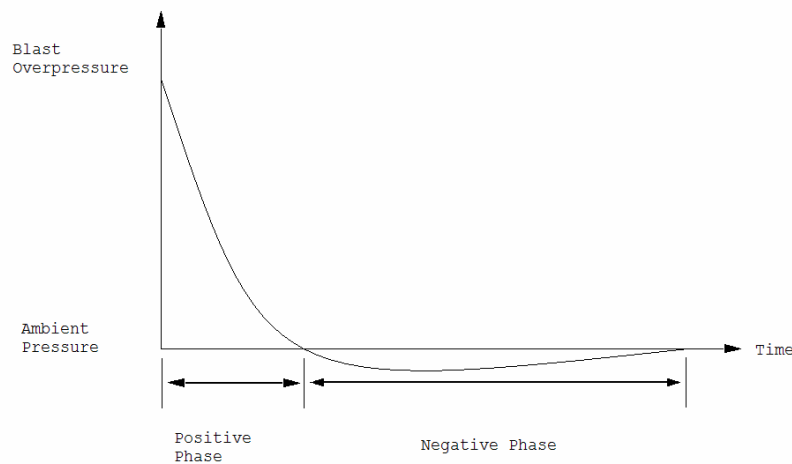


Figure 2.1 [8]: Blast overpressure curve

As mentioned before, “The magnitude of forces produced by an explosion (sic) are a function of the range from the weapon and the amount of explosives. Typically, such forces are found based on the scaled distance from the weapon to the target, where [6]:

$$Z = \frac{R}{W^{1/3}}$$

Z= Scaled distance

R= Range from weapon to target

W= Weapon charge weight (TNT_{eq})”

This is the well known Hopkinson-Cranz law of blast scaling, “or cube root scaling” (Hopkinson, 1915; Cranz, 1926). It states that self-similar blast waves are produced at identical scaled distances “when two explosive charges of similar geometry and of the same explosive, but of different sizes, are detonated in the same atmosphere.” [9] Table 2.1 shows a categorization of the relationship between the overpressure and its consequences in terms of scaling distance.

Table 2.1: Scaled distance and consequences [10]

Scaled distance (*) ($Z=R/W^{1/3}$)	Overpressure (psi)	Consequences
3000-890	0.01-0.04	Minimum damage to glass panels
420-200	0.1-0.2	Typical window glass breakage
200-100	0.2-0.4	Minimum overpressure for debris and missile damage
82-41	0.5-1.1	Windows shattered, plaster cracked, minor damage to some building.
44-28	1.1-1.8	Panels of sheet metal buckled
44-24	1.0-2.2	Failure of wooden siding for conventional homes
28-20	1.8-2.9	Failure of walls constructed of concrete blocks or cinder blocks
20-16	2.9-4.4	Oil storage tanks ruptured
14-11	4-7	Serious damage to steel framed buildings, collapse of wood framed buildings
6.7-4.5	6-9	Severe damage to reinforced concrete structures
3.8-2.7	10-12	Probable total destruction of most buildings

*Z is in $\text{ft}/\text{lb}^{1/3}$

By using this table we can estimate an unknown factor by keeping the others (in the scaled distance expression) constants. For instance, in the explosion of an Iranian train in February 2004, the news said “51 train cars in Iran filled with gasoline, fertilizer and sulphur products derailed and caught fire. *Windows were shattered six miles away.*” [11] So according to the cited law, $Z=420-200$, and $R=6$ miles. Therefore we can estimate the mass of explosive in terms of TNT_{eq} by accordingly replacing these values in the expression and looking for the amount of explosive that satisfies the terms. Then, we obtain $W=190,680-1,770,600$ kg of TNT_{eq} (420,000-3,900,000 lb). If we assume that the train loaded just gasoline and we know that gasoline is 10 times more energetic than TNT, we can infer that the Iranian train kept 42,000-390,000 lb of gasoline. Finally, if we divide this amount by fifty

cars we get 840 - 7,800 lb (381.36 - 3,541.2 kg) per car, which is a realistic estimate. So this is going to work as an introduction to the next topic, TNT equivalent.

2.1.2 TNT equivalent

TNT equivalency is a way of expressing any type of explosive in terms of its charge weight, so that any explosive can be compared to (or can be expressed as a function of) TNT. The idea is based on the knowledge that we have about TNT, whose properties have been widely explored and measured. If we assume that any explosive material has an explosive power, this characteristic can be expressed in TNT units of mass. However, “the definition of TNT equivalency is complex. There are many experimental bases for comparison of explosives, such as heat of combustion, heat of detonation, detonation energy as measured of brisance, fragmentation tests, among others.” [12] The choice of measuring all these different aspects of the behavior of any explosive is not always possible, and the data is not always consistent. Thus, for the same explosive sometimes we can get different results: “In Table 3.8 of Cooper the data for [different tests] give TNT equivalencies of C-4 as 116, 130, 115 and 147% respectively.” [13]

Therefore, “we must be careful to define the context in which a TNT equivalency value is stated.” [10] For the purpose of this work, we will consider the equivalency of the Space Shuttle fuel in terms that will be defined later. Also it is important to mention an aspect of TNT equivalency measurements with respect to the criteria or scales most commonly applied: the first one consists of a measure of the peak overpressure (according to the energy released in the explosion); the second one consists of a measure of the peak overpressure plus the remaining energy up to the end (see Figure 2.1) when the shock wave is over. The latter is known as “long time scale”, the former as “short time scale.” [10]

2.2 Rocket Propellants

This is a general description of propellants, some of their definitions, distinctive characteristics and configurations. This is, in fact, an introductory note to the study of the Space Shuttle, and it is going to be used in Chapters 3 and 4.

A propellant is a chemical mixture that consists of a fuel and an oxidizer. The fuel is a substance or component that burns when combined with oxygen under certain conditions of temperature and pressure. As a consequence, the consumption of the fuel releases gases, and these gases are used for producing propulsion. On the other hand, the oxidizer is the component that supports the oxygen that the fuel needs in order to burn.

The way for measuring the capacity of any propellant is specific impulse. It establishes how many pounds (or kilograms) of thrust are obtained by the consumption of one pound (or kilogram) of propellant in one second [14]. So that's why the specific impulse is expressed in seconds ($\text{kg}/(\text{kg/s})$).

Propellants can be divided into three categories: liquid, solid, and hybrid propellants.

2.2.1 Liquid propellants

In a liquid propellant, the fuel and the oxidizer are stored in separate tanks and they are mixed in a combustion chamber. This characteristic allows the engine to be throttled, obturated, and even stopped or restarted. The way of feeding the components in the combustion chamber is by using valves, pipes, and turbo-pumps, then it is possible to exert the aforementioned control over the engine.

Liquid propellants used by NASA can be classified into three types, petroleum, cryogenic, and hypergolic:

- Petroleum: the petroleum used as rocket fuel is highly refined kerosene called RP-1. Liquid oxygen is used as the oxidizer.
- Cryogenic: these are liquefied gases stored at very low temperatures. This is the case with liquid oxygen (LO_2) and liquid hydrogen (LH_2), which remain in a liquid state at -183°C (-298°F) and -253°C (-423°F), respectively. Liquid hydrogen delivers a specific impulse about 40% higher than other rocket fuels. LH_2 and LO_2 are used in the main engines of the space shuttle.
- Hypergolic: these are propellants that ignite spontaneously when fuel and oxidizer contact each other. That is the reason why they do not need an ignition source. Among their components are hydrazine, monomethyl hydrazine, and unsymmetrical dimethyl hydrazine. All of them are highly toxic and must be managed with extreme care. The easy start and restart capability make them appropriate for the spacecraft maneuvering system. In fact, they are present in the space shuttle's orbital maneuvering system (OMS) and the reaction control system (RCS).

2.2.2 Solid propellants

Solid propellants are the simplest of all rocket designs. They consist of a solid mix of fuel and oxidizer. They look like a paste or a rubber that can be extruded in order to charge a casing, usually steel. This paste has an internal geometrical configuration that regulates the consumption rate of the propellant. Thus, the simplest shapes will be like a cylinder with an internal channel, and the more sophisticated systems will include combinations of shapes like stars and cones or triangles in a row. Unlike liquid propellant engines, solid propellants cannot be shut down once they have been ignited, so they will burn until the propellant is exhausted. There are two types of solid propellants, homogeneous and heterogeneous. The

former are simple or double base, i.e., just nitrocellulose or a combination of nitrocellulose and nitroglycerine plus a plasticizer, respectively. The latter are heterogeneous powders that use a salt as an oxidizer (often ammonium perchlorate) and aluminum as a fuel. The proportion can vary from 60 to 90% in oxidizer. Additional compounds can be added as a catalyst, in order to increase or reduce the burning rate. The Space Shuttle uses the largest solid rocket propellant engines ever built. Each booster contains 504,000 kg (1,111,320 pounds) of propellant and can produce up to 1,498,200 kg (3,300,000 lb) equivalents to 14,680,000 N of thrust [14].

2.2.3 Hybrid propellants

Hybrid propellant engines combine liquid and solid substances. The solid is usually the fuel and the liquid is injected into it. They have high performances (similar to that of solid propellants) and their combustion can be moderated, stopped, or restarted. But they are rarely built because of the difficulty in making use of these concepts for very large thrusts [14].

2.3 The Space Shuttle Basics

2.3.1 A brief description of components

The Space Shuttle is a spacecraft that is made up of two systems: the propulsion and the orbital system. The propulsion system is made up by two solid rocket boosters (SRB) and the main engine. The external tank provides the fuel and the oxidizer that will be mixed and transformed in thrust through the three engines of the orbiter, the aforementioned Space Shuttle main engine, SSME (see Figure 2.2).

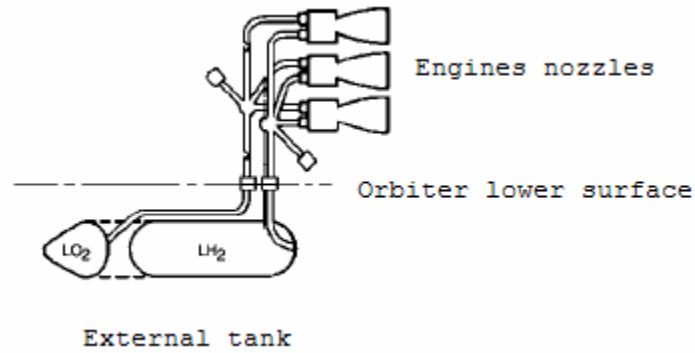


Figure 2.2 [15]: SS Engines

Thus, we see that solid and liquid propellants participate in the system. The solid propellant is located in both solid rocket boosters, while the liquid propellant is located in the external tank and combusted in the main engine. The launch configuration of the Space Shuttle can offer us the entire system for study (see Figures 2.3-2.5).

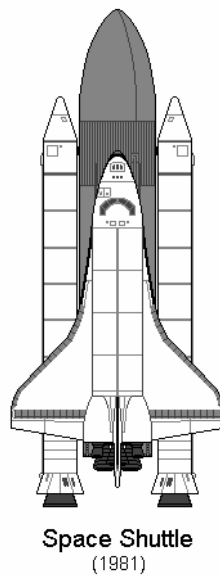


Figure 2.3 [16]: SS Launch configuration

2.3.2 The orbiter (orbital maneuvering system and the external tank basics)

The orbiter is the component that houses the crew of the Space Shuttle and the elements that will be carried to space. In terms of thrust, the orbiter houses the main rocket engine, where the combustion of liquid oxygen and hydrogen takes place. This is in fact the sum of three engines that are the output of the respective combustion chambers through the three corresponding nozzles (see Figure 2.4).

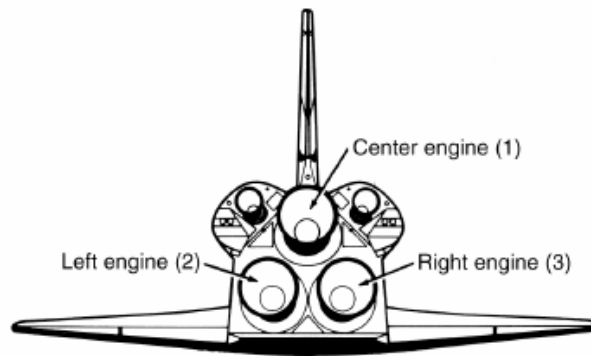


Figure 2.4 [15]: SS Nozzles

“The shuttle launches like a rocket, maneuvers in Earth orbit like a spacecraft and lands like an airplane.” [16] So this is the comparative advantage of this spacecraft, it can be recovered and reused after every space mission. The orbital maneuvering system (OMS) on the other hand is in charge of providing the thrust that the spacecraft needs for orbit insertion, orbit circularization, orbit transfer, rendezvous, deorbit, abort to orbit and abort once around, and can provide up to 1,000 pounds (454 kg) of propellant to the aft reaction control system (RCS). This RCS is used to null any residual velocity, to provide altitude hold for on-orbit operations and can be used also if an OMS engine eventually fails by completing the corresponding thrusting period. The propellant used for both the OMS and RCS is

hypergolic, in which the fuel and the oxidizer ignite spontaneously on contact with each other [17].

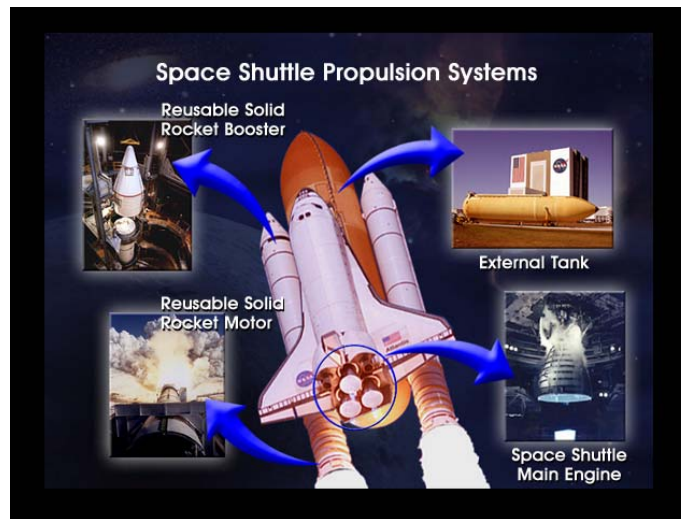


Figure 2.5 [18]: SS Propulsion Systems

The external tank (ET), as was mentioned before, contains the liquid hydrogen (fuel) and liquid oxygen (oxidizer) that are supplied under pressure to the three Space Shuttle main engines during lift-off and ascent. Additionally, it provides structural support for attachment with the solid rocket boosters and orbiter, and also absorbs the total thrust loads of the three main engines and the two solid rocket motors [19]. The ET is jettisoned after being used and impacts in a remote ocean area. Actually, it is the only component that is lost as the spacecraft rises up to 109 km of altitude. It is not recovered.

Finally “the ET is attached to the orbiter at one forward point and two aft points. In the aft attachment area, there are also umbilicals that carry fluids, electrical signals and power between the tank and the orbiter. Electrical signals and controls between the orbiter and the two solid rocket boosters (SRB) also are routed through those umbilicals.” [19]

2.3.3 The propulsion systems

The propulsion system is made up by the Space Shuttle main engine (SSME), the orbital maneuvering system (OMS), and the SRB. The solid rocket booster consists of two external cylinders (see Figure 2.3) that are attached to the external tank, and they provide the main thrust to the Space Shuttle at the moment of the lift-off (71.4%) [20]. The solid rockets have been previously filled with solid rocket propellant, which is consumed during the ascent. After that (two minutes after), the cases are separated and fall and impact into the Atlantic Ocean for recovery.

The propellant mixture consists of an ammonium perchlorate (oxidizer, 69.6% by weight), aluminum (fuel, 16%), iron oxide (a catalyst, 0.4%), a polymer (a binder that holds the mixture together, 12.04%), and an epoxy curing agent (1.96%). The shape of the internal channel corresponds to an eleven-point star in the forward motor segment and a double-truncated cone perforation in each of the aft segments and aft closures [14].

2.3.4 Summary

Table 2.2 summarizes some of the main characteristics of the components, as long as they participate in the thrust of the Space Shuttle. In another words, they have been considered because they support the explosive component in terms of the risk that the spacecraft represents. That's why we have incorporated the column "TNT equivalency" that will be used later, in chapters three and four.

So it is important to mention here some of the problems that we will encounter. The first is how much TNT equivalent we have in terms of the propellant load in the Space Shuttle, and second, how that propellant is going to vary with time. The information that we need for supporting our work is reviewed in the following points of this chapter.

Table 2.2: Space Shuttle propellants [21]

Components	Length (m)	Diameter (m)	Oxidizer	Fuel	Propellant	Propellant mass (kg)	TNTeq of the Propellant mass (kg)	Burn time (s)	Separation (s)
External Tank	46.88	8.40	Liquid Oxygen	Liquid Hydrogen	.....	730,000.00	2,100.00	520.00	530.00
Solid rocket boosters	45.56	3.71	Aluminum	Ammonium Perchlorate	TB-H1148 HB Polymer	504,000.00 (each SRB)	1,318,464.00	124.00	124.00
Space Shuttle main engine	4.24	2.39 (maximum)	Liquid Oxygen	Liquid Hydrogen	.....	.....	.....	520.00	.....
Orbital Maneuvering System	1.96	1.17 (maximum)	Nitrogen tetroxide (N ₂ O ₄)	Monomethyl hydrazine (MMH)	.....	6,743 N ₂ O ₄ in each pod; 4,087 MMH in each pod	.....	Qualified for 500 starts	.....

2.4 Space Shuttle Engines and TNT Equivalency

The rate of consumption of propellant during the first ten seconds is a topic that is highly related with our work. Actually, it has to do with how much of the propellant mass has been consumed and therefore how much remains during every moment of those ten seconds. In order to do that, we need to know where the Space Shuttle is with respect to its path in the ascending stage, so we need to track it during these first ten seconds. Table 2.3 shows the altitude as a function of the time.

Table 2.3: SS Time vs. Height [22]

Time (s)	Altitude (m)
0	0
1	0
2	0
3	15
4	35
5	62
6	93
7	130
8	173
9	222
10	280

On the other hand, we know that the propellant begins to lose mass as a function of lift-off and the subsequent ascent stage. How much and how fast does it occur? We know that at lift-off (T minus 0 seconds) the Space Shuttle Main Engine (SSME) and the solid rocket boosters (SRB) are working at 100 percent thrust level. The former, according Table 2.2, works for 520 seconds, and the latter for 124 seconds. By the time the first minute has passed, the Shuttle has already consumed more than one and a half million pounds of fuel (681,000 kg), which is a third of the total propellant mass. After about two minutes, the propellant in the boosters (SRB) is exhausted, and the casings are jettisoned. Therefore only the SSME provides the entire thrust through 8½ minutes after launch [23], after which the engines are stopped. So even with different rates of burning for each one, we can assume, first, that at the moment of the lift-off and during the first ten seconds, the mass of propellant has been reduced by a minimum quantity, and despite that, we could say also that there is an ascending rate of consumption during the same time because the Shuttle needs to overcome its inertia. The SSME average mass flow is, linearly, 730,000 kg divided by 520 seconds, which is 1,403.8 kg/s [21]. The SRB on the other hand spends 10,000 kg/s approximately [24]. In addition, we can observe that the SRB internal channel shape yields a different burning rate, i.e. faster, at the moment of the lift-off up to fifty seconds, than the remaining propellant mass burning rate, seventy seconds later. If we take into account these data—even linearly—we can assume that the SRB burns almost constantly, and the SSME burns according to the regulation of the turbo-pumps, faster or slower based on the inputs of the Space Shuttle flight control system (FCS). So whether or not this approach is valid for the first ten seconds, because the propellant consumption, according to our assumption, after that time is actually the sixth part of the first minute of thrust (114,038 kg of 681,000 kg). Table

2.4 summarizes this rationale. We have also added a column to the TNT equivalency although its basis will be reviewed below.

Table 2.4: Rate consumption and TNT equivalent

Time (s)	Propulsion system	Mass of remaining liquid propellant (kg)	Propulsion system	Mass of remaining solid propellant (kg)	Total mass of TNT equivalent (kg)
0	SSME	730,000.00	SRB	1,008,000.00	1,320,564.00
1	SSME	728,596.20	SRB	998,000.00	1,307,484.00
2	SSME	727,192.40	SRB	988,000.00	1,294,404.00
3	SSME	725,788.60	SRB	978,000.00	1,281,324.00
4	SSME	724,384.80	SRB	968,000.00	1,268,244.00
5	SSME	722,981.00	SRB	958,000.00	1,255,164.00
6	SSME	721,577.20	SRB	948,000.00	1,242,084.00
7	SSME	720,173.40	SRB	938,000.00	1,229,004.00
8	SSME	718,769.60	SRB	928,000.00	1,215,924.00
9	SSME	717,365.80	SRB	918,000.00	1,202,844.00
10	SSME	715,962.00	SRB	908,000.00	1,189,764.00

According to our data, the rate of consumption takes into account what occurs at the moment of lift-off plus ten seconds. The rate probably will vary —especially for the SSME case— as long as the Space Shuttle keeps going on in the ascending path. We have to consider that at the moment of the main engine cutoff (MECO) the internal system of the Shuttle still houses around 5,000 kg of liquid propellant that will be dumped out into space, before the reentry.

2.4.1 The basis for TNT equivalency

The nature of the propellants affects the explosion yield and therefore the consequences over people and facilities. The solid and liquid propellants have different behaviors even if they are subject to similar conditions of pressure and temperature. Thus, we are going to take

them separately (as solid and liquid propellant) and finally meet them in order to get the data that we need to work, i.e., the sum of both in terms of TNT equivalent units.

2.4.1.1 The Solid Rocket Propellant

As was mentioned in table 2.2, the solid rocket boosters are made up of aluminum and ammonium perchlorate (fuel and oxidizer respectively). We will assume that the TNT equivalency for the quasi-static pressure method works well by comparing heats of combustion, which considers the total energy released during the complete reaction of the explosive components with respect to the same concept in terms of TNT [12]. Therefore we have [25]:

TNT: 4560 J/g

TB-H1148 HB¹: 5966 J/g

The TNT equivalency formula is:

$$TNT \text{ equivalency quasi-static } P = \frac{HE \text{ heat of combustion, } J / g}{TNT \text{ heat of combustion, } J / g}$$

Replacing values we have:

TNT equivalent for solid propellant: 1.308

This means that every 1 gram of solid propellant, we will consider as 1.308 grams of TNT.

2.4.1.2 The Liquid Propellant

The LO₂ and LH₂ are subject to a different approach. What we know is that in accidental explosions they do not detonate completely as the solid rocket propellants eventually do. Liquid propellants stored in tanks have a TNT equivalent that involves just 20% of the total

¹ Denomination for SRB propellant based on Othmer [25]

propellant weight. Likewise, the equivalent TNT weight of propellant flowing in fuel lines has an equivalent explosive yield of 60% of the propellant weight in a period of, say, 2 seconds [26]. Real accidental explosions and the Project PYRO [27] tests facilitated the identification of a relationship between the weight of propellants (W_p) and the TNT equivalent weight (W_T). The W_p in tanks (of similar shape) will tend to vary as the cube of a characteristic tank dimension ($W_p \approx d^3$). On the other hand “the equivalent TNT weight that participates in a detonation can be expected to vary in direct proportion to a mixing area, which in turn should tend to vary roughly as the square of a characteristic tank dimension ($W_T \approx d^2$).” [26] The combination of these two expressions leads us to a scaling law suggested by the results of the aforementioned project and test. So we have:

$$W_T \approx W_p^{2/3}$$

The simple two-thirds power law shown [above] appears to provide an improved empirical model for initial estimates of the TNT equivalence of LO₂/LH₂ propellants over a wide range of propellant weights. The data suggest that a scaling law for the maximum TNT equivalent for these propellants can be given by $W_T \approx 4 * W_p^{2/3}$. This is the principal result of this Note. The empirically determined scaling constant (4) may vary substantially for other types of propellants. However, it is estimated to be a reasonable maximum value for LO₂/LH₂ propellant explosions from a variety of tank configurations and failure modes, which were demonstrated very well by the experimental studies considered here. [26]

If we take the data supported by this note and plot them, we get a graphic as it is shown in Figure 2.6.

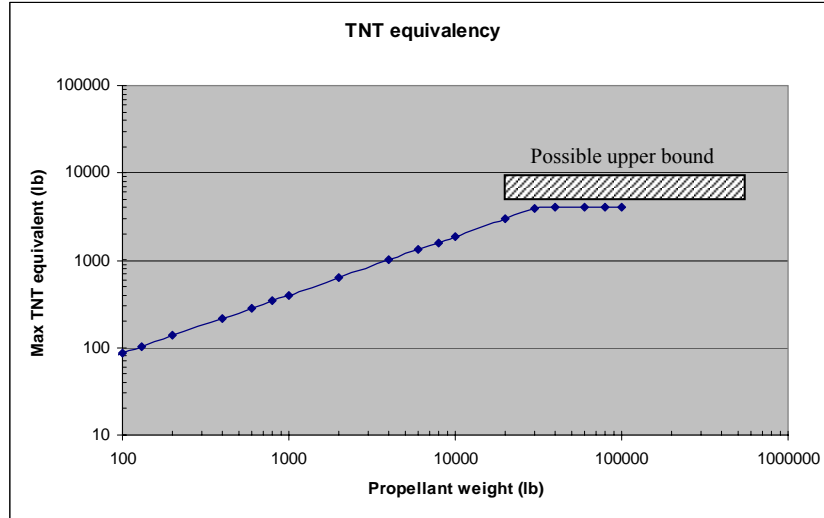


Figure 2.6 [26]: Propellant weight vs. TNT equivalent

The constant value for the extreme weights represents “a possible upper bound in TNT equivalents for LO_2/LH_2 based on studies by Farber.” [28] So this work established that over some quantities of liquid propellants, the TNT factor does not increase constantly as we could think, but it remains constant for large enough amounts of propellant (i.e., up to 2,100 kg {4,600 lb}). From George P. Sutton’s work reported in his last edition “Rocket Propellant Elements” [29], we believe it is reasonable to consider that an important percentage as mentioned before, is not going to detonate but will instead become vaporized water.

So if we apply the first of the aforementioned relationships, we have:

$$W_T \approx (730,000)^{2/3} = 8,107.4 \text{ kg (17,876.8 lb)}$$

However, the formula provided by Sutherland says that:

$$W_T \approx 4 * W_P^{2/3} = 4 * 8,107.4 = 32,429.6 \text{ kg (71,507.2 lb)}$$

As a consequence and taking into account what Sutherland indicates in his note with respect to the possible upper bound (see the graph in Figure 2.6), we will consider in this work up to 2,100 kg (~ 4,600 lb) of equivalent TNT for the liquid propellant mass.

2.5 Blast FX®

Blast FX version 2.2 is an explosive effects analysis software package, prepared by Northrop Grumman Mission Systems. It is a software tool that was designed to calculate the damage to a building from an explosive charge detonated in close proximity [8]. This software can say how much damage was sustained by a facility that has been built with some characteristic materials and is being occupied by workers, visitors, or any people at the moment of the explosion. Therefore, it has been designed for constructing models of buildings and populating them, also for locating an explosive device, and finally for evaluating the damage after the explosion.

2.5.1 What BlastFX can do

By using BlastFX, we can construct a building according to some specifications. These specifications include floors and walls, beams and columns. A sample of general data is developed below in table 2.5. So the researcher must collect these data and load them into the application. To do this he or she must visit the facility, get the data and transpose them to the worksheet in the program. Figure 2.7 shows, as an example, the data for a beam type.

Table 2.5: Building main characteristics in BlastFX® [8]

Floors and walls		Beams and columns	
General information	Identification name	General information	Identification name
Construction	Material, rebar spacing, thickness, specific weight	Construction shape	Steel or square concrete
Fixity	Edges of component are free to rotate, otherwise are fixed to adjoining structure	Material	Specifies a concrete or steel column type.
Glass	Glass type, heat treatment, fragment retention film	Measurements	Column width and depth or the column diameter
Window	Window size, pane layout	Steel types	List of AISC standard steel types

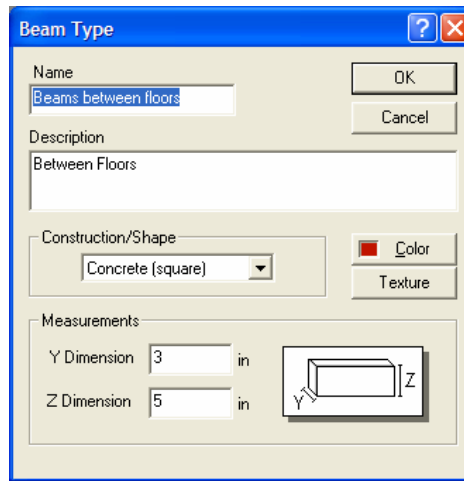


Figure 2.7 [8]: BlastFX® snapshot for beams

Thus, following the aforementioned collection of details, the researcher constructs a virtual building. After that, he or she populates it with people and finally the explosive device is put or located inside or outside the building as Figure 2.8 shows.

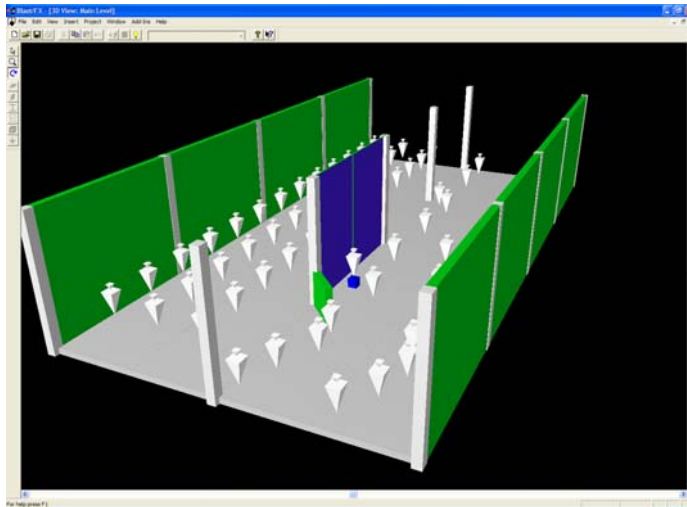


Figure 2.8 [8]: BlastFX® snapshot for scenario

Here the image is shown in a 3-D view, including the people, the walls and the columns. The explosive device can be expressed as an amount of some explosive composition like C-4, ANFO², and Black powder, among others. The software calculates the quantity of each one in terms of TNT equivalent like Figure 2.9 shows for Composition C-4.

Explosive Device	
Name	Pipe Bomb
Description	Bomb hidden in cloth knapsack
Device	Fragmentation
Explosive	
Type	Composition C-4
Charge	4.25 lbs
TNT Equiv.	5.44 lbs
Fragmentation	
<input type="radio"/> None <input checked="" type="radio"/> Standard <input type="radio"/> Custom	

Figure 2.9 [8]: BlastFX® snapshot for explosive device

² C-4 is a chemical explosive compound ($C_3H_6N_6O_6$) blended with a plastic binder material; ANFO is an explosive composition based on Ammonium Nitrate (92%), fuel, oil, and additions.

Because propellants are not good explosives or not as good as other explosives, they have not been included here, and that is why we have to estimate the quantity of propellant in the SS, in terms of TNT equivalent.

Finally, the software is activated and shows the results both, as a written report as well as illustrations. The latter whether in 2-D or 3-D features (see Figures 2.10 and 2.11), where you can perceive the severity of damage assuming the intensity of the color (red people and panels have been absolutely destroyed; the cross in the yellow square shows the original location of the explosive device).

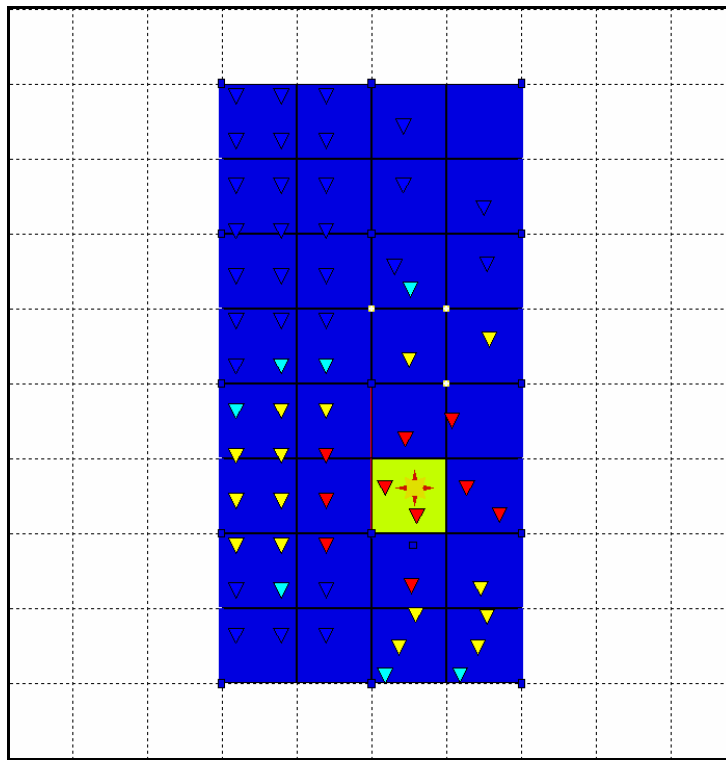


Figure 2.10 [8]: BlastFX® snapshot for showing results in 2D.

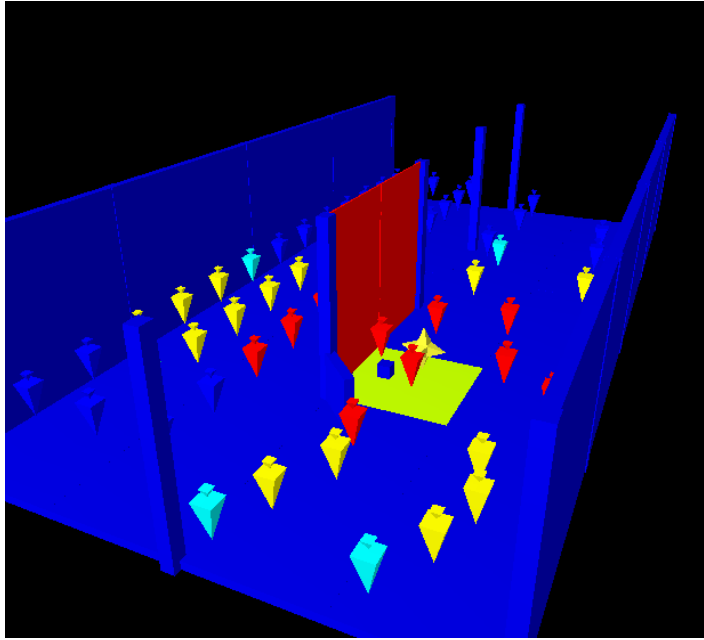


Figure 2.11 [8]: BlastFX® snapshot for showing results in 3D.

The report summarizes the damage that the explosion caused and then the researcher will have to interpret the results according to what he or she expected to see and actually saw. In Chapter 4 we will come back to this step at the moment of analyzing the inputs and the results that we got in our study case.

Additionally we have included in figure 2.12 a diagram with the information flow as a way of complementing the text in terms of BlastFX® inputs and outputs.

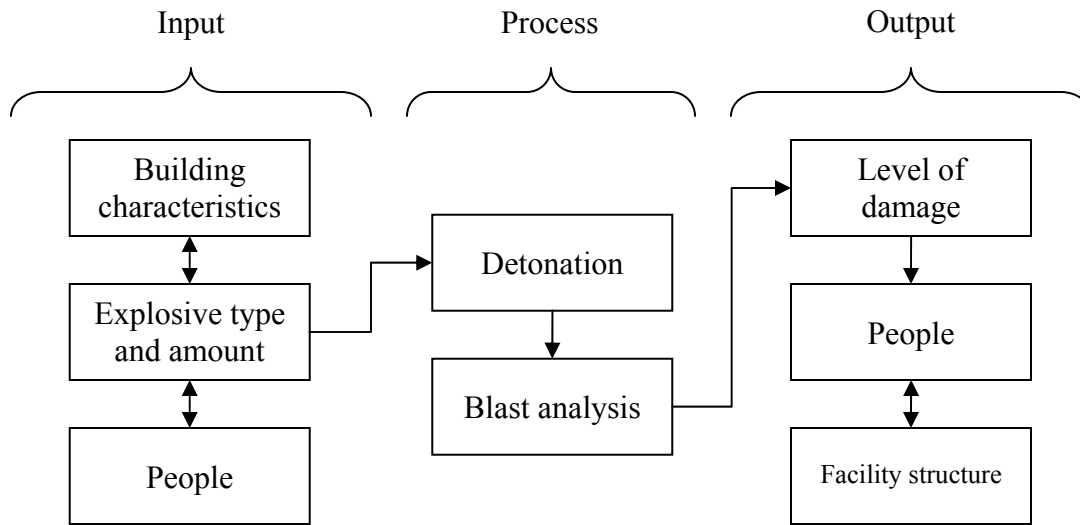


Figure 2.12: BlastFX® information flow

2.5.2 What other software do

There are other software tools that are similar to BlastFX®. They are loaded with data and then they render a report with the level of damage.

BlastX®, for instance³, is used nowadays by the Safety Office of the Eastern Range (ER) at Kennedy Space Center (KSC). This is a blast overpressures assessment model, which evaluates inadvertent detonation hazards as a function of meteorological conditions. Research into TNT equivalences have been developed and have contributed to the development and refinement of BlastX for ER [30]. It also treats the combined shock wave (including multiple reflections off walls) and explosive gas pressure generated by the detonation of a high explosive [9].

BlastinW®, a forerunner to BlastX, is also described in the literature (US Department of Energy, 1992). The loads of the initial shock waves are predicted using free field curve,

³ Please note that BlastX \neq BlastFX

fits to blast data and after that are converted to wall shock loads using results from hydro code calculations. This model is in agreement with the standard TNT pressure and impulse peak values. The code purports to properly handle Mach reflections, and it does account for loads for multiple shock reflections for all walls in the assumed closed room [24]. In other words, it can create a scenario made up of two buildings and run it, and get results separately for everyone (BlastFX® cannot do this).

Shock® is a program for estimating internal shock loads. It can be used for calculating the blast impulse and pressure, in all or just in part of a cubicle surface that is limited by one to four rigid reflecting surfaces. The code also calculates blast parameters for scaled stand off distances ($R/W^{1/3}$) between 0.2 and 100 ft/lb^{1/3} (see Table 2.1). The program does not account for gas pressure load contributions [24].

2.5.3 Comparison

BlastX® is capable of evaluating blast damage at a considerable distance, involving large amounts of explosive. In fact, it is a result of a development toward this research field starting from a previous application, called BlastinW®. Following the same path, Shock® has incorporated the scaled distance approach (see 2.1.1 and Table 2.1) and now has the capacity of operating with devices that have been located far from the facility at risk.

A disadvantage of using BlastFX® is that it does not include the mitigating effects of berms or blast walls as those other programs do. Intervening structures and/or structural elements also not contiguous with the primary structure should not be modeled when they interfere with the straight line of sight between blast and primary structure. BlastFX® cannot model multiple explosions or detonation of secondary devices.

Conversely, the advantages of using BlastFX® —even though it has been designed for analysis of the vicinity of buildings or directly inside them— are its flexible interface, speed, and simplicity to input building, population and explosion data. Comparison over the years indicates that the results of using BlastFX(R) are accurate to within about $\pm 25\%$ with respect to damage and casualties.

However, putting aside the features of the software, the importance of this work lays in our capability of extracting valid conclusions with respect to the Space Shuttle and to the unexpected failure associated to it and its propulsion systems at KSC. The methodology developed in Chapter 3 looks to jump over these limitations, without forgetting that we have new applications or different available software.

2.5.4 BlastFX® and a real case

“On the morning of April 19, 1995, Timothy McVeigh parked a rented Ryder truck with explosives in front of the complex and, at 9:02 am (Central Time), a massive explosion occurred which sheared the entire north side of the building, killing 169 people.” [31] Figure 2.13 and 2.14 show the building after the bombing and a graphic distribution of pressure waves respectively.

In order to compare BlastFX® with a real situation, we simulated the main characteristics of this attack. To do that we constructed a building by using the software tools and then we located an explosive device at the same distance as the real explosive was placed. The results of the effects on the front wall were compared with a report that gathered and analyzed information about the case [32].



Figure 2.13 [33]: Alfred P. Murrah Building

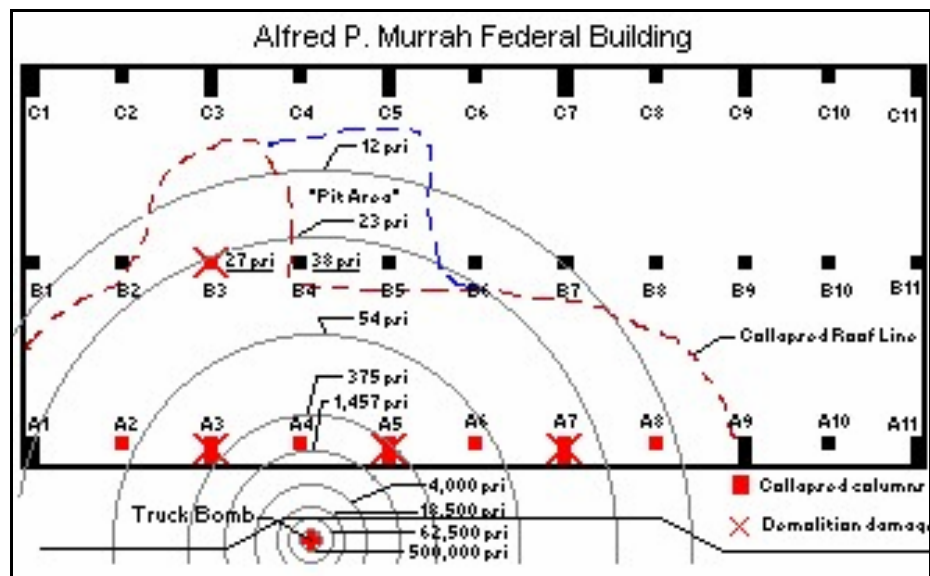


Figure 2.14 [34]: Alfred P. Murrah Building overpressures

So we located the explosive at a distance of 5.09 m (16.71 ft). The amount was based on the real 1,540.39 kg of TNT equivalent (4,800 lb ammonium nitrate [35]). The building that we constructed can be seen in Figure 2.15.

Despite of the differences between these two buildings the point here is the blast and the damage exerted or, in other words, how much the overpressure is in some points according to what we see in Figure 2.14. So we located the explosive and ran the application, and the results are summarized in Figure 2.16.

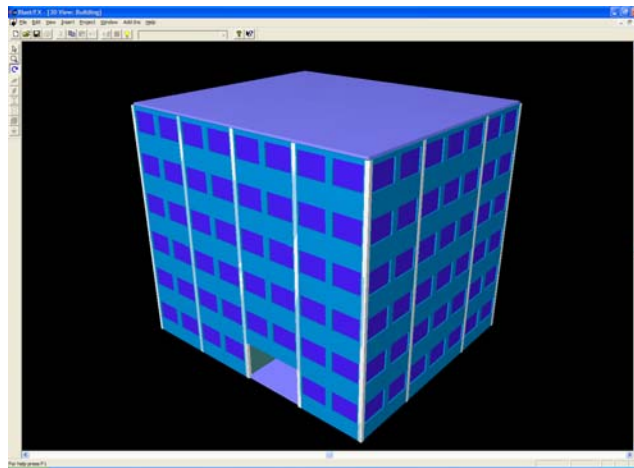


Figure 2.15 [8]: BlastFX® snapshot for simulated building

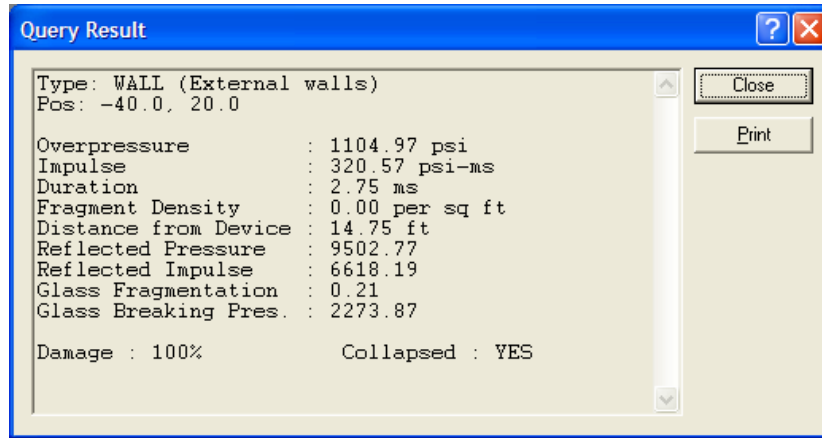


Figure 2.16 [8]: BlastFX® snapshot for query result

The front (or external) wall—which is what we are comparing— was struck with an overpressure of 1,104.97 psi (7.605 MPa) and was completely destroyed (collapsed). So the question is how accurate is the result against the reality. If we take the above mentioned data (Figure 2.14) and compare them with ours, then we have in table 2.6:

Table 2.6: Comparison with real cases

Concept/building	Alfred P. Murrah building	BlastFX®
Overpressure on the front wall (MPa)	10	7.6
Beams and columns	Collapsed	Collapsed
Damage/collapsed	100%/collapsed	100%/collapsed

The difference in overpressure is big (24%), but is within the range of BlastFX® which establish a $\pm 25\%$ [8], and the consequences are basically the same. So this is a condition that we need to take into account at the moment of evaluating our results.

2.6 Summary of Chapter 2

This chapter provides useful information for blast effects in the area of propellants. The lack of literature in the simulation community for blast is a limitation as long as the data for supporting and developing models is widely spread and has not been integrated as we could expect. In a special manner we could say that the information is hidden behind the softwares or the application that provides this kind of information. The majority of the information available, also, is pointed toward *explosives* and our work is pointed toward *propellants*. On the other hand the information (in the field of the accidental propellant explosion and risk analysis) is based on experimental data with limited amounts of explosive, i.e., under the threshold represented by the propellant mass of the SS, or it is based on nuclear bomb detonations experience, earthquakes and so on, which are over our threshold or focus. The main idea here is related to the difficulty of saying what is going to happen, under given circumstances, when an explosive mix releases part or all of its internal energy. So what we know so far is there are some limits and explosive performances in this field of study, and what we will do next is to use this material for elaborating a reasonable answer that corresponds with this information.

2.7 The Next Chapter

The next chapter describes the methodology that we use for interacting with BlastFX® and the flow diagram that we incorporated in order to indicate the step by step scheme that the information follows from the input to the output as a measure of damage to people and buildings.

CHAPTER 3. METHODOLOGY

3.1 Constructing a Model

A model is an ideal representation of reality. The model here is a representation of how things work according to some physical laws and a software application. Thus, we can predict an eventual scenario within the limitations of some specific assumptions.

Our model works as follows: first, it needs to establish a failure (i.e., an accident, say, an undesirable explosion of the SS propulsion system); after that, it determines how much of the propellant mass we have at the moment of the accident and if it is relevant; third, it says what is going to happen with the buildings and facilities and mainly the people both inside and outside of those buildings. Finally, it is going to give us a result in order to let us know the detail of the damage for being evaluated.

Besides, it is a model, because it is a representation of the reality and it works in the same order as reality does, because things can fail and then that failure determines a change in a current situation, but always keeping the same direction, “the thermodynamic arrow of time, the direction of time in which disorder or entropy increases.” [36] This is also known as a causal chain, or cause and effect principle.

3.1.1 Modularity

The simpler the model is, the faster the change for improving or adjusting it is. This concept feeds this work as long as the same concept or working idea has been implemented in the Virtual Range development for producing a single response, and therefore this work should respond to that feature if it is going to be integrated with it. The modularity provides the

capacity of incorporating as layer new information about an accident, as well as to replace older software or data and substitute them for a new one or updated information.

The assumptions in terms of the burning rate of the propellants and our calculus for estimating the TNT equivalency are good examples of data that probably will experience modifications according to the propellants or as new fuels are developed. The same occurs with the software; in chapter two we mentioned the advantages and disadvantages of using BlastFX®, a software that could be replaced for a new version or a different application that considers, for instance, the meteorological conditions. Figure 3.1 illustrates this idea.

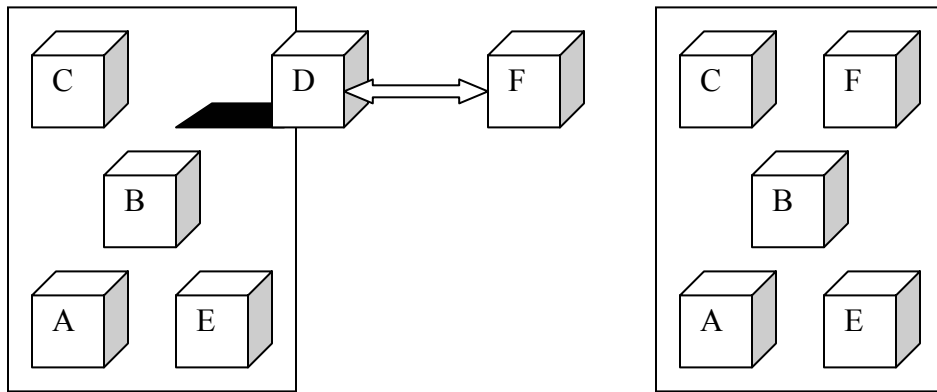


Figure 3.1: Modular components

Even if we change module D by module F at any level, the background remains the same. In this particular case the background is our methodology, which takes into account the constraints of BlastFX®, the characteristics of the scaled law, and the data. Any one of them can be changed or replaced. If we consider the TNT equivalency, we could adjust it as many times as we consider it necessary in order to re-create the reality as accurately as we can. On the other hand we can add weather conditions, as well as a fragmentation factor and so on. In

other words, what we are doing here is leaving open the entrance for improving or adjusting the level of representation as many times as we need it.

3.1.2 Following directions

To be able to apply what we have found in our literature survey (Chapter 2) we have to follow some steps based on our assumptions and the scenario involved in the model. To evaluate an accident during a launch of a spacecraft, we need to:

- Know the propellant mass in terms of TNT equivalency
- Know the distance between the source of the explosion and the place that we are assessing
- Know some general characteristics of the building, like number of stores, height, and length
- Apply the Hopkinson-Cranz scaled distance for knowing the overpressure rate at a given point inside a range of 5,000 m (16,400 ft)
- Load BlastFX® with different amounts of TNT equivalent explosive mass in the closer vicinity case
- Evaluate and compare the results
- Draw conclusions and suggestions

These directions should point toward Virtual Range, where the data of the blast could become a layer to join with similar results in terms of fragments, fireball, toxic gases, among others, as we will see in 3.2.1.

3.2 Components of the Methodology

The components of the methodology are:

- Virtual Range (external)
- The input data
- The output data

3.2.1 Virtual Range and this thesis

The architecture that supports the Virtual Range project, is a virtual engineering environment which provides a simulation for evaluating an eventual disaster of rockets and spacecrafts [22]. The model consists of hardware and a software category. The hardware is related to the parallel-distributed processing computers (HLA). The software is the virtual support of the work, and it consists of some different software and applications.

They are the response to the need for creating a single tool for facing a highly complex problem. The hardware is basically the network where data interchanging occurs, running through it in order to be processed and render the results of the application.

In this particular case SPEEDES® is the supporting platform, a simulation engine that allows us to perform parallel processing on high performance computers, networks of workstation, or combinations of networked computers and HPC platforms [22].

The software has a role of performance, so it processes the information starting from a data source for calculating the aforementioned level of damage. To do this the architecture needs an accident which is given by a probability of failure starting from Arena®; then the accident —with respect to the blast— fires an altitude and a propellant amount in Excel®. The propellant amount determines a level of expected damage rendered through the system itself.

In our case, we will support data and analysis for providing a new layer in Virtual Range with respect to the blast at the moment of the launch; thus, our methodology is supported by the model depicted by Figure 3.2.

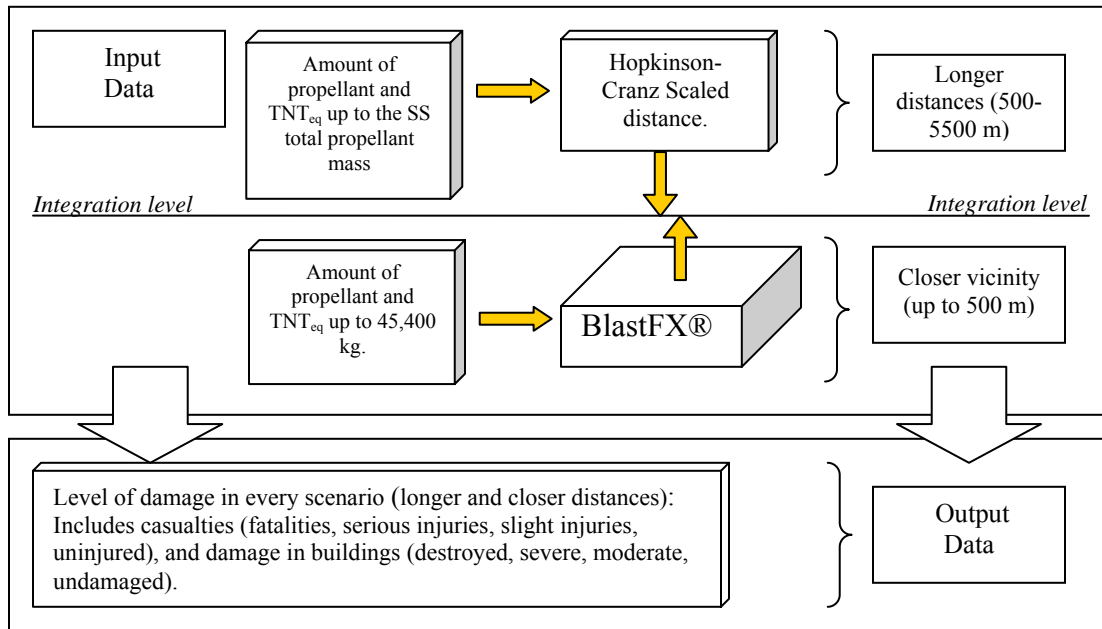


Figure 3.2a: Methodology. Here we see the integration of BlastFX® and the Hopkinson-Cranz scaled distance in order to get information for both longer distances and closer vicinity. The idea is to make possible the analysis of the explosion despite of the limitations of the software and the scaled law itself, but under the umbrella of what we know about propellant explosions and blast.

Figure 3.2b shows the relationship between Virtual Range and this study; there we see how the blast is going to be integrated in the context of that previous work.

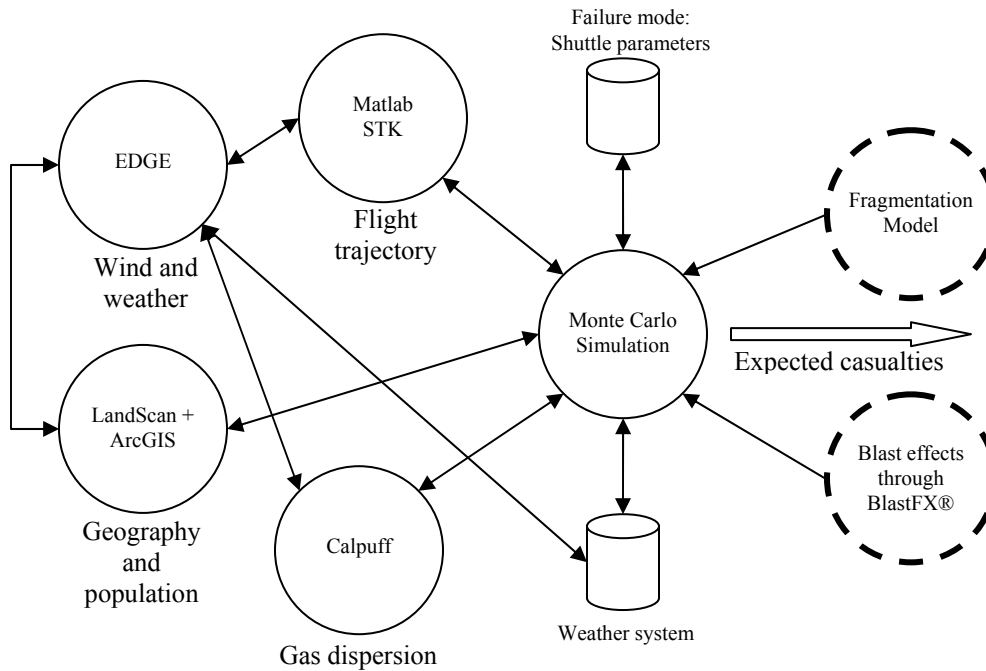


Figure 3.2b: Integration with Virtual Range system architecture. As we see, this thesis should be integrated into the model for providing data about blast. Dash lines represent current research.

3.2.2. The input data

The input data corresponds to the database level and it is based on TNT equivalency of the remaining propellant (solid and liquid); the time considered (10 seconds), which is considerably less than the time that the Virtual Range considers after launch (120 seconds); and the distances between the facilities that make up the scenario.

3.2.2.1 The Scenario

The scenario involves the propellant mass, the position of the SS, and the facilities that we incorporate in our work for being evaluated after an explosion. The launch pad is the aforementioned LC-39A, and the buildings: the Press Site and the Launch Control Center or LCC (see Figure 3.3 and 3.4). The Press Site was selected because at the moment of the launch it is occupied by journalists and photographers, who will represent in our scenario the people outside of buildings. Conversely, the LCC was selected for representing people inside of a reinforced building, apparently designed with security parameters.



Figure 3.3: Press site at KSC [18]



Figure 3.4: Launch Control Center at KSC [18]

3.2.2.2 The Virtual Scenario

The virtual scenario is being used with BlastFX® represents both facilities, with people integrated into the area. The quantity of people we considered in every scenario are 111 persons at the Press Site and 179 persons at the LCC (see Figure 3.5 and 3.6, below).

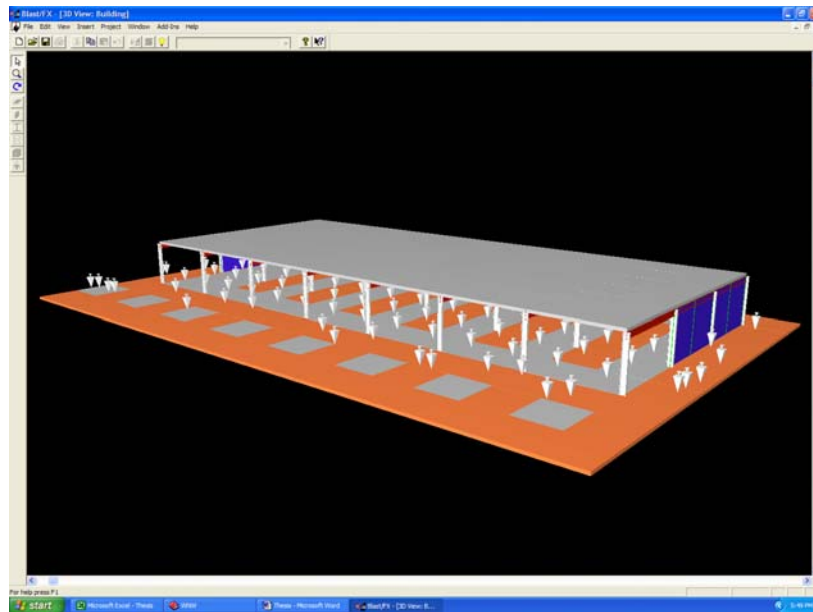


Figure 3.5 [8]: BlastFX® snapshot for Press Site

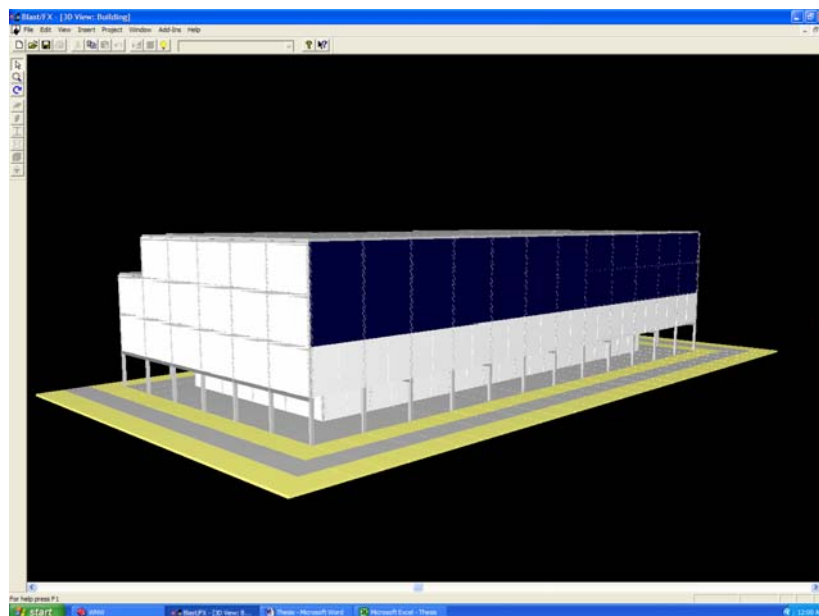


Figure 3.6 [8]: BlastFX® snapshot for Press Site

Even though these quantities could be different from reality, we think that they can provide what we are looking for, which is to know the effects of the blast over a given population. Also, we have to say that every building has been loaded in a different scenario (or in different files), because BlastFX® cannot provide data from two buildings in the same grid. Table 3.1 shows the distances between these two buildings, and with respect to the launch pad LC-39A.

Table 3.1: Distances at KSC

Distances (m)	LC-39A	LCC	Press Site
LC-39A	-	5500	4800
LCC	5500	-	400
Press Site	4800	400	-

The characteristics of BlastFX® are very restrictive in terms of what we want to do. It does not consider the effect of the wind and weather temperature. Also, it assess an amount of TNT equivalent of 45,400 kg (100,000 lb), which is the upper bound of the application, and the grid over which we have constructed our virtual buildings represents a square of 600 x 600 m. So our criteria have been to place alternatively three explosive devices (45,400, 22,700, and 11,350 kg) at 5 different distances (500, 400, 300, 200, and 100 m), in order to be able to evaluate levels of damage concerning these facilities under different conditions of explosive amounts and distances.

3.2.2.3 The Actual Scenario

On the other hand we use the scaled distance law expression for determining the peak overpressure of the explosion at longer distances (from 500 to 5,000 m), in order to trace a schema of the resulting blast overpressure rate (P_o) in the actual scenario (see figures 3.7 and 3.8), covering from LC-39A up to the LCC and the Press Site.

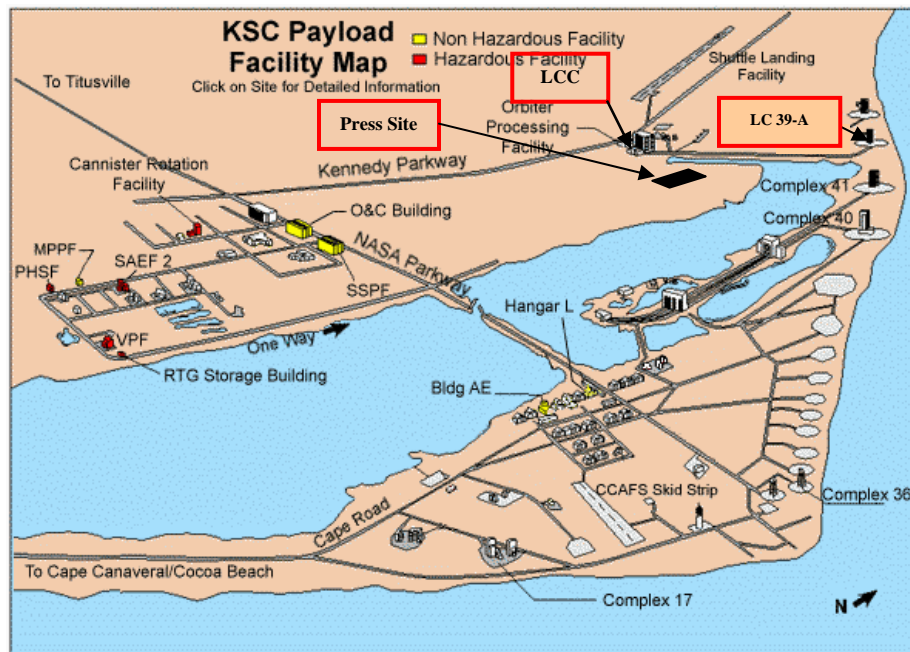


Figure 3.7 [18]: KSC facility map

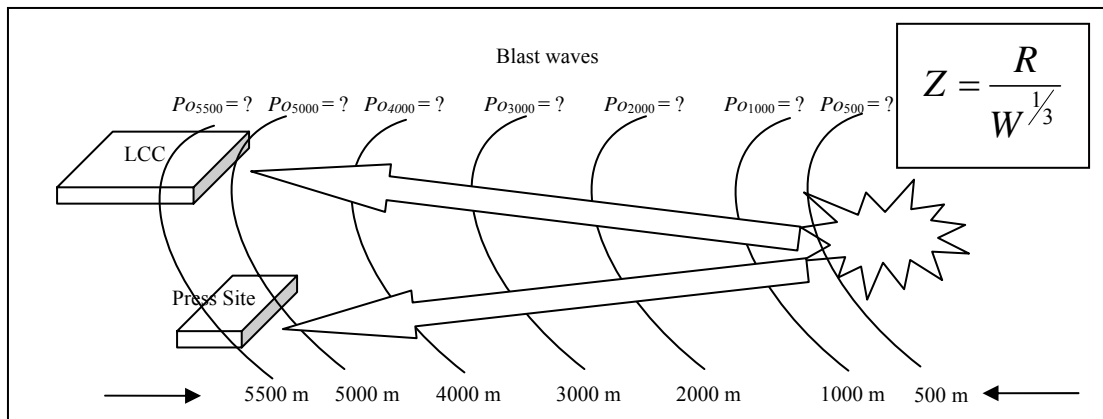


Figure 3.8: Blast waves and the scenarios

Inside the square, Z is the scaled distance formula. Now, we can estimate the overpressure by using Table 2.1 or by incorporating the temperature and overpressure conditions into the formula and getting the results directly from the scaling curve cited by Cooper in “Explosives Engineering” [37], which is shown below.

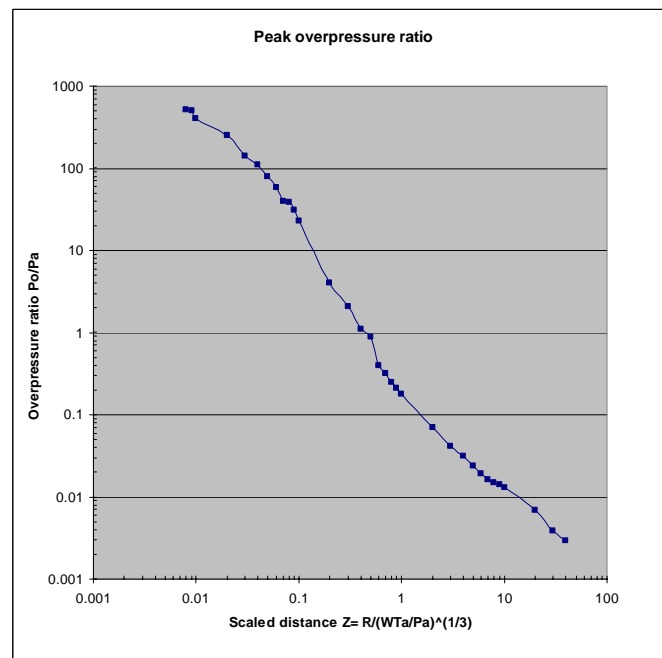


Figure 3.9 [37]: Scaled distance vs Overpressure

In Figure 3.9, R is distance from the center of the charge (m), W is weight of the charge (kg), P_o is peak overpressure (bars), P_a is ambient pressure (bars), and T_a is ambient temperature (Kelvin).

Thus, according the latter, we have:

$$Z = \frac{R}{\frac{WT_a}{P_a}}$$

Where T_a is ambient temperature in Kelvin and P_a is ambient pressure in bar. If we assume 293 K and 1.013 bars as normal conditions, then we get, for instance, $Z=6.852$ (for $R=5,000$ m, and $W=1,320,564$ kg).

Bringing Z to the curve, we get $P_o/P_a=0.018$ bars. Operating we get $P_o=0.018$ bars or 0.264 psi, which is consistent with data rendering by Table 2.1.

3.2.3 The output data

After running BlastFX®, we get a report. Likewise after running our scaled law, we are going to get concentric curves with different overpressure rates. Every set of curves can be related with several amounts of TNT equivalent in order to make up different scenarios, which represent the risks evaluated from two perspectives regarding the amount. On the other hand, we can oversize the amount of TNT for representing an accident before 4 seconds, when the altitude of the SS is just 35 m, and the soil itself tends to reflect and therefore to increase the overpressure, as we will see below. The idea is to incorporate alternatives other than that supplied by our collecting data. At last we will get a set of different potential damage, over different but realistic scenarios at KSC.

3.3 The Methodology

3.3.1 Analysis

Different scenarios represent the multiplicity of the real world. In this case we have to bear in mind the fact that BlastFX® has $\pm 25\%$ accuracy in rendering results. We also need to consider Sutherland's [26] possible upper bound in TNT equivalences for LO₂/LH₂ liquid propellants, as well as the augmented effect of an explosion occurring in close proximity of the ground, which increases the effective yield in a range that covers from 160 to 180% [37]. Furthermore we need to consider the amount of TNT equivalent, whose magnitude could evolve out of parameters because it is too big to behave as a car bomb but not big enough to be a tactical nuclear bomb. We will incorporate all these concepts as assumptions (see 3.3.2) and by increasing or decreasing the amount of TNT involved in every scenario. The scenarios will be based on distances directly from the source of the explosive (see Figure 3.7), every 500 m (1,640 ft) up to 5,500 m (18,040 ft). If we take into account KSC and the LC-39A, we see that the blast has a long distance to cover.

Finally, in order to avoid confusion, we have separated the explosion phenomena into three main components (see Figure 3.10):

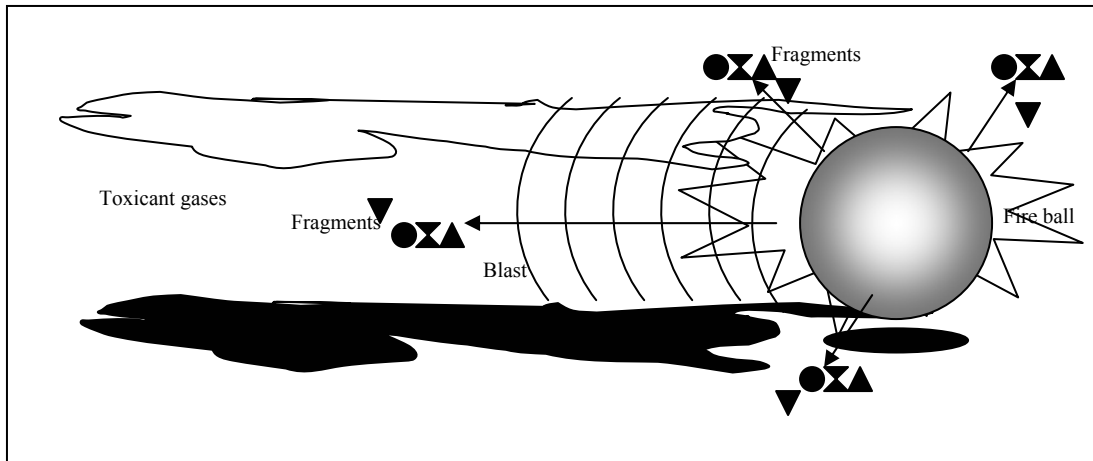


Figure 3.10: Composition of an explosion

So according to the figure we will work with *blast*. This means that the other components are not being considered. However, it is important to mention this in terms of components, because the casualties are normally related to the fragmentation and fire ball. The combined effects of fragment and blast are more complicated than the extent of this research, and the available practical approaches for assessing such effects are very limited [9].

3.3.2 Assumptions

Next are the assumptions for carrying out our experiments. All have been integrated as criteria for the examples that you will see later in Chapter 4.

- The explosive yield of the liquid propellant won't overpass the possible upper bound described by Sutherland [27], and will give just the amount considered by this work (see table 2.4).
- The first four seconds of the launch will be considered as *proximity* to the ground, because of the length of the entire SS system (~ 56 m) [21], and the low altitude at

that moment (35 m) [22]. This will result in an increased amount of TNT as was mentioned in 3.3.1.

- The next six seconds will be considered as *not proximity*, which means that the explosion will be evaluated as «in air» (actual amount of TNT equivalent) [37].
- The linear distance between the SS and the buildings considered in this study, will be constant (5,000 m) with respect to Table 3.1, because the difference in terms of altitude between T_0 (0 seconds) and T_f (10 seconds), is minimum (if we consider 280 m observed at a distance of 5,000 m).
- This work won't consider extreme weather conditions. So it will perform under normal conditions (1 atm and 298 K).
- For our purposes, the propellant mass is going to detonate, despite it is reasonable to think that it could deflagrate slowly, without causing so much damage to the surrounding area.

3.3.3 Scenario design

We need to establish a scenario for consideration. The scenario will be comprised of the press site, the LCC, launch pad LC-39A, and the distances between them and the Space Shuttle. The distances will be based in the information supplied by the NASA web site (see table 3.1).

The accidents will take place at different distances from these facilities. For being able to apply BlastFX®, the running will be performed in the *close proximity* of the buildings (0–500 m), from the maximum load of BlastFX®, i.e., 45,400 kg (100,000 lb) through 11,350 kg (25,000 lb) of TNT equivalent at different distances, configuring several scenarios for an accident, as the next chapter shows.

On the other hand, the Hopkinson-Cranz scaled distance (see 3.2.2.2), will be used for estimating the blast damage at *longer distances*, starting from LC-39A up to 5,500 m. This scaled distance will give us an overpressure and a related damage estimation based on Kinney and Graham works (see table 2.10, reference [10] and [38]).

So the results will render for us, as was mentioned in 3.2.3, eleven pressure waves separated by 500 m, over the study area of KSC (Figure 3.7). Likewise, in the close proximity we will get BlastFX®'s damage report for distances from 500 up to 100 m, with respect to both, the LCC and the Press Site. Figure 3.11 illustrates the working idea.

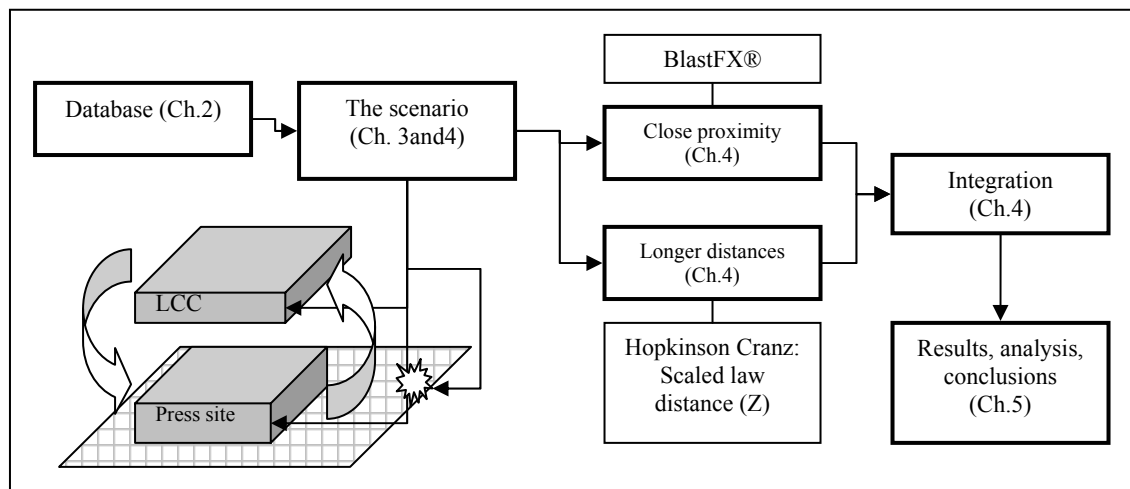


Figure 3.11: Conceptual design

Finally the results will be tabulated and integrated. Chapter 4 discusses the results in order to provide analysis tools for further conclusions in Chapter 5.

3.4 The Virtual Range Connection

As mentioned before, this work can be integrated into the Virtual Range as a blast layer. To do this, it is necessary to load the data of blast through coordinates over the Arcview® image

of the zone (in this particular case, KSC). Arcview® is an active image of the surface of the Earth, and it combines geographic representation with population data (provided by Landscan®), making it possible to know the effects of an accident in terms of people exposed to the consequences of that accident. Previous works have been developed for risk assessment in the Virtual Range, which have incorporated the effect of a gas cloud over a portion of Florida by linking Calpuff (which calculates different concentration levels of gas in a coordinate plane) with a Geographic Information System (GIS), represented by an Arcview® image.

3.4.1 Interaction

The Virtual Range holds a big capacity for data integration and software interaction, and it gives results based on a simulation model that provides a realistic dimension of a launch and landing of a spacecraft in terms of risk assessment. However, BlastFX® does not have incorporated coordinates for a GIS application, even in the latest version; that's the reason why it is a local-like tool, mainly focused on risk assessment from the perspective of terrorist attacks, with a limited range of explosive amount (namely from 0 through 45,400 kg of TNT equivalent).

As a consequence, future developments should include a way of jumping over this limitation, creating conditions for incorporating a blast layer. Figure 3.13 shows how the Virtual Range incorporates the toxicant layer through Arcview®. Every point is a geographical reference and so is a unique point. BlastFX® cannot do this as Calpuff can.

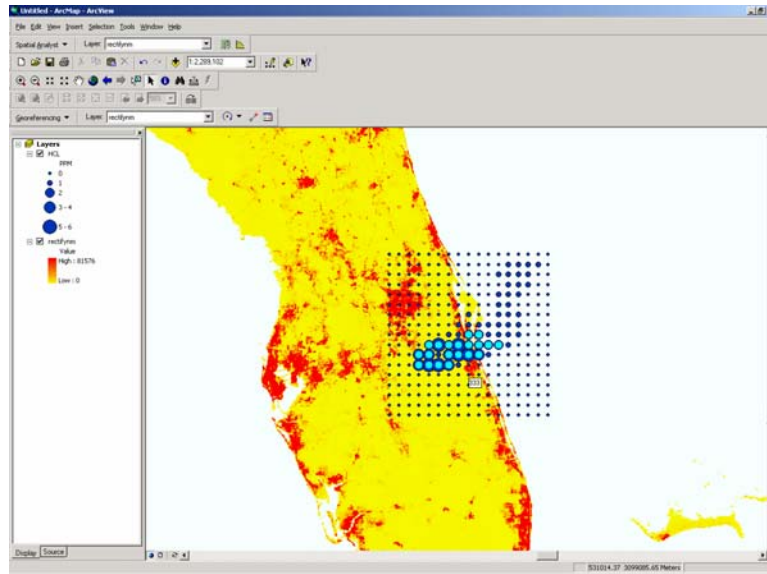


Figure 3.12 [22]: Snapshot for GIS over Florida State

Also, the Arcview® image does not provide the resolution that we need to load a blast layer in the surrounding area of our scenario. If we take into account the distances we cover and the surface equivalent (a square of 5,000 x 5,000 m), then we realize that in this case we just would see pixels instead of buildings, paths, and facilities. Every pixel in Arcview® represents a square of an equivalent surface that is too big (or too poor in the close proximity) for our local purposes. That's why we are going to render our results through tables and reports. As a consequence we are going to consider the distances directly from launch pad LC-39A toward the two buildings included in our study, the Launch Control Center and the Press Site, without considering geographical coordinates.

On the other hand, for evaluating the *close proximity* case, we are going to work with the internal coordinates that BlastFX® provides, i.e., working over the grid that supports the virtual scenario.

3.5 Next Chapter

Chapter 4 focuses on the experiments for determining the level of damage at KSC, as a consequence of an accident during the first ten seconds of launch operations. That work has been divided into two levels, longer distances and close proximities through 3 examples. Chapter 4 also provides analysis and discussion.

CHAPTER 4. THE EXECUTION OF THE MODEL

4.1 Three Examples of an Execution

As mentioned in Chapter 3, we have divided this stage of the thesis into two parts, given the capacities of BlastFX® and what we know about the phenomena of blasting. In example 1 we have gathered all the information we have for establishing a blast wave propagation chart based on scaled law distance, indicating the overpressure rate at every point given a radius distance from the center of launch pad LC-39A (see Figure 4.1).

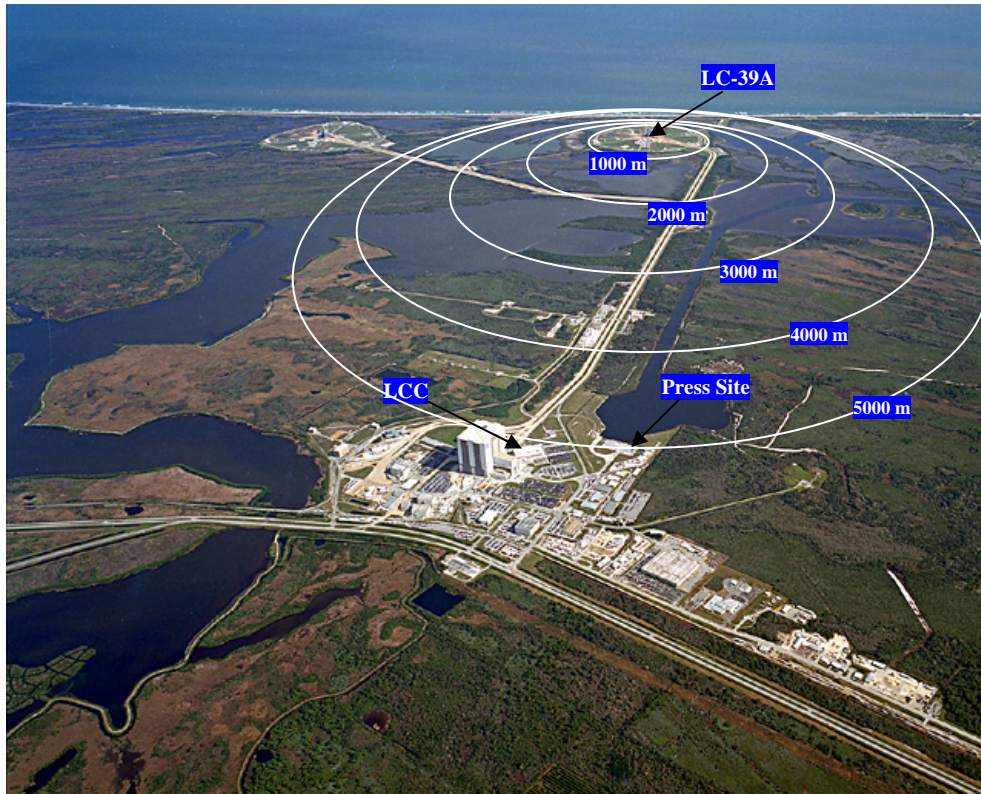


Figure 4.1[18]: KSC aerial view. The concentric circles represent approximate distances with respect to the source of an accidental blast.

Examples 2 and 3 show different results based on BlastFX® performance. In this case we have worked with 3 amounts of TNT equivalent: 45,400 kg (100,000 lb), 22,700 kg

(50,000 lb) and 11,350 kg (25,000 lb), respectively, located at 500 m, 400 m, 300 m, 200 m and 100 m, in every case.

At the end of the chapter we gather and discuss the results as a whole.

4.1.1 Example 1

4.1.1.1 Category: Longer distances.

4.1.1.2 Processing: By applying equation $Z = R / (W * T_a / P_a)^{1/3}$, and Figure 3.9, we get the overpressure rate at different distances and its consequences. The results were tabulated below. In figure 4.2 we plotted R vs. Po. as a way of visualize the results with respect to the predictions of the scaling law.

4.1.1.3 Results

Table 4.1: Results at longer distances

R (m)	W (kg)	T _a (K)	P _a (bar)	Z	Po/Pa	Po (bar)	Po (psi)
5500	1320564	298	1.013	7.537730375	0.014	0.01418	0.206
5000	1320564	298	1.013	6.852482159	0.017	0.01722	0.250
4500	1320564	298	1.013	6.167233943	0.021	0.02127	0.309
4000	1320564	298	1.013	5.481985727	0.022	0.02229	0.323
3500	1320564	298	1.013	4.796737512	0.027	0.02735	0.397
3000	1320564	298	1.013	4.111489296	0.031	0.03140	0.455
2500	1320564	298	1.013	3.426241080	0.038	0.03849	0.558
2000	1320564	298	1.013	2.740992864	0.049	0.04964	0.720
1500	1320564	298	1.013	2.055744648	0.064	0.06483	0.940
1000	1320564	298	1.013	1.370496432	0.120	0.12156	1.763
500	1320564	298	1.013	0.685248216	0.380	0.38494	5.583

* (R is distance in m; W is propellant mass in kg of TNTeq; T_a is ambient temperature; P_a is ambient pressure; Z is scaled distance; Po is peak overpressure in bar and psi)

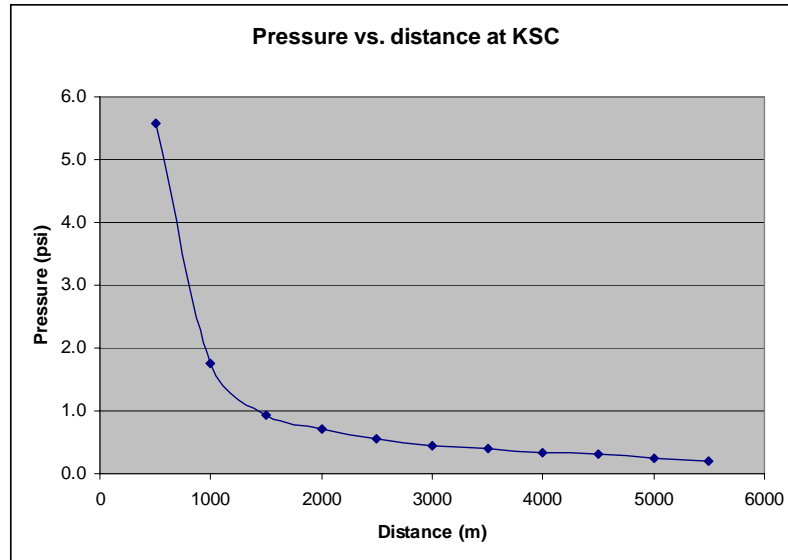


Figure 4.2: Pressure decaying as long the distance increases

4.1.1.4 Discussion

According distances decrease from 5,500 to 500 m, P_o increases from 0.206 psi to 5.583 psi as long as we are closer to the source of the explosion. Conversely, the peak overpressure decays rapidly as long as we stand off from the core of the explosion (see figure 4.2). Now, if we increase the propellant mass, W , in 160% (see 3.3.1), i.e., from 1,320,564 kg to 2,112,902 kg (4,658,948 lb), we get 0.279 and 7.052 psi, respectively. This comparison was summarized in table 4.2.

We have added a column for representing damage in the human body. This damage is caused by the effect of the shock overpressure in ears and lungs because of the air that these organs contain. Comparing the data in Table 4.2 with the information available in Cooper [37], we shouldn't expect fatalities under those circumstances if we take into account that a fatality curve jumps over the peak overpressure reached at that distance according to our calculations.

Table 4.2: Comparing results at longer distances

R (m)	Po (psi) for W1 (kg)	Po (psi) for W2 (kg)	Damage on the human body
	1,320,564	2,112,902	
5500	0.206	0.279	No damage
5000	0.250	0.309	No damage
4500	0.309	0.323	No damage
4000	0.323	0.411	No damage
3500	0.397	0.426	No damage
3000	0.455	0.470	No damage
2500	0.558	0.602	No damage
2000	0.720	0.779	No damage
1500	0.940	1.175	No damage
1000	1.763	1.763	1% eardrum rupture
500	5.583	7.052	Threshold lung rupture

Recall, on the other hand, what we are doing here is comparing two scenarios, which are the first 4 seconds and the following 6 (see 3.3.2) of the SS launch. The former represents an explosion in the proximity of the ground and the latter an explosion in the air [37]. The increase of 160% is significant in the close proximity of the launch pad. At a distance of 5,000 m from the source of the blast, the pressure is similar to the previous value. So the reason, according to what we have seen before, is the exponential decay of the blast insofar as the distance increases, so even though the peak overpressure at the source is bigger and bigger as long as we have larger amounts of TNT equivalent (even 1.6 times more), at 5000 m the performance tends to be similar across a broad range of explosive intensities⁴. Therefore we have to consider the worst scenario for our buildings (in particular), i.e., 2,112,902 kg of TNT equivalent exploding at ground level. If this happens, in terms of blast, the overpressure would be situated around 0.300 psi. So looking at Table 2.1, we read

⁴ This may seem very intuitive but if we compare a 20 KTon nuclear bomb with a 20 MTon, it is not so evident when we think that the latter—even being 1,000 times more powerful than the former—it is just 20 times in terms of blast.

“minimum overpressure for debris and missile damage,” which means that some buildings with annealed glasses (the most commonly found in residential construction [8]), could be affected, which wouldn’t be the case at the LCC, where the glass should meet higher safety standards (like fully tempered glasses). If this is the case, then the building and its population under that overpressure won’t suffer any significant damage (see Figure 4.3).

So, what would probably happen with people located outside of the buildings? To answer this question we can review table 4.3 with data provided by the Department of Defense [39]. There we can see that 3.4 psi are still capable of affecting a percentage of people with eardrum rupture. If we consider 100 persons at the press site, theoretically speaking just one of them would be affected as a consequence of the explosion under that overpressure rate.

However we have to remark that 0.300 psi theoretically can generate up to 160 decibels (dB) according Cooper [37], who says that are enough to damage the eardrum, and the level of this damage goes from partial loss of hearing and pain through “healable small tears or ruptures of the tympanic membrane.” [37] The latter statement corresponds to a damage quantified as Level 1 (which is the lower one) according to Cooper.

Table 4.3: Effects of blast on people [39]

Effects on people	Dose (psi)
1% eardrum rupture	3.4
50 % eardrum rupture	16
Threshold lung rupture	10 (50 msec duration); 20-30 (3 msec duration)
1% mortality	27 (50 msec duration); 60-70 (3 msec duration)

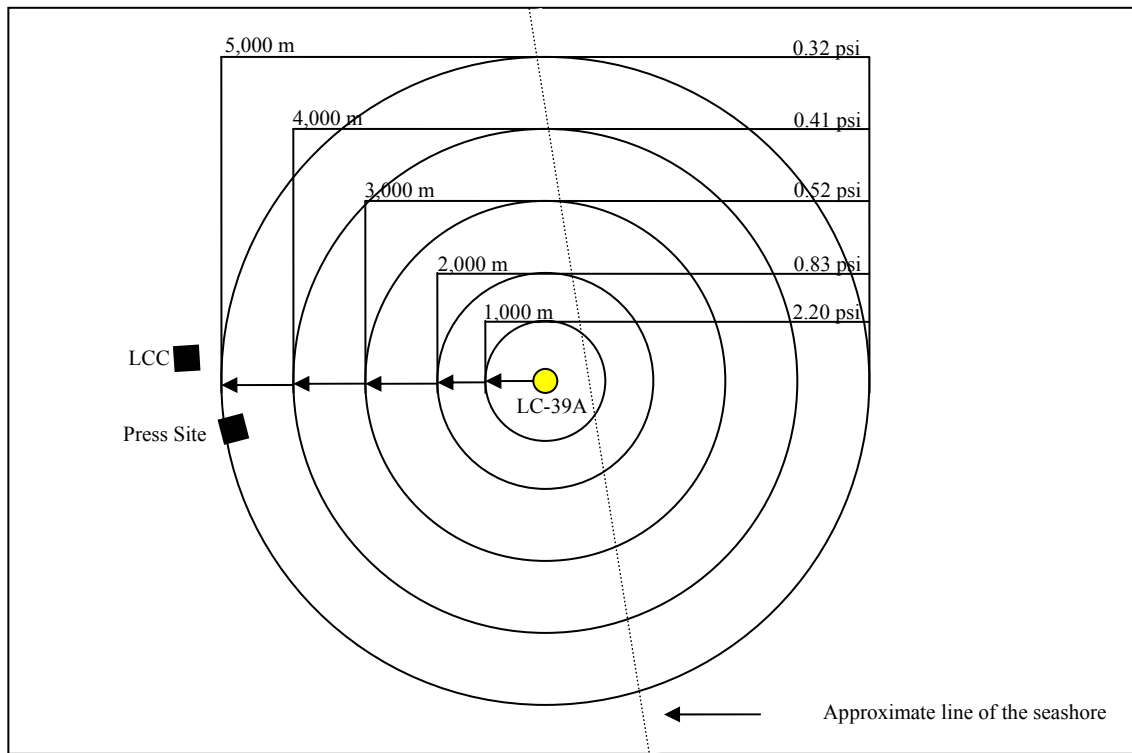


Figure 4.3: Overpressure results: rate at different distances from launch pad LC-39A.
The locations of the buildings are approximate.

4.1.2 Example 2

4.1.2.1 Category: Close Proximity

Building: Press site

- People: 111
- Explosive amounts: 45,400 kg (100,000 lb), 22,700 kg (50,000 lb), 11,350 kg (25,000 lb).
- Distances: 500, 400, 300, 200, 100 m.
- Basic features of the facility: The press site was designed in BlastFX® by using a concrete floor, columns of steel (AISC) S15x50, as well as beams of similar characteristics, and a concrete wall on the back side; likewise the roof was put at a

height of 3.65 m (12 ft). The surface covered an area of 1,846 m² (16,000 sq ft), and the people were situated both under the roof (75%) and in the surrounding area (25%).

4.1.2.2 Processing: By applying BlastFX®, as follows:

We try 5 distances against 3 amounts of TNT equivalent. The explosive devices were placed over the grid at the aforementioned distances, and at a height of 10 ft (maximum provided by the software).

4.1.2.3 Results

The results that correspond to the larger amount of TNT are summarized in tables 4.4a and 4.4b (the details of the other amounts can be viewed in BlastFX® summary report in Appendix). To get them in this fashion we asked for “component damage,” “expected casualty severity,” and “destroyed and collapsed components,” all of which are under the concept of “overpressure.”

Table 4.4a: Effects on people at Press Site by using BlastFX®

Building	Scenario			Distance (m)	Casualties (*)			
	Device	Compound	Charge (kg)		F	SI	MI	U
Press site	Accidental explosion	TNT	45,400	100	0	74	37	0
"	"	"	"	200	0	0	0	111
"	"	"	"	300	0	0	0	111
"	"	"	"	400	0	0	0	111
"	"	"	"	500	0	0	0	111

* In casualties, F is fatalities, SI is serious injuries, MI is minor injuries, and U is uninjured.

Table 4.4b: Effects on structure at Press Site by using BlastFX® for building

Damage	100 m				500 m				Total
	D	S	M	U	D	S	M	U	
Beams	0	0	0	48	0	0	0	48	48
Columns	0	0	0	32	0	0	0	32	32
Floors	181	49	0	14	0	0	0	244	244
Walls	22	0	0	0	8	0	0	14	22
Total	203	49	0	94	8	0	0	338	346

* In buildings, D is destroyed, S is severe, M is moderate, and U is undamaged.

In table 4.4b we have included those results related to distances of 100 and 500 m (over the building structure), the extremes, mainly for representing a general tendency, which have to do with an expected greater damage at 100 m, over the other distances included. At 200 m, however, we also find severe and moderate damage. Figure 4.4 shows the representation of the press site after a detonation of 11,350 kg (25,000 lb) of TNT at 100 m.

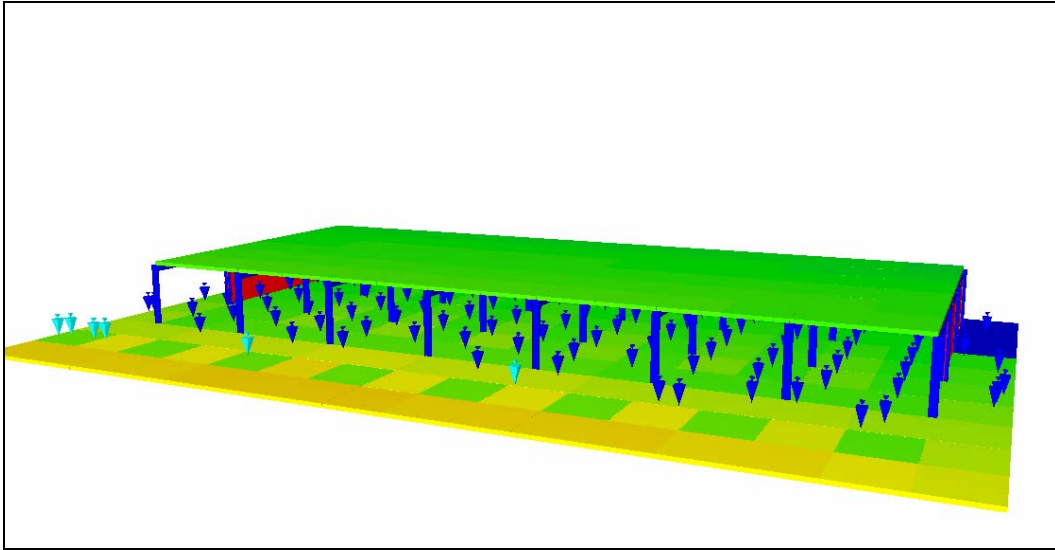


Figure 4.4 BlastFX® snapshot for results at Press Site 3D. Blue colors represent no damage. The six people at the foreground colored in light-blue represent slight injuries.

4.1.3 Example 3

4.1.3.1 Category: Close proximity

Building: Launch Control Center

- People: 179 (1st floor: 41, 2nd floor: 65; 3rd floor: 36; 4th floor: 37). No people outside.
- Explosive amounts: 45,000 kg (100,000 lb), 22,700 kg (50,000 lb), 11,350 kg (25,000 lb).
- Distances: 500, 400, 300, 200, 100 m.
- Basic features of the facility: This 4 story building was designed by using the strongest materials that BlastFX® offers in its menu. The floors are 2-way reinforced concrete⁵, and square columns are 12 x 14 in, likewise the beams. The external walls were 2-way reinforced concrete, while the internal walls were just 1-way reinforced concrete. The columns were put every 20 ft and the beams every 40 ft.

4.1.3.2 Processing: By applying BlastFX®, as follows:

We try 5 distances against 3 amounts of TNT equivalent. The explosive devices were placed over the grid at the aforementioned distances, and at a height of 10 ft (maximum provided by the software), such as we did with the Press Site.

⁵ 2-way reinforced concrete - refers to concrete sections with rebar laid out parallel, running in two directions, typically crossing at a 90 degree angle.

4.1.3.3 Results

Adopting the same criteria as in example 2, we have tables 4.5a and 4.5b:

Table 4.5a: Effects on people at LCC by using BlastFX®

Building	Scenario			Distance (m)	Casualties			
	Device	Compound	Charge (kg)		F	SI	MI	U
LCC	Accidental explosion	TNT	45,400	100	46	0	0	133
"	"	"	"	200	0	0	0	179
"	"	"	"	300	0	0	0	179
"	"	"	"	400	0	0	0	179
"	"	"	"	500	0	0	0	179

* In casualties, F is fatalities, SI is serious injuries, MI is minor injuries, and U is uninjured.

Table 4.5b: Effects on structure at LCC by using BlastFX® for building

Damage	100 m				500 m				Total
	D	S	M	U	D	S	M	U	
Beams	40	0	0	290	0	0	0	330	330
Columns	0	0	0	209	0	0	0	209	209
Floors	394	88	234	892	0	0	0	1608	1608
Walls	102	0	66	198	8	0	0	366	366
Total	536	88	300	1589	8	0	0	2513	2513

* In buildings, D is destroyed, S is severe, M is moderate, and U is undamaged.

We have considered the same data as in example 2. In this case it makes sense the level of damage increases according distances are closer to the facility, as well as the fatalities revealed by table 4.5a. This is not an unexpected output if we consider the influence of the construction material over people, when they are loaded with a huge amount of blast yield. Figure 4.5 shows the appearance of the LCC building after being bombed with 11,350 kg (25,000 lb) of TNT at a height of 10 ft and 500 m in distance.

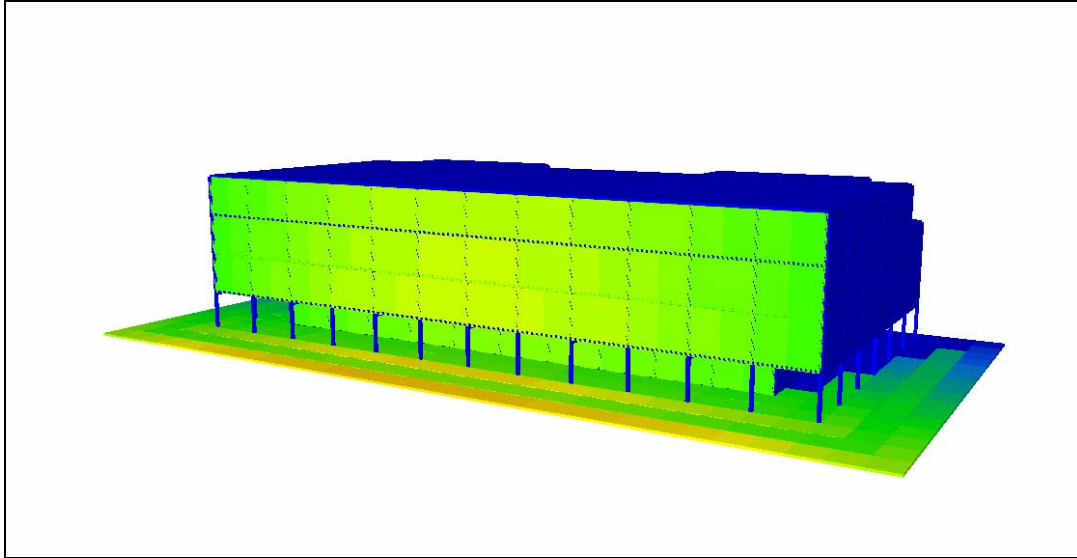


Figure 4.5 BlastFX® snapshot for results at the LCC 3D. Blue colors represent no damage. Green and yellow represent increasing level of damage.

Figure 4.6 illustrates the aspect of the building after 45,400 kg (100,000 lb) of TNT detonating at 100 m off. The red coloring indicates the severity of the damage in terms of collapsed components. Figure 4.7 shows the aspect offered by the first floor (2D view) under the same circumstance.

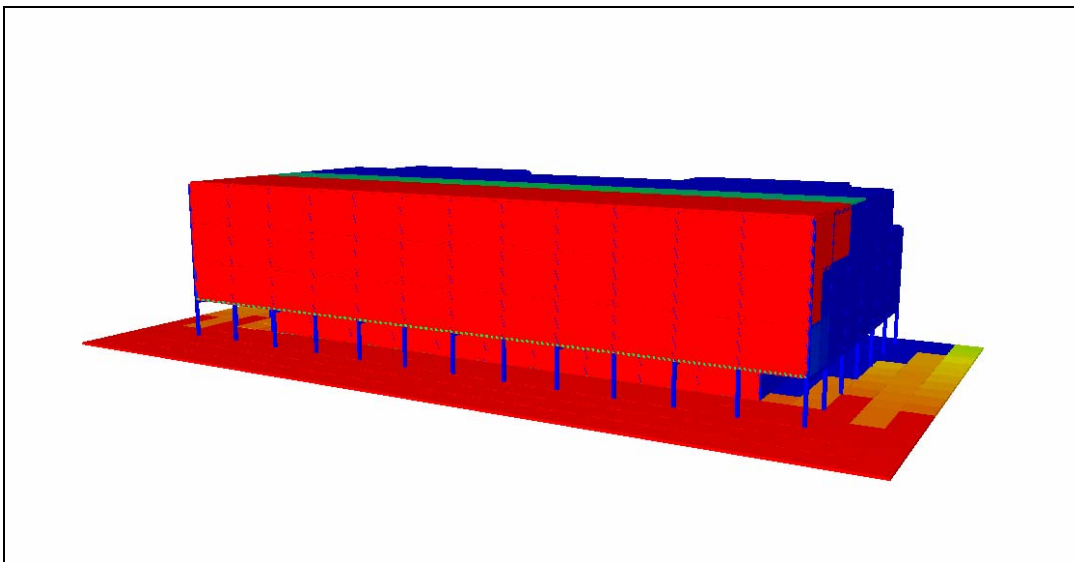


Figure 4.6 : BlastFX® snapshot for results at the LCC 3D. Red coloring represents collapsed components.

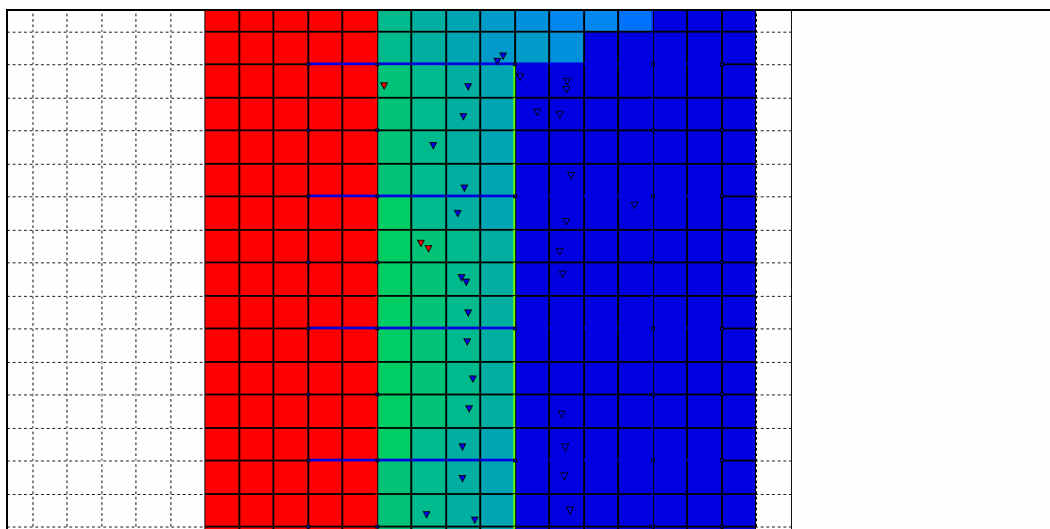


Figure 4.7 : BlastFX® snapshot for results at LCC 2D. Red colored triangles represent fatalities.

4.1.4 General discussion

- The blast overpressure decays exponentially. That is why large amounts of explosive represent decaying amounts of blast through relatively short distances. This phenomenon is present in these three examples. We can consider, for instance, the 45,400 kg (100,000 lb) of TNT equivalent over the LCC building in terms of blast overpressure, and then comparing with Z , the scaled law. Table 4.6 shows these data.

Table 4.6: Comparison between closer and longer distances

Distance (m)	Amount of TNT (kg)	Facility	Overpressure according BlastFX® (psi)	Overpressure according “Z” (psi)
100	45,400	LCC	37.58	13.22
200	"	"	6.47	3.379
300	"	"	3.11	2.20
400	"	"	2.00	1.34
500	"	"	1.46	0.96

- The difference is bigger as long as we are closer to the charge, but this circumstance can be interpreted as a result of the method employed by the software for measuring overpressure. In this case BlastFX® is representing damage in a column as a function of pressure-impulse values as opposed to scaled range [8]. Hence we have to consider the reflected overpressure which increases the total load (for getting this parameter in BlastFX®, we could do it by clicking on a particular column or the object affected by the explosion).
- Furthermore, if we review the consequences of the explosion at 100 m against the Press Site, the overpressure differs because of the material where the software is measuring the overpressure. In the case mentioned in Table 4.6 (LCC), the material was concrete, but it is steel in the case of the Press Site. So the overpressure fell down from 37.58 to 21.47. And if we click on a human icon, we get 20.87 psi⁶.
- The effect of an accidental explosion in the launch pad at the moment of the launch or during the next 10 seconds is minimal (theoretically speaking). For people and buildings located 5,000 m from the source of the explosion, the accident—in terms of blast— does not affect them.
- By using the cube root scaled law, we can infer that for duplicating an overpressure rate or a given blast intensity over some point, we need to increase the total charge of the explosive eight times [40]. But in this case we have to consider the density of the medium through which the blast wave is being transmitted. That's why to duplicate, for instance, the overpressure from, say, 0.54 to 1.06 MPa at 20 m, we just need to duplicate the amount of TNT from 500 to 1,000 kg [7].

⁶ This data does not appear in table but it was obtained directly from the software through the interface.

- But, as long as the distance is longer, for destroying a building like the LCC from 5,000 m, we would need to dramatically increase the amount of the Space Shuttle's TNT equivalent. A bomb like the one dropped on Hiroshima, which was about 20 kT (20,000,000 kg TNT), at a distance of 1,000 m, would produce “just” 3.4 psi if detonated at 3,048 m of altitude.
- Something similar happened with the Press Site. Nevertheless, the number of fatalities here, according BlastFX®, was zero (100 m, 45.400 kg), but 100% of the people suffered some kind of injury or harm (see Table 4.4a). Here the results are biased by the absence of a structure that multiplies the effect of the blast with fragments like projectiles, highly related with the collapse of the building. In the Alfred P. Murrah Building bombing attack, 40% of people who survived cited glass breakage as the cause of their injuries.

4.2 Summary

The actual amount of propellant mass in terms of TNT equivalent of the Space Shuttle would not cause damage to people and buildings of the surrounding area, over a radius of 5,000 m from the launch pad, LC-39A, at the moment of the launch.

For affecting people and facilities, the amount of propellant mass would have to be increased too many times, probably more than necessary for breaking the inertia and the gravity attraction. Or, which can presumably occur, being changed for other energetic blends that this study does not cover, such as nuclear energetic sources for providing thrust, with different and maybe worse consequences.

An accident, however, could occur during the assembling stage, which is carried out inside the Vehicle Assembly Building (VAB). The amount of TNT equivalent that the current propellant mass represents would destroy that building. A previous study demonstrates this assertion by implementing a simulation based on 454,000 kg (1,000,000 lb) [41], a third part of the actual mass, and ten times the amount that destroyed the LCC at a distance of 100 m, according our simulation in BlastFX®.

CHAPTER 5. CONCLUSIONS

5.1 Answer for research questions

In 1.1 we formulated some questions for carrying out this research. The adequate answers to those questions provide us a way for getting results. Briefly, we will follow that sequence in the next paragraph, looking for answers and making some comments when necessary.

We include all the data we collected for representing with accuracy the whole phenomenon of a blast, i.e., the propellant mass, the distances involved, the main features of the buildings, and the range of launch (the first ten seconds). All the data we use was based on updated sources, mainly the NASA websites and several related links. The explosive phenomenon, values, and formulas were obtained from bibliography especially and reiteratively cited as a confident source and in some cases from the internet. Even though some websites do not provide their original sources or render (apparently) the data carelessly, they were contrasted before being added to this work. The data related to propellant and consumption were found from different sources, but despite the existence of some methods for calculating it, our data is consistent with the performance of the Space Shuttle (at least for the first ten seconds). Some constraints exist for getting information about buildings at KSC. We understand that this is a delicate and sensitive area, so our estimation of consistency or strength of the building was based on our criteria and what BlastFX® recommends. However, we think it is a good enough approach for evaluating a reinforced building built for withstanding accidental explosions like this. The operation of the Space Shuttle, for the purposes of this research, was an open source if we consider that we just took the moment of the launch and did not need more detailed data for evaluating it as we did. However, it is important to mention that to comprehend the makeup and working of the engines, the

information was distributed widely, so it was necessary to spend a lot of time gathering, analyzing, and evaluating reiteratively what we collected in order to get and join a confident information range. The maps that we got were mainly drawings. The Arcview® image at the scale that we needed just rendered pixels, so this was a constraint for representing our result in a better way than making graphs or mere schemes. With respect to the number of workers (LCC), journalists and photographers (Press Site), we made assumptions, because we couldn't obtain the exact number of people involved in these activities. For previous and subsequent activities of the launch, we got everything we needed that was general data. The reports and results rendered by BlastFX® were added in the Appendix and specific aspects for analysis were put in tables in Chapter 4. These results were based on two scenarios, longer distances and close proximity, which have already been discussed.

5.2. Conclusions

This work provides two kinds of data, neither one nor the other provides exactly the same results. When we compare the data drawn from the scaled law and BlastFX®, and then we contrast them, we realize that the outputs are based on different methods for representing actual phenomena, like blast effects of explosion. The software mentioned above deals with the “Effects of blast explosion” published by the National Defense Research Council (NDRC), which is based on World War II bomb types, so damage is represented as a function of pressure-impulse values as opposed to scaled range. [8] That is why we experienced some differences when we dealt with the output data.

How much accuracy is required for establishing the effects of an accidental explosion of the Space Shuttle on the launch pad, from 0 through ten seconds after launch? What we

did we consider the propellant mass as a TNT equivalent amount by comparing heat of combustion (2.4.1.1) in the case of the SRB, knowing that it presents some differences as long as we could use diverse methods for calculating it. Nowadays there are some software tools like Cheetah® that give us the amount of TNT equivalency of almost any explosive blend with consistent and confident accuracy.

In further developments we suggest that the work focus on one method for calculating TNT equivalency and just one method for evaluating this amount in terms of damage at the longest and closest distances. According to our literature survey, there is no integrated package that processes the whole data set as input and then renders it as an output, so we think it is possible and necessary to reduce the management of data —for blasting— to two sources: one for calculation of the TNT equivalency, and the other for estimation of the expected damage at longest and closest distances.

But in the absence of such architectures we have developed a way of measuring the data and evaluating it. We have increased the amount of the explosive 1.6 times and upon consistent theory and a limited but validated application, we have concluded that the overpressure generated by an accidental explosion in the LC 39-A does not cause damage either to the LCC building or to the Press Site. Obviously, we cannot set aside the composition of an explosion that involves a fireball and fragments flying supersonically like missiles, which would affect the results.

5.3 Contributions

This work is related to the Virtual Range project, which has been developed for two years and evaluates the risk associated with an accident of the SS from launch to landing. This

involves several scenarios where blast, debris, fireballs, and toxicants interact over a given population (based on Arcview® data images). Every one of these effects is being loaded as a layer over the geographical reference, which is designed for many different components like people and buildings. So it is a very complex scenario. The Virtual Range deals with launch and reentry, and also the different scenarios related to a probability of failure and their varied consequences. Therefore, it has to incorporate a rather large portion of the Earth.

So this thesis provides data for the first ten seconds in terms of blast. As we mentioned above, this data was evaluated by using the available documentation and software tools for analysis. Our methodology was originally designed for being loaded as a layer in the Virtual Range architecture, but the constraints of BlastFX® and the known and already discussed accuracy of the scaled law just gave us the chance of evaluating discretely and manually the inputs and the outputs. Separating both long and short distances, we could work with the software as well as the scaled law.

In a special sense, the methodology used here is the result of the real capacities of our means. Thus, what we did was to re-evaluate not our goals but also the manner of reaching them; initially the integration of the model was thought as a whole in the Virtual Range but as was explained, that proved impossible. However, the results gotten and provided through this work can be eventually added to that superior development.

On the other hand, this work provides numerous concepts and explanations related to explosives, explosions, TNT equivalency, and propellant classification, so it is a good starting point for blast phenomenon studies. Likewise, it is a good source for introducing the NASA Space Shuttle, its main characteristics and performances, the composition of its propellant mass, and the stages and timing involved in the launch stage up to the complete

consumption of the fuel. The bigger part of the time available for carrying out the literature survey was spent in getting information related to the SS, followed by the time spent in TNT equivalency and, finally, the two scenarios involved in the study. Although the information is an open source, it is not ideally organized but widely spread and over classified.

5.4 Further development

This work is not complete if it is not integrated as a layer in the Virtual Range. However, it is complete as long as it provides valid information and analysis for blast and TNT equivalency. Nevertheless, we suggest following some measures for improving this work:

- Verify the possibility of integrating our data for getting complete and realistic results in the Virtual Range. A dynamic data base would make it easier and faster to obtain and analyze them, so the point is that we need to reduce the information to facts by working with current software tools based on updated methods of measuring explosion effects. Neural networks or some other learning algorithm could provide a way of evaluating data from an integrated data base, loaded with propellant mass, TNT equivalency calculations, and distances involved. So from this perspective this work could be, again, a good point for starting.
- Incorporate software for calculations of TNT equivalency. Cheetah® provides this feature in different versions with accuracy and a wide range of information available for theoretical support in order to understand how it calculates and renders those results and the method by which they were previously evaluated.

- BlastFX® is a good tool for evaluating the level of damage as a consequence of explosions. However, it was designed focusing on terrorist attacks, so the amounts of TNT involved are related to quantities affordable by terrorist groups. The Alfred P. Murrah building was attacked through a 1,814 kg (or so) of a TNT equivalent bomb, thousands of times less than the equivalent charge representing by the Space Shuttle propellant mass. Some applications, maybe more suitable for these purposes, were already mentioned in Chapter 2 (2.4.2), and should be considered for incorporation in the Virtual Range.
- The scaled law distance has suffered several adjustments, mainly because of the huge range of the explosive behavior of blend, or compositions different from TNT. In fact, the solid and liquid propellants do not detonate, so maybe they were overestimated in Chapter 2. In this particular case, it is very important to take into account this circumstance, and the way to remediate it is to pass through a re-evaluation of the equivalency method employed here for the purposes of the Virtual Range. However, this work bore in mind an estimation oriented to the worst of the possible scenarios into the imposed limits considered here, i.e., the ten seconds after launch and the eventual explosion of the whole propellant mass.
- In the bibliography there is a very wide range of information available. The information consulted here and which is considered basic for purposes of further development must include:
 - “Explosive shocks in air” by G.F.Kinney and K.J. Graham. The latest edition (1985 or so) is unfortunately out of print. Despite the data and the

enormous research in the area of explosives and explosions, this publication cannot be forgotten. It is a very frequently cited work.

- “Explosives engineering” by P.W.Cooper provides an exhaustive revision of all these topics and provides updated information, graphs, and tables from an engineering perspective.
- “Rocket propulsion elements” by G.P.Sutton and O.Biblarz is the main recognized source on this topic. It is often referenced by different authors and experts.

These three recommendations cover the range that underlies this work: 1) the SS propellant, 2) the propellant mass of the SS as an explosive, and 3) the behavior of the explosive mass in terms of blast.

- Also it is important to add updated studies about two sources for new propellant devices. The first is related to nuclear fuel; some historical understanding should give us an idea about the consequences of using it, not only in terms of blast but also in terms of a social perspective. On the other hand, some information should also be included with respect to a new scope in the development of hybrid rocket propulsion systems “that offer the advantage of a higher safety level with a TNT equivalent approximately = 0.” [42] So both represent tendencies that should be known and analyzed at the moment of facing new challenges.
- We could add the fireball and debris but in a lower scale. For studying and analyzing the fragmentation phenomenon, there are no ultimate or irrefutable models, despite the fact that several laws can predict the behavior of a particle,

as the chaotic environment of an explosion, faced with a highly complex phenomena also related with the varied materials involved and the probable circumstances in which it could happen. In any case, these books are a good beginning for getting knowledge in this field.

5.5 General conclusion

An undesirable and unexpected explosion of the Space Shuttle at the moment of launch will not affect the people and buildings studied here, at least not much more than was predicted in this work in terms of blast. However, an explosion in the close proximity of any building with the amounts involved here, especially at the moment of the integration and stacking of the complete Space Shuttle vehicle in the VAB building, will cause the destruction of the facility, if it occurs inside of a radius of 100 m.

Additionally, it is important to mention the position of the liquid fuel tanks in the area of the LC-39A. These tanks load 242,000 and 3,674,000 kg (533,610 and 8,101,170 lb) of Liquid Hydrogen and Liquid Oxygen, respectively. Both are separated, the former at the northeast corner and the latter at the northwest corner of the LC-39A. The risk of an explosion associated with them is low when they are under controlled and suitable storage conditions even for several years (8 to 10). Liquid Hydrogen is unstable and can detonate due to impurities, temperature, and shock [29]. Liquid Oxygen is stable and usually does not burn if it is not pressurized with organic matter, so “handling and storage are safe when contact materials are clean.” [29] Therefore, they should be out of range for tourists and visitors. According to what we saw along this work, it seems clear that an unexpected explosion of one of them, say, the Liquid Hydrogen tank, could cause damage in the very close proximity

in terms of blast. So that from 25 up to 800 m the high decaying of the overpressure with the distance will reduce the blast effect over people [40].

Longer distances, finally, with the amounts considered in this study cannot be provided with BlastFX®. However, we know a reinforced building above ground could resist up to 8-10 psi overpressure, therefore 500 m is close enough to make it collapse in these conditions. Some other sources, however, provide information on blast analysis and establish still longer distances for causing the same damage [41]. Therefore, further research should take into account that predictable methods and applications can imply different results for equivalent inputs. That will be interesting to establish a realistic range of output in order to incorporate a whole and accurate perspective in the Virtual Range, ideally jumping over the limitations of one or the other method employed.

APPENDIX

BlastFX® Reports

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Press Site

No. of Levels: 2

Press site first level

Height: 12.0 (ft)

Elevation: 0.0 (ft)

No. of Components: 262

Population: 111

Roof

Height: 12.0 (ft)

Elevation: 12.0 (ft)

No. of Components: 84

Population: 0

Scenario

Name: Acc Expl at 100 m

Description: Acc Expl at 100 m KSC

Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 100000.0 (lbs)

TNT Equiv: 100000.0 (lbs)

Device Position: (637.3, 960.0, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

Casualties

Fatalities: 0 / 0%

Serious Injuries: 74 / 66%

Slight Injuries: 37 / 33%

Uninjured: 0 / 0%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	48	48
Columns	0	0	0	32	32
Floors	181	49	0	14	244
Walls	22	0	0	0	22
Total	203	49	0	94	346

Glass Lites: 8

Broken: 8

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Press Site

No. of Levels: 2

Press site first level

Height: 12.0 (ft)

Elevation: 0.0 (ft)

No. of Components: 262

Population: 111

Roof

Height: 12.0 (ft)

Elevation: 12.0 (ft)

No. of Components: 84

Population: 0

Scenario

Name: Acc Expl at 200 m

Description: Acc Expl at 200 m KSC

Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 100000.0 (lbs)

TNT Equiv: 100000.0 (lbs)

Device Position: (307.3, 960.0, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

Casualties

Fatalities: 0 / 0%

Serious Injuries: 0 / 0%

Slight Injuries: 0 / 0%

Uninjured: 111 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	48	48
Columns	0	0	0	32	32
Floors	0	152	42	50	244
Walls	8	14	0	0	22
Total	8	166	42	130	346

Glass Lites: 8

Broken: 8

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No. of Components: 262

Population: 111

Roof

Height: 12.0 (ft)

Elevation: 12.0 (ft)

No. of Components: 84

Population: 0

Scenario

Name: Acc Expl at 300 m

Description: Acc Expl at 300 m KSC

Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 100000.0 (lbs)

TNT Equiv: 100000.0 (lbs)

Device Position: (-22.7, 959.8, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

Casualties

Fatalities: 0 / 0%

Serious Injuries: 0 / 0%

Slight Injuries: 0 / 0%

Uninjured: 111 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	48	48
Columns	0	0	0	32	32
Floors	0	0	152	92	244
Walls	8	0	0	14	22
Total	8	0	152	186	346

Glass Lites: 8

Broken: 8

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Population: 111

Roof

Height: 12.0 (ft)

Elevation: 12.0 (ft)

No. of Components: 84

Population: 0

Scenario

Name: Acc Expl at 400 m

Description: Acc Expl at 400 m KSC

Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 100000.0 (lbs)

TNT Equiv: 100000.0 (lbs)

Device Position: (-353.3, 959.8, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

Casualties

Fatalities: 0 / 0%

Serious Injuries: 0 / 0%

Slight Injuries: 0 / 0%

Uninjured: 111 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	48	48
Columns	0	0	0	32	32
Floors	0	0	0	244	244
Walls	8	0	0	14	22
Total	8	0	0	338	346

Glass Lites: 8

Broken: 8

BLAST/FX SUMMARY REPORT

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No. of Levels: 2

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Height: 12.0 (ft)

Elevation: 0.0 (ft)

No. of Components: 262

Population: 111

Roof

Height: 12.0 (ft)

Elevation: 12.0 (ft)

No. of Components: 84

Population: 0

Scenario

Name: Acc Expl at 500 m

Description: Acc Expl at 500 m KSC

Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 100000.0 (lbs)

TNT Equiv: 100000.0 (lbs)

Device Position: (-684.3, 959.8, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

Casualties

Fatalities: 0 / 0%

Serious Injuries: 0 / 0%

Slight Injuries: 0 / 0%

Uninjured: 111 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	48	48
Columns	0	0	0	32	32
Floors	0	0	0	244	244
Walls	8	0	0	14	22
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Elevation: 12.0 (ft)

No. of Components: 84

Population: 0

Scenario

Name: Acc Expl at 100 m

Description: Acc Expl at 100 m KSC

Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 50000.0 (lbs)

TNT Equiv: 50000.0 (lbs)

Device Position: (637.3, 960.0, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

Casualties

Fatalities: 0 / 0%

Serious Injuries: 74 / 66%

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Population: 0

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Description: Acc Expl at 200 m KSC

Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 50000.0 (lbs)

TNT Equiv: 50000.0 (lbs)

Device Position: (307.3, 960.0, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

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Damage

	Destroyed	Severe	Moderate	Undamaged	Total
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Population: 0

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Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 50000.0 (lbs)

TNT Equiv: 50000.0 (lbs)

Device Position: (-22.7, 959.8, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

Casualties

Fatalities: 0 / 0%

Serious Injuries: 0 / 0%

Slight Injuries: 0 / 0%

Uninjured: 111 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	48	48
Columns	0	0	0	32	32
Floors	0	0	152	92	244
Walls	8	0	0	14	22
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Population: 0

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Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 50000.0 (lbs)

TNT Equiv: 50000.0 (lbs)

Device Position: (-353.3, 959.8, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

Casualties

Fatalities: 0 / 0%

Serious Injuries: 0 / 0%

Slight Injuries: 0 / 0%

Uninjured: 111 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	48	48
Columns	0	0	0	32	32
Floors	0	0	0	244	244
Walls	8	0	0	14	22
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Elevation: 12.0 (ft)

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Population: 0

Scenario

Name: Acc Expl at 500 m

Description: Acc Expl at 500 m KSC

Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 50000.0 (lbs)

TNT Equiv: 50000.0 (lbs)

Device Position: (-684.3, 959.8, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

Casualties

Fatalities: 0 / 0%

Serious Injuries: 0 / 0%

Slight Injuries: 0 / 0%

Uninjured: 111 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	48	48
Columns	0	0	0	32	32
Floors	0	0	0	244	244
Walls	8	0	0	14	22
Total	8	0	0	338	346

Glass Lites: 8

Broken: 8

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Press Site

No. of Levels: 2

Press site first level

Height: 12.0 (ft)

Elevation: 0.0 (ft)

No. of Components: 262

Population: 111

Roof

Height: 12.0 (ft)

Elevation: 12.0 (ft)

No. of Components: 84

Population: 0

Scenario

Name: Acc Expl at 100 m

Description: Acc Expl at 100 m KSC

Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 25000.0 (lbs)

TNT Equiv: 25000.0 (lbs)

Device Position: (637.3, 960.0, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

Casualties

Fatalities: 0 / 0%

Serious Injuries: 74 / 66%

Slight Injuries: 37 / 33%

Uninjured: 0 / 0%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	48	48
Columns	0	0	0	32	32
Floors	181	49	0	14	244
Walls	22	0	0	0	22
Total	203	49	0	94	346

Glass Lites: 8

Broken: 8

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Press Site

No. of Levels: 2

Press site first level

Height: 12.0 (ft)

Elevation: 0.0 (ft)

No. of Components: 262

Population: 111

Roof

Height: 12.0 (ft)

Elevation: 12.0 (ft)

No. of Components: 84

Population: 0

Scenario

Name: Acc Expl at 200 m

Description: Acc Expl at 200 m KSC

Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 25000.0 (lbs)

TNT Equiv: 25000.0 (lbs)

Device Position: (307.3, 960.0, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

Casualties

Fatalities: 0 / 0%

Serious Injuries: 0 / 0%

Slight Injuries: 0 / 0%

Uninjured: 111 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	48	48
Columns	0	0	0	32	32
Floors	0	152	42	50	244
Walls	8	14	0	0	22
Total	8	166	42	130	346

Glass Lites: 8

Broken: 8

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Press Site

No. of Levels: 2

Press site first level

Height: 12.0 (ft)

Elevation: 0.0 (ft)

No. of Components: 262

Population: 111

Roof

Height: 12.0 (ft)

Elevation: 12.0 (ft)

No. of Components: 84

Population: 0

Scenario

Name: Acc Expl at 300 m

Description: Acc Expl at 300 m KSC

Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 25000.0 (lbs)

TNT Equiv: 25000.0 (lbs)

Device Position: (-22.7, 959.8, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

Casualties

Fatalities: 0 / 0%

Serious Injuries: 0 / 0%

Slight Injuries: 0 / 0%

Uninjured: 111 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	48	48
Columns	0	0	0	32	32
Floors	0	0	152	92	244
Walls	8	0	0	14	22
Total	8	0	152	186	346

Glass Lites: 8

Broken: 8

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Press Site
No. of Levels: 2

Press site first level

Height: 12.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 262
Population: 111
Roof
Height: 12.0 (ft)
Elevation: 12.0 (ft)
No. of Components: 84
Population: 0

Scenario

Name: Acc Expl at 400 m
Description: Acc Expl at 400 m KSC

Device: Accidental explosion
Description: Accidental explosion at KSC
Compound: TNT
Charge: 25000.0 (lbs)
TNT Equiv: 25000.0 (lbs)
Device Position: (-353.3, 959.8, 10.0) (ft)

Population Set: People at KSC press site
Description: Journalists and photographers
No. of People: 111

Casualties

Fatalities: 0 / 0%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%
Uninjured: 111 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	48	48
Columns	0	0	0	32	32
Floors	0	0	0	244	244
Walls	8	0	0	14	22
Total	8	0	0	338	346

Glass Lites: 8

Broken: 8

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Press Site

No. of Levels: 2

Press site first level

Height: 12.0 (ft)

Elevation: 0.0 (ft)

No. of Components: 262

Population: 111

Roof

Height: 12.0 (ft)

Elevation: 12.0 (ft)

No. of Components: 84

Population: 0

Scenario

Name: Acc Expl at 500 m

Description: Acc Expl at 500 m KSC

Device: Accidental explosion

Description: Accidental explosion at KSC

Compound: TNT

Charge: 25000.0 (lbs)

TNT Equiv: 25000.0 (lbs)

Device Position: (-684.3, 959.8, 10.0) (ft)

Population Set: People at KSC press site

Description: Journalists and photographers

No. of People: 111

Casualties

Fatalities: 0 / 0%

Serious Injuries: 0 / 0%

Slight Injuries: 0 / 0%

Uninjured: 111 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	48	48
Columns	0	0	0	32	32
Floors	0	0	0	244	244
Walls	8	0	0	14	22
Total	8	0	0	338	346

Glass Lites: 8

Broken: 8

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 100 m
Description: Acc Expl at 100 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 100000.0 (lbs)
TNT Equiv: 100000.0 (lbs)
Device Position: (637.3, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 46 / 25%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 133 / 74%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	40	0	0	290	330
Columns	0	0	0	209	209
Floors	394	88	234	892	1608
Walls	102	0	66	198	366
Total	536	88	300	1589	2513

Glass Lites: 0

Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 200 m
Description: Acc Expl at 200 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 100000.0 (lbs)
TNT Equiv: 100000.0 (lbs)
Device Position: (307.3, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 0 / 0%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 179 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	330	330
Columns	0	0	0	209	209
Floors	0	82	70	1456	1608
Walls	0	92	0	274	366
Total	0	174	70	2269	2513

Glass Lites: 0 # Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 300 m
Description: Acc Expl at 300 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 100000.0 (lbs)
TNT Equiv: 100000.0 (lbs)
Device Position: (-22.7, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 0 / 0%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 179 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	330	330
Columns	0	0	0	209	209
Floors	0	0	118	1490	1608
Walls	0	0	72	294	366
Total	0	0	190	2323	2513

Glass Lites: 0

Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 400 m
Description: Acc Expl at 400 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 100000.0 (lbs)
TNT Equiv: 100000.0 (lbs)
Device Position: (-353.3, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 0 / 0%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 179 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	330	330
Columns	0	0	0	209	209
Floors	0	0	0	1608	1608
Walls	0	0	0	366	366
Total	0	0	0	2513	2513

Glass Lites: 0

Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 500 m
Description: Acc Expl at 500 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 100000.0 (lbs)
TNT Equiv: 100000.0 (lbs)
Device Position: (-684.3, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 0 / 0%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 179 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	330	330
Columns	0	0	0	209	209
Floors	0	0	0	1608	1608
Walls	0	0	0	366	366
Total	0	0	0	2513	2513

Glass Lites: 0

Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 100 m
Description: Acc Expl at 100 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 50000.0 (lbs)
TNT Equiv: 50000.0 (lbs)
Device Position: (637.3, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 46 / 25%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 133 / 74%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	40	0	0	290	330
Columns	0	0	0	209	209
Floors	394	88	234	892	1608
Walls	102	0	66	198	366
Total	536	88	300	1589	2513

Glass Lites: 0

Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 200 m
Description: Acc Expl at 200 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 50000.0 (lbs)
TNT Equiv: 50000.0 (lbs)
Device Position: (307.3, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 0 / 0%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 179 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	330	330
Columns	0	0	0	209	209
Floors	0	82	70	1456	1608
Walls	0	92	0	274	366
Total	0	174	70	2269	2513

Glass Lites: 0 # Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 300 m
Description: Acc Expl at 300 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 50000.0 (lbs)
TNT Equiv: 50000.0 (lbs)
Device Position: (-22.7, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 0 / 0%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 179 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	330	330
Columns	0	0	0	209	209
Floors	0	0	118	1490	1608
Walls	0	0	72	294	366
Total	0	0	190	2323	2513

Glass Lites: 0 # Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 400 m
Description: Acc Expl at 400 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 50000.0 (lbs)
TNT Equiv: 50000.0 (lbs)
Device Position: (-353.3, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 0 / 0%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 179 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	330	330
Columns	0	0	0	209	209
Floors	0	0	0	1608	1608
Walls	0	0	0	366	366
Total	0	0	0	2513	2513

Glass Lites: 0 # Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 500 m
Description: Acc Expl at 500 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 50000.0 (lbs)
TNT Equiv: 50000.0 (lbs)
Device Position: (-684.3, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 0 / 0%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 179 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	330	330
Columns	0	0	0	209	209
Floors	0	0	0	1608	1608
Walls	0	0	0	366	366
Total	0	0	0	2513	2513

Glass Lites: 0 # Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 100 m
Description: Acc Expl at 100 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 25000.0 (lbs)
TNT Equiv: 25000.0 (lbs)
Device Position: (637.3, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 46 / 25%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 133 / 74%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	40	0	0	290	330
Columns	0	0	0	209	209
Floors	394	88	234	892	1608
Walls	102	0	66	198	366
Total	536	88	300	1589	2513

Glass Lites: 0

Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 200 m
Description: Acc Expl at 200 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 25000.0 (lbs)
TNT Equiv: 25000.0 (lbs)
Device Position: (307.3, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 0 / 0%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 179 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	330	330
Columns	0	0	0	209	209
Floors	0	82	70	1456	1608
Walls	0	92	0	274	366
Total	0	174	70	2269	2513

Glass Lites: 0 # Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 300 m
Description: Acc Expl at 300 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 25000.0 (lbs)
TNT Equiv: 25000.0 (lbs)
Device Position: (-22.7, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 0 / 0%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 179 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	330	330
Columns	0	0	0	209	209
Floors	0	0	118	1490	1608
Walls	0	0	72	294	366
Total	0	0	190	2323	2513

Glass Lites: 0 # Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 400 m
Description: Acc Expl at 400 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 25000.0 (lbs)
TNT Equiv: 25000.0 (lbs)
Device Position: (-353.3, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 0 / 0%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 179 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	330	330
Columns	0	0	0	209	209
Floors	0	0	0	1608	1608
Walls	0	0	0	366	366
Total	0	0	0	2513	2513

Glass Lites: 0 # Broken: 0

BLAST/FX SUMMARY REPORT

Monday, June 28, 2004

Building

Description: Launch Control Center
No. of Levels: 5

First Floor

Height: 15.0 (ft)
Elevation: 0.0 (ft)
No. of Components: 707
Population: 41

Second Floor

Height: 15.0 (ft)
Elevation: 15.0 (ft)
No. of Components: 514
Population: 65

Third Floor

Height: 15.0 (ft)
Elevation: 30.0 (ft)
No. of Components: 514
Population: 36

Fourth Floor

Height: 15.0 (ft)
Elevation: 45.0 (ft)
No. of Components: 514
Population: 37

Roof

Height: 15.0 (ft)
Elevation: 60.0 (ft)
No. of Components: 264
Population: 0

Scenario

Name: Acc Expl at 500 m
Description: Acc Expl at 500 m KSC

Device: Accidental Explosion
Description: Accidental Explosion at KSC
Compound: TNT
Charge: 25000.0 (lbs)
TNT Equiv: 25000.0 (lbs)
Device Position: (-684.3, 0.0, 10.0) (ft)

Population Set: Workers
Description: Workers at LCC - KSC
No. of People: 179

Casualties

Fatalities: 0 / 0%
Serious Injuries: 0 / 0%
Slight Injuries: 0 / 0%

Uninjured: 179 / 100%

Damage

	Destroyed	Severe	Moderate	Undamaged	Total
Beams	0	0	0	330	330
Columns	0	0	0	209	209
Floors	0	0	0	1608	1608
Walls	0	0	0	366	366
Total	0	0	0	2513	2513

Glass Lites: 0 # Broken: 0

REFERENCES

- [1] Kelton, Sadowski, Sturrock; “Simulation with Arena”; 3th Ed. 2004.
- [2] Abolhassan Astaneh-Asl, Heidari, Zhao; “Analysis of car-bomb effects on buildings using MSC-Dytran software and protective measures”; 2003.
- [3] HID-Safety report assessment guide chemical warehouses: “Hazards”; <http://www.hse.gov.uk/comah/sragcwh/hazards/images/hazards.pdf>; 2002.
- [4] Wikipedia; “Explosive materials”; http://en.wikipedia.org/wiki/Explosive_material; 2002.
- [5] NASA, Office of Safety and Mission Assurance; “Safety standard for explosives, propellants, and pyrotechnics”; 1993.
- [6] United States Army of Engineers; “Establishing a temporary open burn and open detonation site for conventional ordnance and explosive projects”; 1999.
- [7] Mendis, Ngo; “Vulnerability assessment of concrete tall buildings subjected to extreme loading conditions”; 2003.
- [8] Northrop Grumman Corporation, “BlastFX Software User’s Manual”; Copyright ©2003.
- [9] T. Krauthammer; “Blast effects and related threats”; Penn State University; 1999.
- [10] http://www.globalsecurity.org/wmd/library/report/enviro/eis-0157/eis0157_d4.html#7678; “Accident scenarios involving high explosives”; 1991.
- [11] N. Fathi; “The New York Times”; (Ed. Feb. 19); 2004.
- [12] J.L. Maienschein; “Estimating Equivalency of Explosives through a thermochemical approach”; 2002.
- [13] Cooper and S.R. Kurowski; “Introduction to the technology of explosives”; cited by http://www.globalsecurity.org/wmd/library/report/enviro/eis-0157/eis0157_d4.html#7678; 1996.
- [14] R. Braeunig; “Rocket propellants”; in <http://www.braeunig.us/space/propel.htm>; 1996.
- [15] NASA, Boeing, United Space Alliance; “Space Shuttle Main Engine”; <http://www.shuttlepresskit.com/search.html>; 2003.
- [16] NASA; “Space Shuttle”; <http://spaceflight.nasa.gov/shuttle/reference/index.html>; 2002.

- [17] NASA; “Space Shuttle OMS”;
<http://www.spaceflight.nasa.gov/shuttle/reference/shutref/orbiter/oms/overview.html>;
2002.
- [18] NASA; GRIN, “Great Images in NASA”;
http://grin.hq.nasa.gov/BROWSE/space-shuttle_22.html; 2002.
- [19] NASA; “Space Shuttle External Tank”;
www.spaceflight.nasa.gov/shuttle/reference/basics/et/index.html; 2002.
- [20] NASA; “Space Shuttle SRB”;
<http://www.spaceflight.nasa.gov/shuttle/reference/shutref/srb/srb.html>; 2002.
- [21] R. Braeunig; “Space Shuttle”;
<http://www.braeunig.us/space/specs/shuttle.htm>; 1996.
- [22] J. Sepúlveda, L. Rabelo; “Virtual Range Project”; University of Central Florida, USA, Orlando, FL; 2003-2004.
- [23] NASA; “Space Shuttle Ascent”;
www.spaceflight.nasa.gov/shuttle/reference/basics/ascent.html; 2002.
- [24] NASA-Fact-Sheet; “The 21st Century Space Shuttle”;
<http://www.lunaroutpost.com/library/21stCenturyShuttle.pdf>; 2003.
- [25] Kirk Othmer; “Encyclopedia of Chemical Technology”; Vol. 10; Ed. John Wiley and Sons; 1998.
- [26] L.C.Sutherland; “Scaling Law for Estimating Liquid Propellant Explosive Yields”; Journal of Spacecraft and Rockets; 1978.
- [27] Air Force Rocket Propellant Lab; “Liquid Propellant Explosive Hazards-Project PYRO”; AFRPL-TR-68-92, Vols., I, II, III; 1968.
- [28] E.A. Farber; “Prediction of Explosive Yield and Other Characteristics of Liquid Propellant Rocket Explosions”; University of Florida, Gainesville, FL; 1968.
- [29] G.P. Sutton, O. Biblarz; “Rocket Propulsion Elements, *An introduction to the engineering of rockets*”; Wiley and Sons, 7th Ed.; 2001.
- [30] B.F. Boyd, D.E. Harms; “Weather Support to Range Safety for Forecasting Atmospheric Sonic Propagation”; 1999.
- [31] Wikipedia; “The Alfred P. Murrah Building”;
http://en.wikipedia.org/wiki/Alfred_P._Murrah_Federal_Building; 2001.

- [32] Bomb Damage analysis of Alfred P. Murrah Federal Building;
<http://www.whatreallyhappened.com/RANCHO/POLITICS/OK/PARTIN/ok3.htm>.
- [33] “Alfred P. Murrah Building”;
<http://www.cfrterrorism.org/groups/american.html>; 2001.
- [34] “Alfred P. Murrah Building Graph”; <http://www.apfn.org/apfn/okcpat.jpg>;
2001.
- [35] National Memorial Institute for the Prevention of Terrorism located in
Oklahoma City; 2000-2004.
- [36] S.Hawking; “A Brief History of Time”; B.Books; 10th Ed., 1998.
- [37] Paul W. Cooper; “Explosives Engineering”; © 1996 VCH Publishers Inc.;
1996.
- [38] Kinney, G.F., and K.J. Graham; “Explosive Shocks in Air” (2nd edition);
Springer-Verlag; Berlin; 1985.
- [39] Department of Defense, DOD 6055.9-STD; “Ammunition and Explosives
Safety Standards”; U.S.A.; 1999.
- [40] Kinney, G.F.; “Explosive shocks in air”; The Macmillan Company; N.Y.;
1962.
- [41] Bogosian, D., Dunn, B., Chrostowski, J.; “Blast Analysis of Complex
Structures Using Physics-based Fast-running Models”; © 1999 Elsevier Science Ltd.
All rights reserved.
- [42] Dargies, E; Lo, R.E.; “Hybrid Boosters for Future Launch Vehicles”; 1988; ©
2004 ACS on SciFinder.